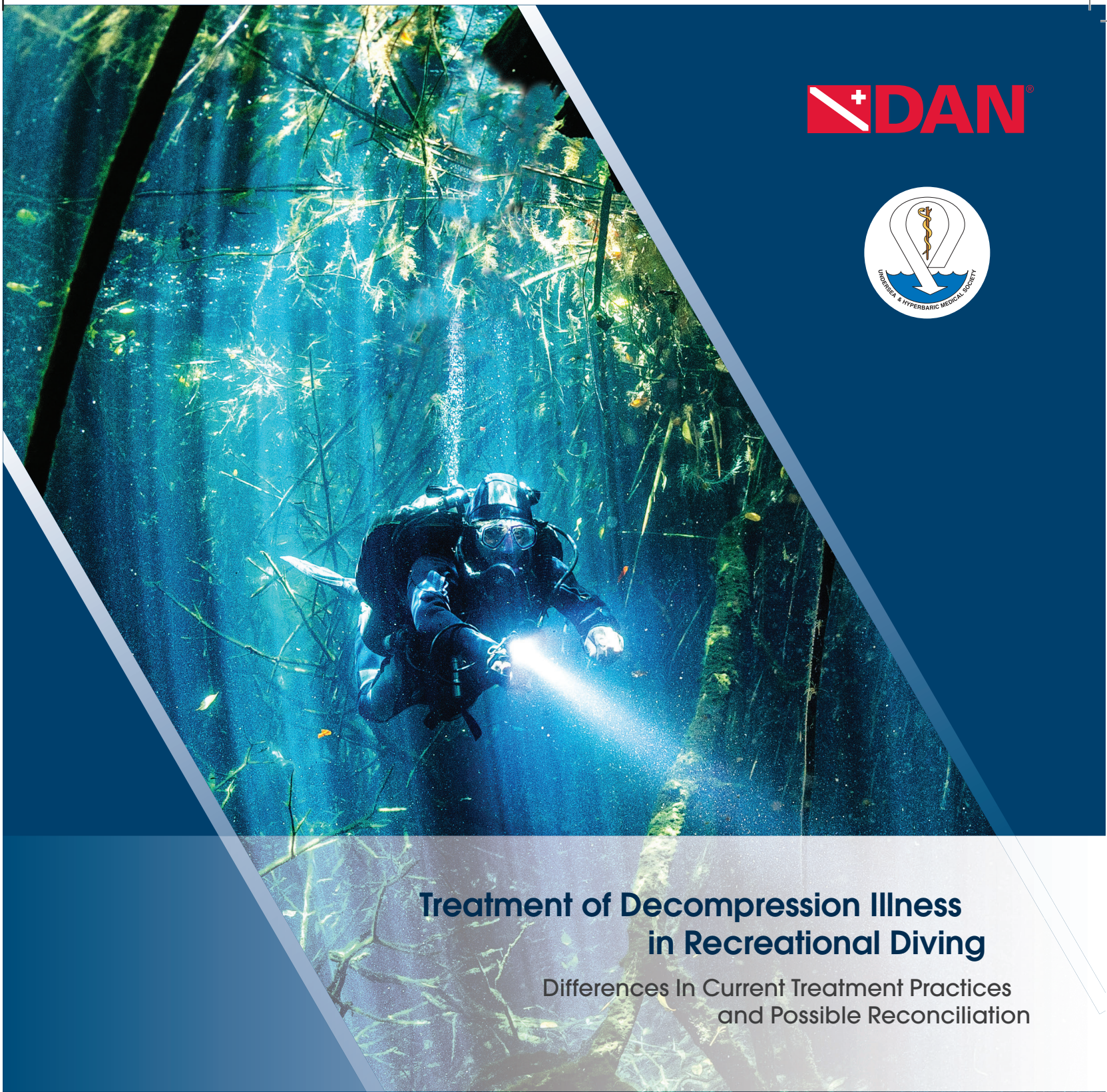
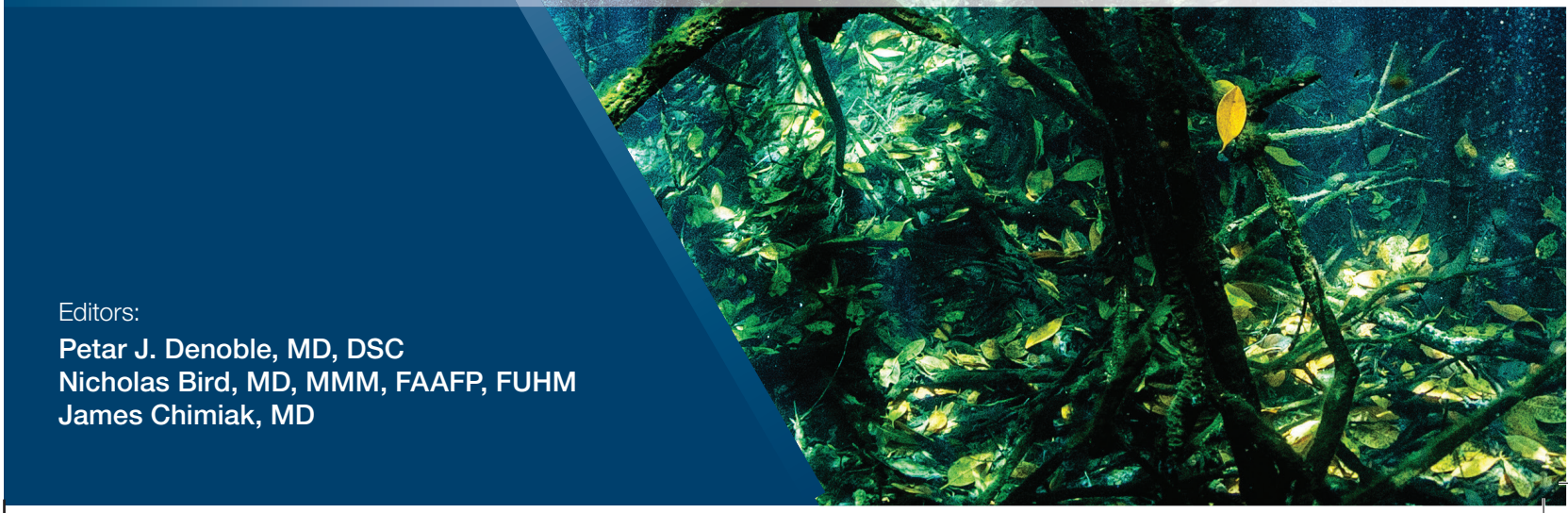


# Treatment of Decompression Illness in Recreational Diving

## Differences In Current Treatment Practices and Possible Reconciliation




Editors:

**Petar J. Denoble, MD, DSC**
**Nicholas Bird, MD, MMM, FAAFP, FUHM**
**James Chimiak, MD**

UHMS Symposium Sponsored by Divers Alert Network

# Treatment of Decompression Illness in Recreational Diving:

## Differences in Current Treatment Practices and Possible Reconciliation

*Workshop Proceedings*
*June 26, 2019*
*Rio Grande, Puerto Rico*

**Editors:**
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This is the fourth in the series of DAN/UHMS workshops dedicated to decompression illness in recreational divers.

2004 - Mitchell SJ, Doolette DJ, Wacholz CJ, Vann RD (eds.). Management of Mild or Marginal Decompression Illness in Remote Locations Workshop Proceedings. Durham, N.C.: Divers Alert Network, 2005. ISBN 0-9673066-6-3. Remote workshop pdf (diversalertnetwork.org)

2017 - Mitchell SJ, Bennett MH, Bryson P, Butler FK, Doolette DJ, Holm JR, Kot J, Lafère P. Pre-hospital management of decompression illness: expert review of key principles and controversies. Diving and Hyperbaric Medicine. 2018 March;48(1):45–55. doi.10.28920/dhm48.1.45-55. PMID: 30028914. Pre-hospital management of decompression illness: expert review of key principles and controversies (nih.gov)

2018 - Denoble P, Marroni A. Differential Diagnosis of Decompression Illness Workshop Proceedings. Durham, NC, Divers Alert Network, 2019, 85 pp. ISBN 13: 978-0-9656942-0-9. 2018 Proceedings Differential Diagnosis.pdf (diversalertnetwork.org)

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# PRE-COURSE SCHEDULE

## TREATMENT OF DECOMPRESSION ILLNESS IN RECREATIONAL DIVING: DIFFERENCES IN CURRENT TREATMENT PRACTICES AND POSSIBLE RECONCILLIATION

WEDNESDAY, June 26, 2019 : 8am-5pm

Program chairs: Peter Denoble, MD, DSc, Nicholas Bird, MD, MMM, FAAFP, FUHM and Jim Chimiak, MD

Standard treatment for decompression illness (DCS) and arterial gas embolism (AGE) both dive-related and iatrogenic, is recompression and hyperbaric oxygen administration. Treatment practices around the world have been mostly derived from the experience of various navies and commercial companies. In the United States, the UHMS provides guidelines based on the U.S. Navy practices with minor adjustments for the recreational diving environment. The mainstay of UHMS recommendations for initial treatment is U.S. Navy Treatment Table 6 for serious cases and Treatment Table 5 for mild cases. Both treatment tables apply maximum pressure of 2.8 bars (equivalent to 18 msw or 60 fsw depth). Some medical centers in the United States like Hawaii, NASA, and Catalina use greater treatment pressures while others that operate monoplace chambers use less pressure and shorter treatment times. In another part of the world, current practice may differ. In France, treatment tables are derived from the French Navy and COMEX tables, and use nitrox and various pressure levels. COMEX 12 and U.S. Navy Table 9 are examples of short and shallow tables. In Russia, treatment pressure sometimes goes higher than 6 bars. Practitioners in China may follow U.S. practice but they have extensive experience with severe and delayed cases in fish farming. Cairns in Australia has extensive experience in treating cases from the Great Barrier Reef and flying after treatment.

A decision to recompress in a case when symptoms resolve before admission may vary. Beyond initial treatment, there are major differences in approach to follow-up treatments, auxiliary treatments and physical rehabilitation of injured divers. Additional differences appear in the recommendation for flying after treatment.

The aim of this workshop is to review variants of current clinical practices, to discuss the rationale for such practices and to consider a need for harmonization of practices.

## SCHEDULE

| Time | Lecture | Faculty |
|---|---|---|
| 08:00-08:30 | Current UHMS guidelines | Nick Bird |
| 08:30-09:00 | Polling, hidden results: DCI treatment principles (see the list of Q&A in Appendix) | Petar Denoble |
| 09:00-09:30 | Current practice in France | Sébastien de Maistre |
| 09:30-10:00 | Current practice in China | Wei-gang Xu |
| 10:00-10:30 | Coffee Break | |
| 10:30-11:00 | Australian experience | David Wilkinson |
| 11:00-11:30 | Could normobaric oxygen be accepted as a definitive treatment? | Richard Moon |
| 11:30-12:00 | Use of short tables in treatment of DCI | Brenna Derksen |
| 12:00-12:30 | Treatment of severe DCS cases | Ian Grover |
| 12:30-13:30 | Lunch break | |
| 13:30-13:45 | Use of deep tables in US Navy | David Southerland |
| 13:45-14:30 | Is it ever too late to treat? | Jake Freiberger |
| 14:30-15:00 | Flying after treatment | Jim Chimiak |
| 15:00-15:30 | When to return to diving after DCI | Jake Freiberger |
| 15:30-15:45 | Coffee break | |
| 15:45-16:45 | Polling, public results: DCI treatment principles. Discussion of each question. Comparison of pre- and post- answers | Petar Denoble |
| 16:45-17:00 | Concluding remarks | Petar Denoble |

# SPEAKER BIOGRAPHIES

**Dr. Petar Denoble** is the Vice-president of Research at Divers Alert Network (DAN). He received his medical degree from the University of Zagreb in Croatia. He specialized in naval and diving medicine and had 13 years of clinical and research experience before joining DAN. He is focused on maintaining high standards in fulfillment of the DAN mission and development of new programs to advance the safety of diving.

**Dr. Nicholas Bird** has held a life-long passion for diving. Inspired by the Undersea World of Jacques Couteau he earned his initial open-water certification in his native Southern California in 1984 and went on to become a PADI open water instructor in 1989.

Dr. Bird is the current Chief Medical Officer for the Kwajalein Hospital. He previously served as the Regional Medical Director for a multi-county network of Duke Urgent Care Centers. He is board-certified in both Family Medicine and Undersea and Hyperbaric Medicine and is a globally recognized expert in diving medicine. His leadership roles include CEO and Chief Medical Officer at Divers Alert Network and current Past President of the Undersea and Hyperbaric Medical Society. He got his start in Hyperbaric Medicine while serving as a flight surgeon in the US Air Force during the Operation Iraqi Freedom and Enduring Freedom campaigns, and went on to complete a fellowship in Diving and Hyperbaric medicine at UC San Diego. He is also an active member of the Kwajalein MIA Project with a desire to assist the mission and provide support as the Diving Medical Officer.

Most recently, he was selected to participate as part of an international group of Diving Medical Experts in collaboration with PADI to revise the Diver Medical Screening Questionnaire. The updated questionnaire was published in 2020, the first revision of this tool in nearly 30-years.

**Dr. Sébastien de Maistre** is a practitioner specialized in diving and hyperbaric medicine, currently working as director of the medical center supporting the French Navy diving school. Formerly, he has worked for five years in the department of diving and hyperbaric medicine at the Sainte-Anne military hospital in Toulon, South of France. The center of Toulon is one of the hyperbaric centers that receive the largest number of diving accident admissions in Europe. He is been a long-time researcher with clinical studies on diving accidents and more basic research work on animal models of decompression sickness that allow us to study specific mechanisms and potential treatments. He is an active member of the European Underwater Baromedical Society for five years and also a member of the French society of diving and hyperbaric medicine ("MEDSUBHYP"), with whom he has co-organized numerous workshops and congresses on physiology and diving medicine.

**Dr. Weigang Xu** is a professor in Diving and Hyperbaric Medicine in Naval Medical University of China. Dr. Xu has been engaged in education, scientific research, and medical support for deep diving for over 23 years, focusing on all aspects of diving medicine.

**Dr. David Wilkinson** is a Senior Anaesthesiologist and has been Medical Director of the Hyperbaric Medicine Unit for over 20 years at the Royal Adelaide Hospital in Adelaide, South Australia. He is the Education Officer for SPUMS and has a 20 year experience of co-ordinating the Divers Emergency Service telephone (the diving hotline in the Asia-Pacific region). He was awarded the FUHM in 2013 and the Medal of the Order of Australia (OAM) in 2016 for services to Hyperbaric Medicine.

**Dr. Richard Moon** is a pulmonologist and anesthesiologist, Medical Director of the Duke Center for Hyperbaric Medicine & Environmental Physiology. His research interests include decompression sickness prevention, monitoring of rebreather divers and pathophysiology/treatment of immersion pulmonary edema.

**Dr. Brenna Derksen** is originally from Arizona, but has also spent time living in Iowa, Colorado, and currently loving life in San Diego. She completed her undergraduate degree at the University of Iowa, her medical degree at the University of Arizona, College of Medicine, and her residency training in Emergency Medicine at the UC San Diego. She is currently a fellow in Undersea and Hyperbaric Medicine with a strong interest in diving medicine and diving emergencies. In her free time she loves being outside or in the ocean, traveling, and is an avid dog lover.

**Dr. Ian Grover** graduated from the University of Iowa College of Medicine in 1994. He then completed a Transitional Internship at the Naval Medical Center San Diego and served as a flight surgeon in the United States Navy for three years. After the Navy, he did his emergency medicine residency at Wake Forest University Baptist Medical Center in Winston-Salem, North Carolina. His interest in diving medicine then brought him to UCSD where he was the hyperbaric fellow for the 2002-2003 academic year. He joined the full time faculty at UCSD in July of 2003. Currently, he is the Medical Director for the UCSD Division of Hyperbaric Medicine and Wound Healing. He serves as a member of the UHMS Education Committee. His research interests include hyperbaric oxygen therapy for preconditioning, critical care in the hyperbaric chamber, and diving medicine.

**Dr. David Southerland** graduated from the University of Mississippi School of Medicine on a Navy Health Professions scholarship as a Lieutenant in 1982. After a Family Practice Internship at Naval Hospital Jacksonville, he attended the Naval Undersea Medical Institute for training in submarine medicine and radiation health, and the Navy Diving and Salvage Training Center for training as a Diving Medical Officer. He then made two strategic deterrent patrols as the Submarine Medical Officer for the USS OHIO (SSBN 726 Blue). David spent a total of seven years at the Naval Submarine Medical Research Laboratory (NSMRL) which does biomedical research in submarine and diving. For four years, he was the Command Diving Medical Officer and as a junior researcher he mainly working with computerized medical decision support systems for use on submarines. David also spent three years as Commanding Officer of NSMRL twenty years later. From 1989 to 1992, he attended out-service training at Duke University in hyperbaric physiology to learn about decompression modeling for divers, and received a MS through the Biomedical Engineering Department. David spent almost 15 years at the Navy Experimental Diving Unit (two tours) where he worked variously a biomedical researcher, medical monitor, research subject (bounce dives, saturation dives, and non-diving experiments), department head, Medical Director, Senior Medical Officer, and consultant on diving medicine issues. In 2012, David retired as a Captain from the U.S. Navy with 30 years Active Duty Service. Since 2012, he has been working as a civilian Undersea Medical Officer (non-clinical) for the Naval Sea Systems Command's Supervisor of Salvage and Diving at the Washington Navy Yard in Washington, D.C.

**Dr. James Chimiak** is the medical director at the Diver's Alert Network. He is board certified in Anesthesiology, Pain Management and is a Hyperbaric and Undersea Medicine specialist. He has qualifications as a Heliox salvage diver, saturation diving medical officer and flight surgeon as well. He has served as a diving medicine consultant that has included NOAA, NASA and all three branches of the military. Special interests include fitness to dive considerations, contaminated diving, telemedicine and evidence based DCI management.

**Dr. John J. Freiberger** is a native of Dallas, Texas and a graduate of the University of Texas Southwestern Medical School. He did his internship, residency, and Critical Care Fellowship in at the Department of Anesthesiology, Critical Care and Pain Medicine at the Massachusetts General Hospital in Boston. He earned his Masters in Public Health at the University of North Carolina and did a fellowship in Undersea and Hyperbaric Medicine at Duke. He is an Associate Professor of Anesthesiology at Duke, a diplomat of the National Board of Public Health, the American Board of Anesthesiology The American Board of Anesthesiology's Special Qualifications in Critical Medicine and the American Board of Preventive Medicine's program in Undersea and Hyperbaric Medicine. He is a NOAA diving medical officer and taught at the annual NOAA diving medicine course until 2019. He is the program director for Duke's ACGME approved Undersea and Hyperbaric Medicine fellowship, a NAVSEA funded investigator studying the cognitive effects of hypercapnia during 200 EAD dives, co-director of Duke's course in the Medicine and Physiology of Extreme Environments, and the director of Duke Dive Medicine, the new extreme environment and diving injury consultation service hosted at the Duke Center for Hyperbaric Medicine and Environmental Physiology.

# TREATMENT OF DECOMPRESSION ILLNESS

## Nicholas Bird, MD, MMM, FAAFP, FUHM

*Paul Bert)(Google Images)*

I was given the distinct honor of initiating this workshop with an overview of decompression illness and how this disease is treated.

I have nothing to disclose.

I begin with a brief historical foundation that brings us to the current day, as well as provide an overview of the physiological mechanisms used to treat decompression illness (DCI).

Let us start with Paul Bert (1833-1886). He was amongst the first to opine that decompression sickness (DCS) was causally linked to bubbles in the blood following decompression, but there was little work on what could be done to prevent it.

This underscores the fact that while a causal relationship is seen between bubble formation and disease symptoms, there wasn't enough known about DCS at that time to predictably prevent its occurance. As a first attempt at effecting reduction or prevention of disease, Paul Bert recommended a very slow linear ascent.

It is somewhat ironic that one of his other contributions to the field of hyperbaric physiology is his caution against breathing oxygen under pressure. We are all aware of the Paul Bert effect, or oxygen toxicity seizures, associated with breathing oxygen at high partial pressures.

He is often characterized as the father of of decompression sickness, but I think he had a negative role with respect to the therapeutic interventions on decompression sickness. I hate to steal some of his thunder, but his discovery of oxygen toxicity seizures and the subsequent prohibition against the use of oxygen to expedite inert gas removal, set the field back several decades. Without the use of oxygen, the treatment of DCS was relegated to very lengthy air tables.

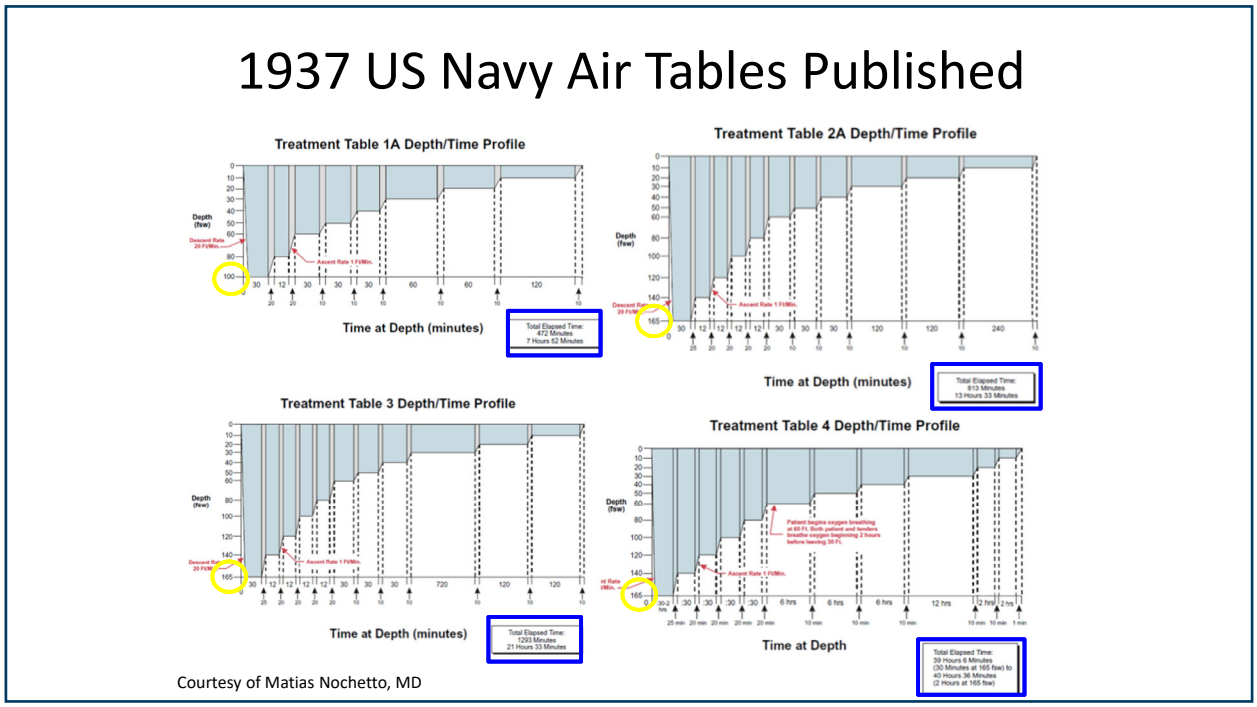



Figure 1. Recompression treatment tables

Figure 1 shows examples of some of the long air tables. These protocols required lengthy treatments and complicated logistical planning and support.

*Albert R. Behnke, PhD, Capt.*

~1936 - Separated the symptoms of AGE and DCS
1939 - Recommended oxygen for recompression
1967 - co-founded UMS (now UHMS)

In the 1930s Behnke evolved our understanding of decompression illness and its treatment. An advocate for separating symptomatology related to decompression sickness from arterial gas embolism, it was his contention that it was important to appreciate the etiological distinction, despite the fact that the treatment approach was essentially equivalent.

His contributions to hyperbaric medicine continued. In 1939 he recommended the use of oxygen for the treatment of DCI. Approximately 60-years after Bert's prohibition against the use of oxygen under pressure, Behnke championed its use as a means to expedite treatment and increase clinical efficacy.
Despite Behnke's support for oxygen in the treatment of DCI, it wasn't until the mid 1960s, another 30-years, before his ideas were adopted.
During these interval years, patients suffering from DCI were treated with long air tables. Change often requires a catalyst, and this came with the invention of the aqualung and scuba, invented by Jacque Cousteau and Emile Gagnon in 1943. The invention of scuba diving, adopted by the military and recreational community, resulted in both greater awarenss of hyperbaric related injuries and an increase in the cases of DCI. Increased cases enabled a critical appraisal of current DCI treatment and a recognition that long air tables were not that effective and carried significant risk to patients and inside attendant staff.

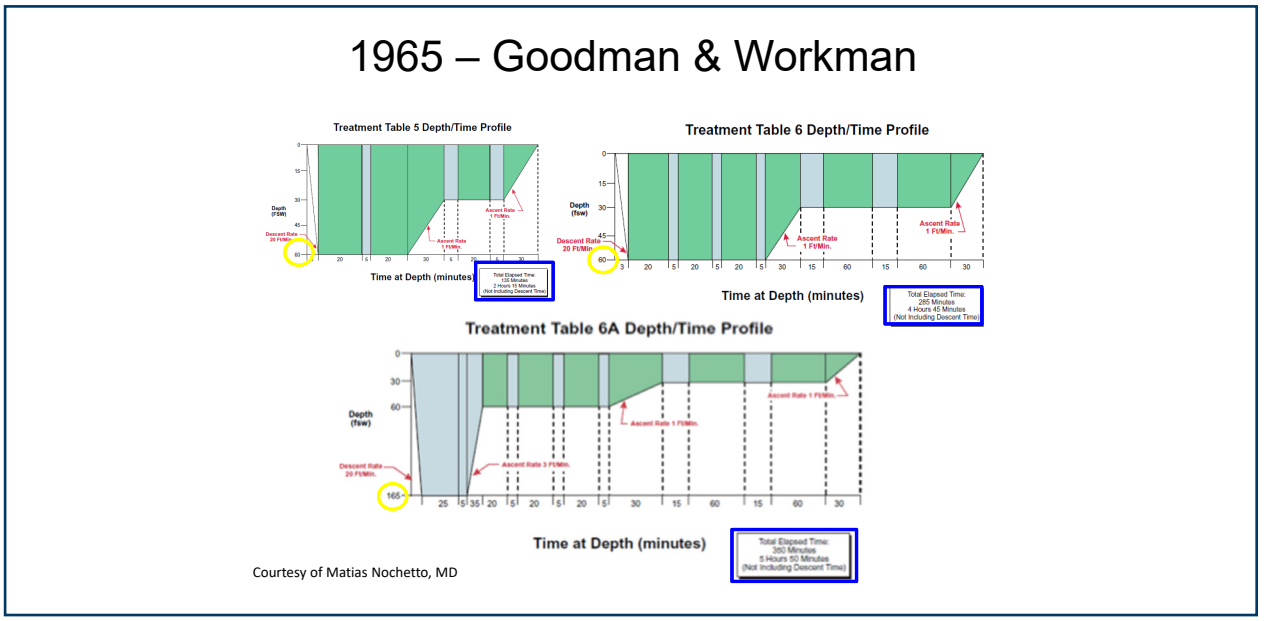



Figure 2. Goodman and Workman treatment tables

It took until 1965 when Goodman and Workman published the oxygen treatment tables we use today, that Behnke's ideas were realized.

The oxygen tables are markedly different, both shallower as well as shorter than their air-table counterparts, with initial treatment depths of 60 feet of seawater or 2.8 ATA. For the acute treatment of AGE, the treatment table 6A was introduced that starts with a deep pressurization to 165 feet of seawater or 6 ATA to maximize Boyle's law and compress bubbles.

So how does this work? Why do we care about oxygen use? One of the big reasons for the efficacy of 100% oxygen, is that it's 100% not nitrogen. We just happened to be able to survive in 100% oxygen environment, but it could be 100% of any gas other than the inert gas(es) inspired by a diver. By increasing the partial pressure of oxygen within our vasculature, we can increase the oxygen diffusion distance and penetrate more deeply into tissues that are ischemic. We can reduce inflammation. We can help reduce bubble size in accordance with Boyle's Law.

We can increase the oxygen gradient. And we can also keep dissolved gas dissolved and prevent bubble formation.

As discussed in the previous pre-course, whether the diagnosis is AGE or DCS (collectively grouped as DCI) all roads lead to a treatment table six (TT6) or its equivalent. Let's quickly talk about that.

The initial step is to determine that we have treatable diagnosis, i.e., DCI. This seems so obvious, doesn't it? We've got to make sure that we have decompression illness (decompression sickness or arterial gas embolism) before we initiate hyperbaric treatment. However, we do not have an objective mechanism or technique to definitively affirm the diagnosis of DCI. How many of you have been on the phone with somebody calling from a remote setting saying, "I think there's a diver and they're injured, therefore must have decompression illness." ...Everybody raises their hand.

## BENEFITS OF HYPERBARIC OXYGEN FOR DECOMPRESSION ILLNESS

- Increase oxygen diffusion distance
- Reduce inflammation
- Reduce bubble size
- Increase oxygen gradient
- Keep dissolved gas in solution

## DCI TREATMENT APPROACH

- Determine treatable diagnosis
- Initiate TT6 or equivalent
  - Treat aggressively up front
  - Consider extensions if necessary, possible and appropriate
- Titrate subsequent treatment(s) as needed to achieve clinical plateau

The first step is to determine if we have a treatable diagnosis. Achieving an acceptable level of certainty over the phone can be challenging.

Whether evaluating the patient in person or over the phone, one of the clinical goals is to initiate a TT6 or it's equivalent as soon as possible, and treat aggressively upfront, as this is your best opportunity to maximally impact the clinical course. If considering the use of extensions, this is the most efficacious opportunity. Subsequent treatments can be titrated as necessary, and treatments may range from a repeat of the initial or other shorter table.

My favorite treatment table 6 comes from the US Air Force. Although offering the equivalent treatment dose of oxygen, operationally this is an easier table to use than the US Navy table for a couple of reasons. The first characteristic of this table that I appreciate is the consistent treatment intervals of 20-minutes on oxygen, followed by 5-minute air-breaks. With the exception of the ascent from 2.8 ATA or 60 feet-of-seawater to 30-feet-of-seawater, the entire treatment routine is consistent.

As divers commonly present to hospitals and treatment centers in the evening, where the clinical staff are more likely tired and therefore more prone to making operational errors, this consistent treatment pattern minimizes operator error. In contrast, the US Navy table, while consistent with the oxygen periods and air-breaks to the USAF table when at 60 feet-of-seawater, switches to 60-minutes on oxygen and 15-minutes on air at the shallower treatment pressure at 30 feet-of-seawater. This portion of the treatment table necessarily occurs later, and the longer periods increase the chances of operational error.

Earlier in this talk I mentioned the treatment table 6A, which is rarely used. In-vivo studies showed no enhancements in the intravascular bubble redistribution beyond 2.8 ATA, and since patients are frequently breathing air, we don't achieve the same level of oxygen diffusion or off-gassing of inert gas. This begs the question of whether the added risk associated with pressurizations to 6 ATA is worth the risk.

There is anecdotal evidence to support the use of other treatment tables that go deeper or last longer, but there is no strong comparative data.

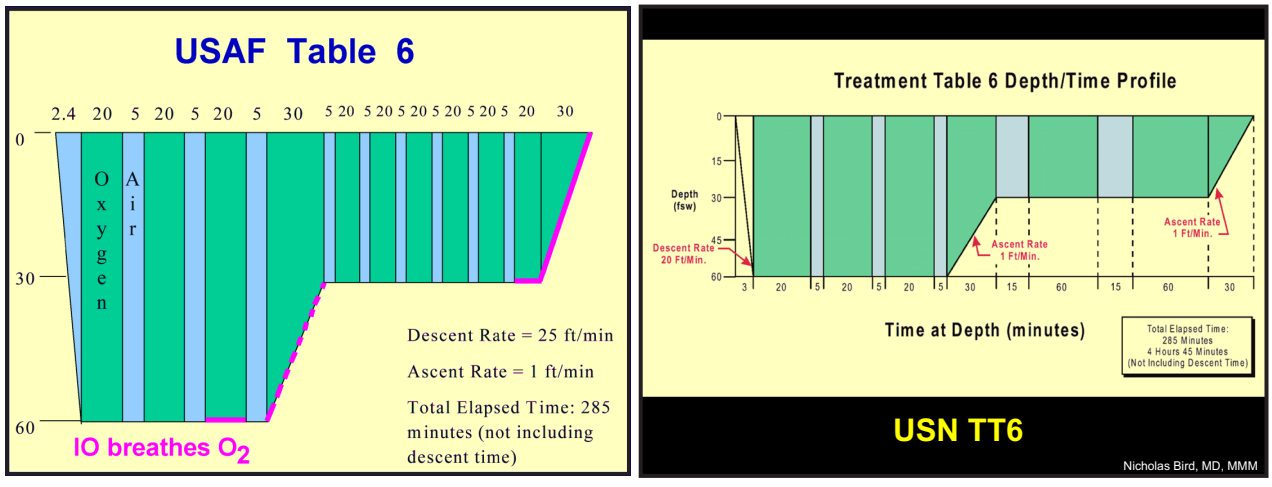



Figure 3. USAF TT6 and USN TT6

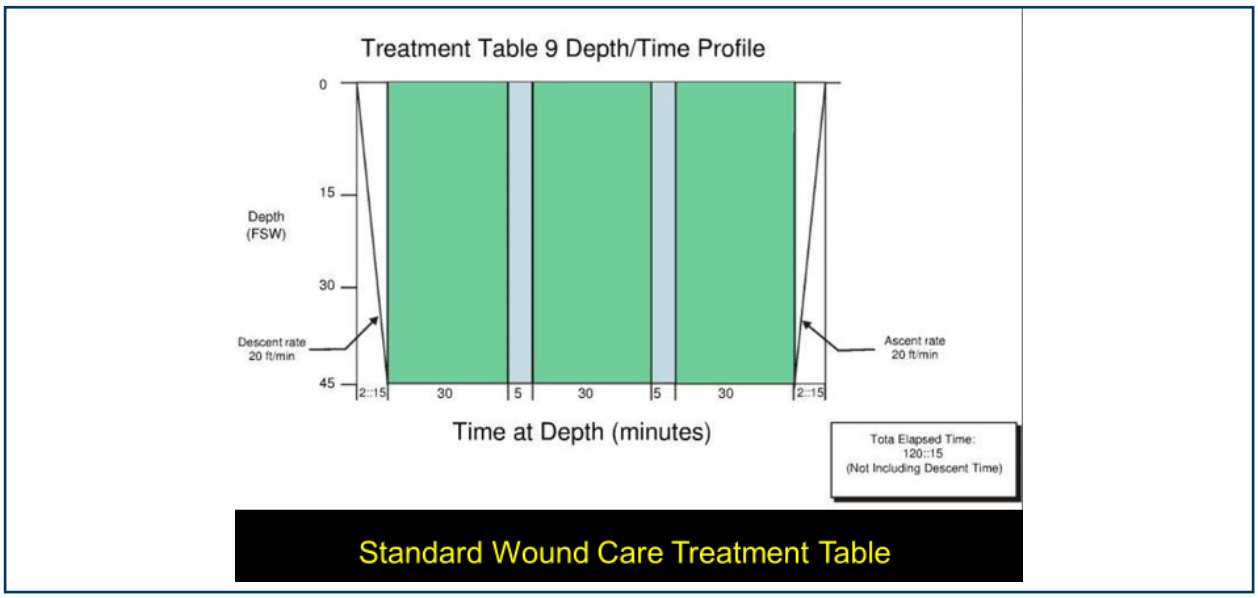



Figure 4. Standard wound care treatment table

## FOLLOW UP TREATMENTS

Following the initial treatment, the use of subsequent treatments and choice of table, is an area of some debate. This should not dissuade clinicians from treating patients who manifest residual symptoms. A common approach is encapsulated in the 'follow-up treatments' slide.

### FOLLOW-UP TREATMENTS

**Common approach:** 1 – 2x daily until 100% resolution or plateau
**U.S. Navy standard:** treat at least once past symptomatic plateau
Follow-up or "tailing" treatments

- Occasional repeat of "definitive table"
- Some units use USN Table 5
- Many use TT9 (standard wound treatment)

In many settings, the choice of follow-up treatment is influenced by both patient status and operational constraints. As an example, if a diver were treated on a Sunday and had very mild residual symptoms, there would be little point in monopolizing a chamber with a treatment table 6, when it would be perfectly acceptable to include that diver with your other wound care patients (undergoing a treatment table 9 (or similar table) and consider treating once or twice daily until there is no further clinical change, or therapeutic plateau.

For more severe cases, we may consider repeating a treatment table 6 or the shorter treatment table 5. An important aspect of DCI is that the clinical course progresses towards resolution. This is important to remember, as not all cases of DCI will achieve complete resolution while undergoing treatment, and at some point, the treatment course will end.

A frequently asked question relates to chamber type and if it matters with respect to treatment effectiveness. Pictured here are three different chambers. Two of these chamber are multiplace, and the others are monoplace. All of these can perform a treatment table 6, all of these can provide oxygen under pressure. As such, they all provide physiologically equivalent treatment environments.

I think one can argue that treatment in the larger chamber is a lot more comfortable, especially with these prolonged treatments.

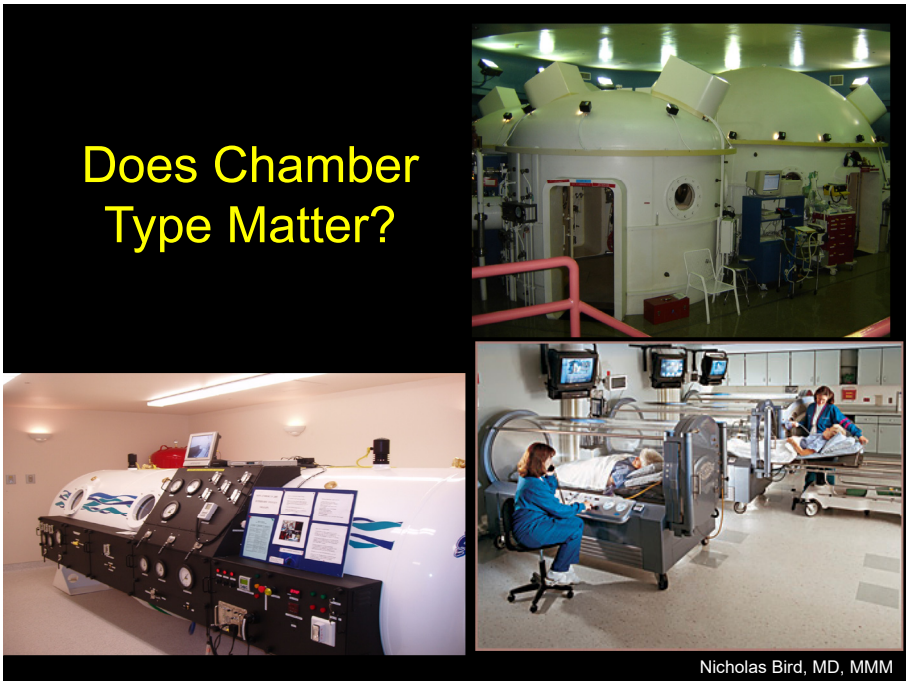



Figure 5. Types of chambers

Another frequently asked question relates to treatment delays, which capture the duration the person has been symptomatic following a dive or ascent and whether there is a standard duration after which treatment is deemed ineffective. Is it a day, a week, is it a year? When do we cut them off from further treatments?

What we have ultimately seen is that symptom severity is the primary prognostic indicator, versus a specific 'time to treatment'. This is especially the case in spinal injury presenting with lower extremity paralysis and urinary retention. I think we can all agree that treating earlier is better and use of surface level oxygen may protect against unchecked disease progression relative to those who don't receive surface level oxygen. The data to date do not support a definitive timeline where hyperbaric oxygen is no longer effective, but most clinicians are reticent to treat much past 7-days of symptoms. That said, there is case report data that supports treatment benefit after up to 14-days.[4]

## IMPACT OF TREATMENT DELAYS

- Symptom severity = primary prognostic indicator[1,2,3]
- Early treatment associated with better outcomes in severe cases[4]
- $SLO_2$ may protect against treatment delays[4]

1. Ball R. Effect of severity, time to HBO (49) cases spinal DCS. UHM 1993; 20(2): 133-145.

2. Desola J et al. Prog fac of dysbarism. MV anal 554 cases. Proc of XXVI ASM/ EUBS. Malta, 14-17 Sep 2000; 17-23.

3. Gempp E et al. RF and tx outcome in spinal DCS. J of Crit Care (2009). Doi:10.1016/j.jcrc.2009.05.011

4. Stipp W. Time to treatment for DCI. H&S Exec 2007. Research Report RR550.

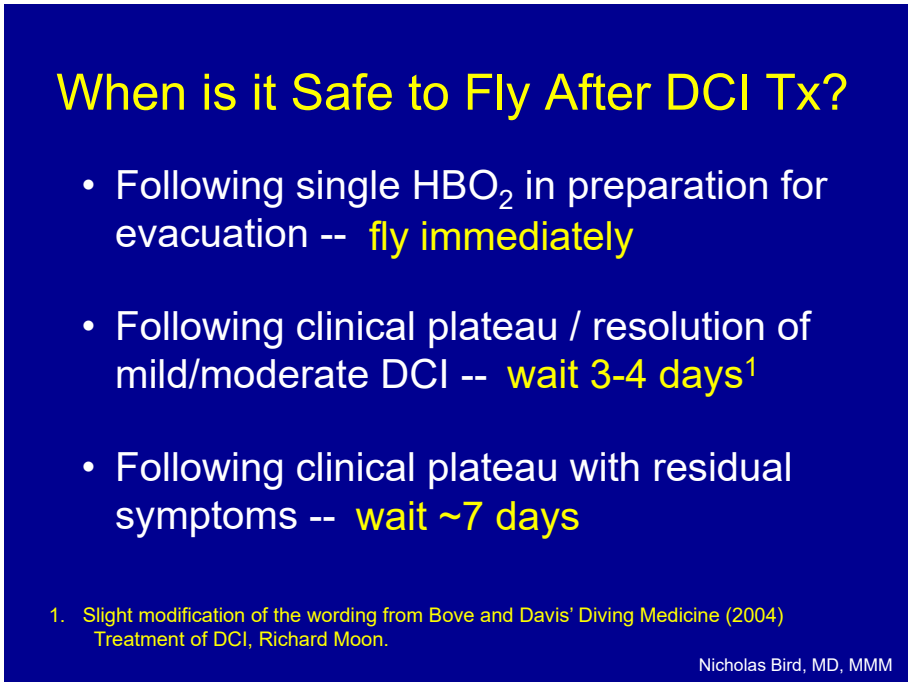



Figure 6. When is it safe to fly after treatment for DCI?

Another common question relates to when we can safety transport a patient on a plane following treatment. This is a debated topic, with differing practices around the world. Factors that should be considered when making this decision include: How severely they were bent (severity of symptoms), how they responded to treatment, and severity or presence of residual symptoms. Did they get complete resolution after one treatment, or did they require multiple treatments?

Another wrinkle to consider relates to where the diver is geographically, their clinical status, and what treatment was administered prior to air travel. In some settings, it may not be feasible or practical to provide a treatment table 6 or other 'definitive' treatment prior to evacuation. However, there may be time to provide a shorter treatment table like a treatment table 5 or 9. In this approach, such a treatment would not be considered definitive, but would optimize inert gas washout, relative to surface supplied oxygen, and reduce the risk of DCI exacerbation in flight.

Back to the question at hand, which is, when can a person safely fly after treatment. Provided here is a structured guideline.

Following a single hyperbaric treatment in preparation for evacuation, it is appropriate to fly immediately. In this scenario the risk to benefit has already been reviewed with the clinical decision to transport the patient, and the risk of symptom exacerbation associated with decompression has been mitigated by some hyperbaric oxygen treatment. As stated above, the duration of post-treatment time recommended across the globe varies and in some cases can lead to considerable consternation. As you might imagine, if a tourist was told after a treatment that they have to remain at sealevel in some country for up to a month, you can imagine that pushback is likely.

Following clinical plateau for mild to moderate initial symptoms, wait 3-4 days to ensure that the clinical plateau persists. It is important to note that in such a case, the patient may have received more than one treatment.

For more severe initial symptoms and in cases where symptoms persist despite treatment, wait approximately 7-days prior to flying. The logic in this setting is that 7-days is sufficient to ensure clinical stability in a patient exposed to one or more hyperbaric oxygen treatments where clinical plateau was achieved, and enough time to ensure that their symptoms have remained stable or improved prior to subsequent decompression exposure.

Thank you very much for your attention.

# DCI TREATMENT PRINCIPLES – RESULTS OF A SURVEY

Petar Denoble, MD, DSc

In this pre-course, we would like to discuss the differences in DCI treatment practices that DAN medics encounter not only in the United States but also around the world. One of the questions is whether we can use some of the lesser protocols, like less pressure in small, monoplace chambers. This question is essential because there are fewer and fewer 24/7 multi-place hyperbaric chambers dedicated to treating divers. At the same time, there are more and more of wound care centers with monoplace chambers and busy schedules that have difficulties engaging in long protocols. In some areas of the world, short and shallow protocols may have been used more extensively, and we could learn from that experience.

There are differences in treatment practices in the world, even among best equipped hyperbaric centers. To learn more about it, we sent a survey before this pre-course. The questions are listed below. We received 134 responses from 23 countries.

### SURVEY QUESTIONS

(134 PARTICIPANTS FROM 23 COUNTRIES)

- Could normobaric oxygen replace standard treatment?
- What is the optimal time to treatment (golden hour)?
- Could DCI be treated in monoplace with < 2.8 bar?
- Is there benefit with a higher (>2.8bar) treatment pressure?
- Is it ever late to recompress?
- How long to treat residual symptoms?
- How long to wait before flying after treatment?

While the utility of surface oxygen first aid is hardly arguable, the primary question remains what do we do after administration of hypobaric oxygen if symptoms resolve completely? Although this is a question for physicians, dive operators think of it and often hesitate to provide surface oxygen because of the provision that once they provide first aid oxygen, they have to evacuate diver for further evaluation and treatment. This is especially a problem with liveaboards in remote places when bringing diver back means an interruption for all aboard.

So we asked our colleagues what they would do in a case when diver improves or completely resolves on normobaric oxygen, and we offer four different statements. The agreement and percentage of those who agree or disagree are shown below.

## NORMOBARIC OXYGEN: WHAT DO WE DO AFTER SURFACE LEVEL OXYGEN?

**Guidelines**

- Normobaric oxygen may result in improvement or even a complete resolution of DCI
- Recurrence is possible and thus HBOT should follow whenever possible

| Statement | Agreement |
|---|---|
| All DCS cases require HBO treatment even if they improve on surface oxygen. | YES (54%) |
| Mild DCS cases may be treated with normobaric oxygen only, even when HBO is available. | NO (76%) |
| Mild cases of DCS that resolve with normobaric oxygen and remain symptom-free for at least six hours do not need HBO. | YES (55%) |
| Severe cases of DCS that have entirely resolved and been symptom-free for 6 hours may be administered surface oxygen and observed for 24 hours without recompression if there is no recurrence of symptoms. | NO (62%.) |

Most respondents (54%) agreed that all DCS cases require HBO treatment even if they improve or resolved on normobaric oxygen, but 46% did not endorse that statement. If the opportunity to treat with HBO is available, 24% of respondents are still inclined to accept normobaric oxygen as definitive treatment, while 76% would still treat with HBO.

Opinions about the need to treat with HBO divers who resolved on normobaric oxygen and have been symptom-free for at least six hours were divided (55%:45%). Many respondents said, "Well, maybe not six, but if due to circumstances, divers are still there 24 hours later and symptom-free, we probably would not need to evacuate them for further treatment."

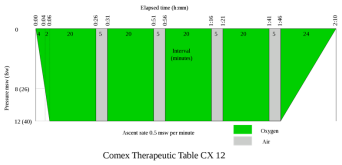
For severe cases, most respondents (62%), but not all, would treat them, even if they had been symptom-free for 24 hours or more.

Some of the short tables using lesser pressure like Comex 12 proved very successful in Europe. In the United States, we have the Kindwall table, USN table 9, and similar, but not everybody accepts these tables as initial treatment.

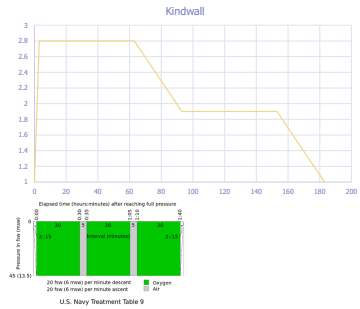
## Short (Comex 12, Kindwall, USN T9, and similar) vs. standard treatment protocols

Shorter or shallower than standard treatment tables are not acceptable as initial treatment for DCS. Agree (72%)

When standard treatment is not available, shorter and shallower HBO protocols are acceptable if administered by trained personnel. Agree (87%)




Comex Therapeutic Table CX 12




U.S. Navy Treatment Table 9

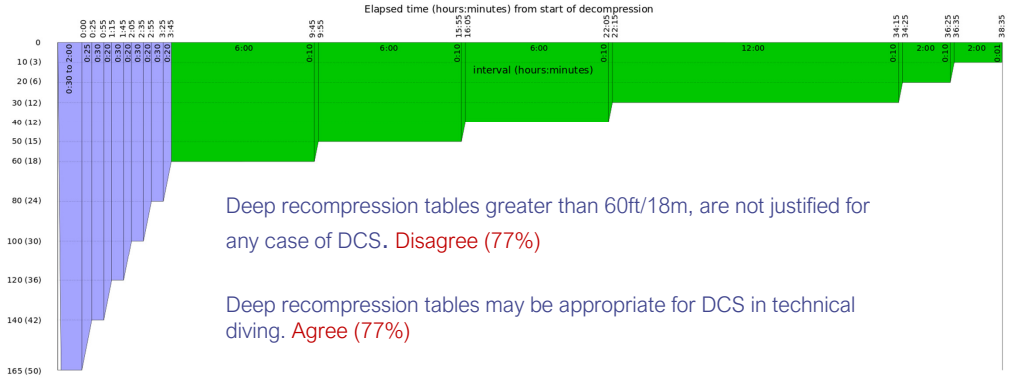
Sometimes there are no better options, but surprisingly, with the statement: "Short term or shorter than standard treatment tables are not acceptable as initial treatment for DCS," 72% agreed. However, slightly different statement - "When standard treatment is not available, shorter and shallower HBO protocols are acceptable if administered by trained personnel" - was acceptable to most people.

We also asked about the use of deep tables. One of the examples here is US Navy Treatment Table 4. I had a bad experience with that table.

But the survey statement was, "Recompression tables greater than 60 feet or 18 meters are not justified for any case of DCS." Most respondents disagree with that, and 77% endorsed the statement that "Deep recompression tables may be appropriate for DCS in technical diving." Also, 74% would use it "for severe DCS cases with a short delay to treatment."

When we tried to learn what is a short delay to treatment, we get answers all over the place. Most people said it's less than one or one to six hours (25%). But the remaining responses varied from 12 to 48 hours. There was no agreement what the

## Deep tables (deeper than 60ft/18m)




Deep recompression tables greater than 60ft/18m, are not justified for any case of DCS. Disagree (77%)

Deep recompression tables may be appropriate for DCS in technical diving. Agree (77%)

Deep recompression tables may be appropriate for severe DCS cases with a short delay to treatment. Agree (74%)

short delay to treatment although one could expect that the delay to treatment should be taken into the equation when deciding about the disposition of injured diver and the choice of the treatment protocol.

The question about the number of HBO treatments we asked because we knew cases where table six was administered ten times in a row, and on the other hand, we have cases treated with one extended table six follow with standard HBO treatment. We offered several statements to probe it. With the statement that "there is no limit to the number and protocol of follow-up treatments," 59% of respondents disagree, while 40% agreed. With a more nuanced statement, "In mild cases standard recompression treatment may be followed with up to two standard HBO sessions," 82% agreed. Similarly, "In severe cases with gradual improvement up to two standard compression protocols are followed by standard HBO sessions, as long as there is a daily improvement," was endorsed by 86% of respondents. We took these statements from the existing guidelines, and as expected, most respondents agreed. However, it is important to notice that there are people who do not agree with this approach.

When it comes to flying after treatment, divers have been advised to wait from 24 hours to up to three weeks. The advice may vary depending on diver's condition, but some centers recommend three weeks for everybody. We offered three different statements covering the advice. The first, "If symptom-free divers should wait for 24 hours. Otherwise, if residual symptoms are present, they should wait for 72 hours." Majority of respondents (61%) disagreed. The second, "In all cases, wait at least 72 hours before flying," was accepted by 63% of respondents. The third statement, "In all cases, wait at least a week before flying," was rejected by 89% or respondents. While it is evident that there are different approaches here, it seems that most respondents would advise waiting for 72 hours and up to a week..

What if symptoms reoccur during the flight? Sixty-one respondents agree that "any symptom that reoccurs during flight, even if it resolves upon landing, should be treated with HBO treatment." The willingness to treat is confirmed further by majority rejecting the statement that "Only cases with persistent symptoms on landing require HBO treatment." It appears that there is a high agreement (81% respondent) that "Any symptom that reoccurs within 24 hours after landing should be treated with HBO."

In conclusion, while this survey brings up some differences, one could read out of it some commonalities.

*Normobaric oxygen (NO) first aid is not a definitive treatment*

- NO may result in complete relief, but recurrence is possible, and thus HBOT should follow whenever possible.
- In mild DCI, when HBOT is not available, non-recompression treatment, including NO may suffice.

*Recompression*

- The standard recompression treatment protocol for DCI is US USN TT6 or equivalents.
- When the standard treatment is not available, protocols with lesser pressure and time may be acceptable.
- USN TT5, CX12 (2.2 bar), and equivalents are acceptable in Type 1 DCS.
- In severe cases not responding to standard treatment, a higher pressure may be used at the discretion of treating physicians.

*Delay to recompression*

- The window for optimal effect may be <2 hours, but It is never too late to treat DCS with neurological deficit.

*Follow-up HBOT*

- Necessary in slow responding cases. Stop when no further improvement on two consecutive HBOT.

*DCI symptoms occurring or recurring during or after the flight*

- All cases with DCI symptoms occurring during flight, even if resolved upon landing, and all cases of DCI symptoms occurring within 24 hours post-flight, should be treated with HBO.

*Flying after treatment*

- Wait at least 72 hours before flying after treatment.

I hope that through the presentations that follow, we will learn more about what are the justifiable variances in practices and what we may consider to do a different way.

# TREATMENT OF DECOMPRESSION ILLNESS IN RECREATIONAL DIVING: CURRENT PRACTICE IN FRANCE

Sebastien de Maistre, MD, PhD; Jean-Eric Blatteau, MD, PhD

Concerning diving accidents, proper diagnosis is essential to determine what treatment is necessary and refer the patient to a medical institution that can provide it.

Decompression sickness (DCS) is a rare pathology. Its incidence is 1 out of 30000 dives. However, it accounts for more than a half among all diving accidents admitted to our hyperbaric center from 2010 to 2017. Serious pulmonary barotrauma is exceptional and accounts for 1 to 2% of all accidents.

DCS classically occurs in an experienced diver, after a saturation dive. The probability of DCS is not the same according to the clinical presentation. In the presence of cardio-respiratory manifestations, the probability of DCS is low. Concerning DCS, two clinical forms predominate: spinal cord and inner ear DCS. Spinal cord DCS is to be feared because it is the most frequent form of DCS (40%), the most serious, and results in sequelae in 20 to 30% cases at discharge after HBO treatment.

Drug treatment protocol is quite similar for decompression sickness and pulmonary barotrauma with cerebral artery gas embolism (CAGE). It requires rehydration, methylprednisolone administration and symptomatic treatment. In case of neurological symptoms, acetylsalicylic acid may be used. Discussions concern the type of hyperbaric treatment to perform. Here, we present Sainte Anne's Military Hospital Experience in the treatment of decompression illness in Recreational Diving.

## DO ALL CASES OF DCI REQUIRE RECOMPRESSION?

Four hyperbaric treatment tables are used in our hyperbaric center (Figure 1). Two (B18 and C18 tables) are used for initial treatment. The others (heliox and OHB15 tables) are used as complementary treatment. For heliox table, a 50% heliox mixture is used from 2.8 to 1.9 ATA.

### CUTANEOUS SIGNS

Clinical studies show that there is a strong link between cutaneous DCS and the presence of a right-to-left shunt, patent foramen ovale most often.[1] The pathophysiology of cutaneous DCS, therefore, seems to be related to embolisation. Given this mechanism we are also looking for cerebral or inner ear damage in case of skin rash, and we retain indication of recompression.

Normobaric oxygen should be performed at water outlet. In case of persistence of signs upon admission, hyperbaric treatment consists in a 2.8 ATA oxygen table for 85 minutes (Figure 2). In other cases, a preventive table is used. If symptoms persist, an allergic cause must be seeked i.e. allergy to the components of the neoprene suit. Finally, right to left shunt has to be searched.

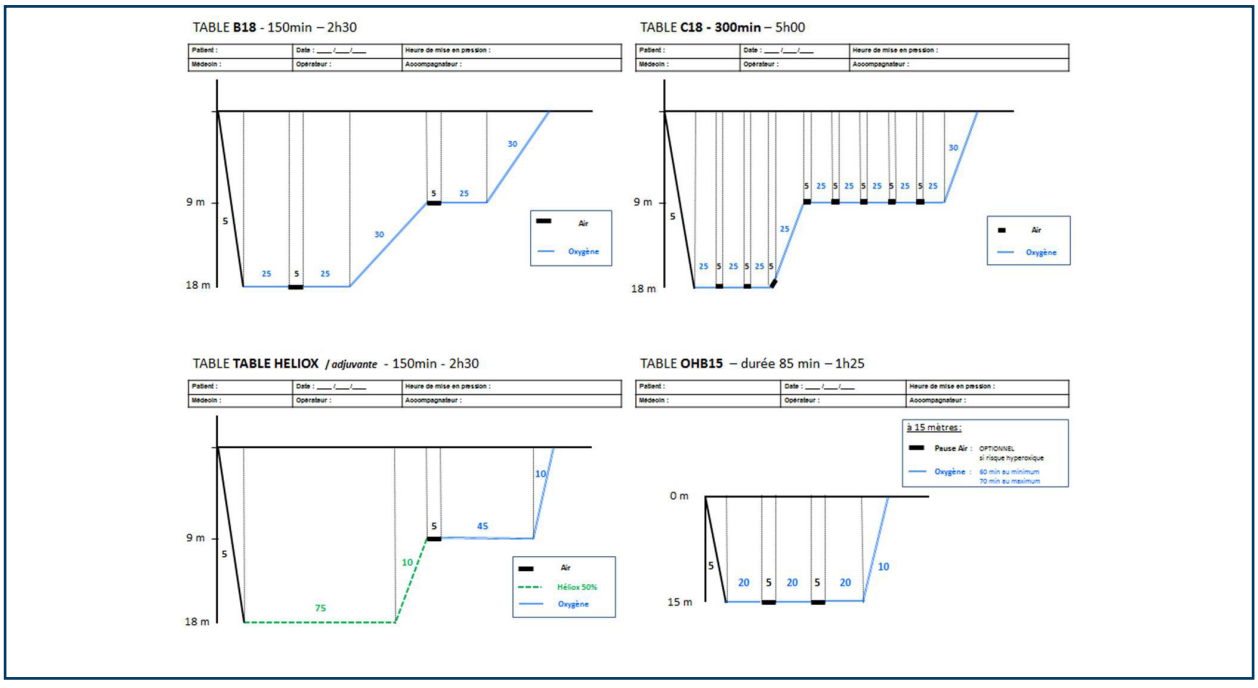



Figure 1. Hyperbaric treatment tables used in the hyperbaric centre of Sainte Anne's Military Hospital

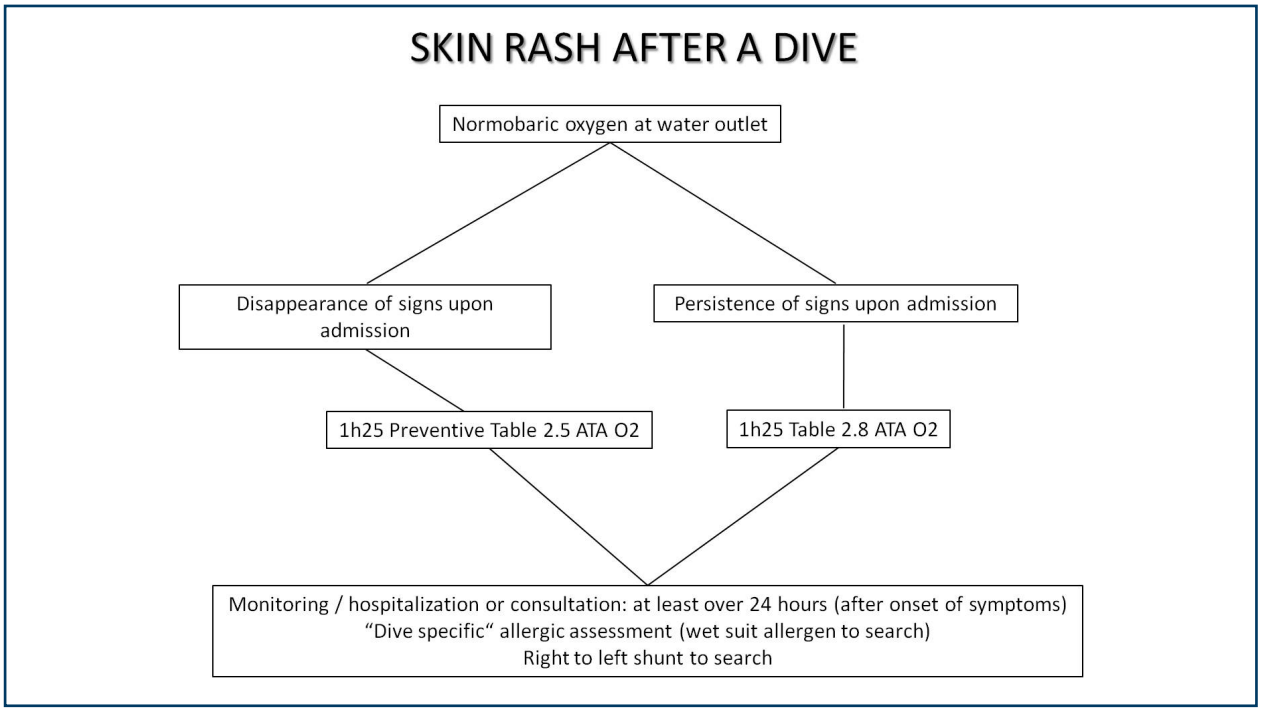



Figure 2. Treatment of a skin rash after a dive

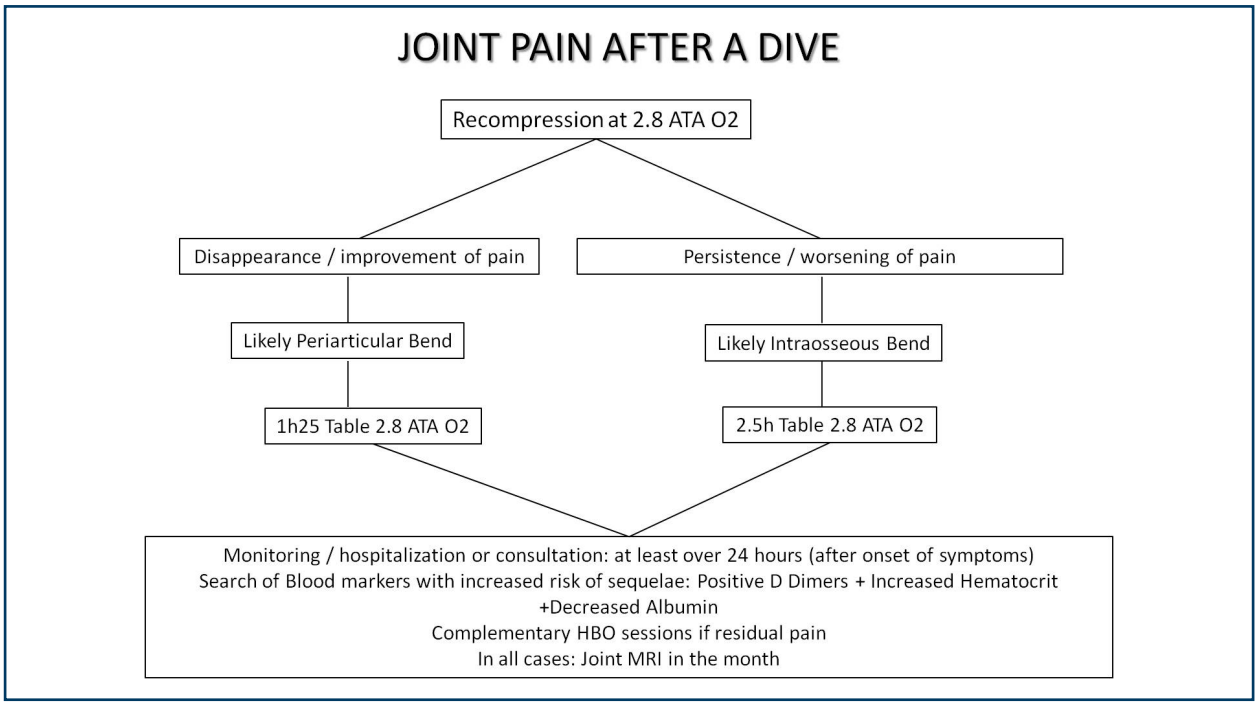



Figure 3. Treatment of a joint pain after a dive

## JOINT PAIN

The presence of joint pain after surfacing especially at the shoulder is very suggestive of decompression sickness. In the absence of recompression, the intensity increases with time with irradiation of pain. The difficulty is that for the same symptom there are two clinical forms. A benign form in two-thirds of cases and a serious form in one third of cases with a bone involvement. This last one can evolve to dysbaric osteonecrosis.[2, 3]

Firstly, a recompression at 2.8 ATA oxygen is performed (Figure 3). The periarticular form, the most common, affecting muscle and tendon insertions, immediately improves with recompression whereas intraosseous form is often aggravated by recompression. That's why a longer hyperbaric treatment is performed in case of persistence or worsening of pain.

## VESTIBULO COCHLEAR SIGNS

Inner ear DCS are very common in France. Vestibular signs, the most common (3/4 of cases), occur shortly after surfacing and are dominated by intense rotary vertigo accompanied by nausea and vomiting. But in some cases, diagnosis is not easy. There are often associated forms with inner ear barotrauma (BT). The problem is that inner ear DCS should be recompressed whereas in case of severe BT with fistula, recompression is not indicated.[4] In doubt, recompression should be performed because inner ear is more frequent than fistula.

In all cases, an hyperbaric treatment with a 2.8 ATA oxygen table for 2.5 hours should be performed (Figure 4). Symptomatic treatment may be necessary. Audiometry + videonystagmography + posturography are performed early after initial treatment. Finally, right to left shunt has to be searched.

## NEUROLOGICAL SIGNS

Most of the time, neurological signs are linked to spinal cord DCS. Typical signs of spinal cord DCS are progressive neurological manifestations in the limbs without the involvement of the cranial nerves. There is a high risk of sequelea (20-30%).

Cerebral DCS is most often linked to the existence of a right-to-left shunt (80% of cases) with a mechanism of cerebral arterial aeroembolism. Outcome is favorable with HBO. Depending on the context, and especially in the presence of an emergency ascent with expiratory blocking, one must mention the pulmonary barotrauma diagnosis which can also lead to cerebral aeroembolism.

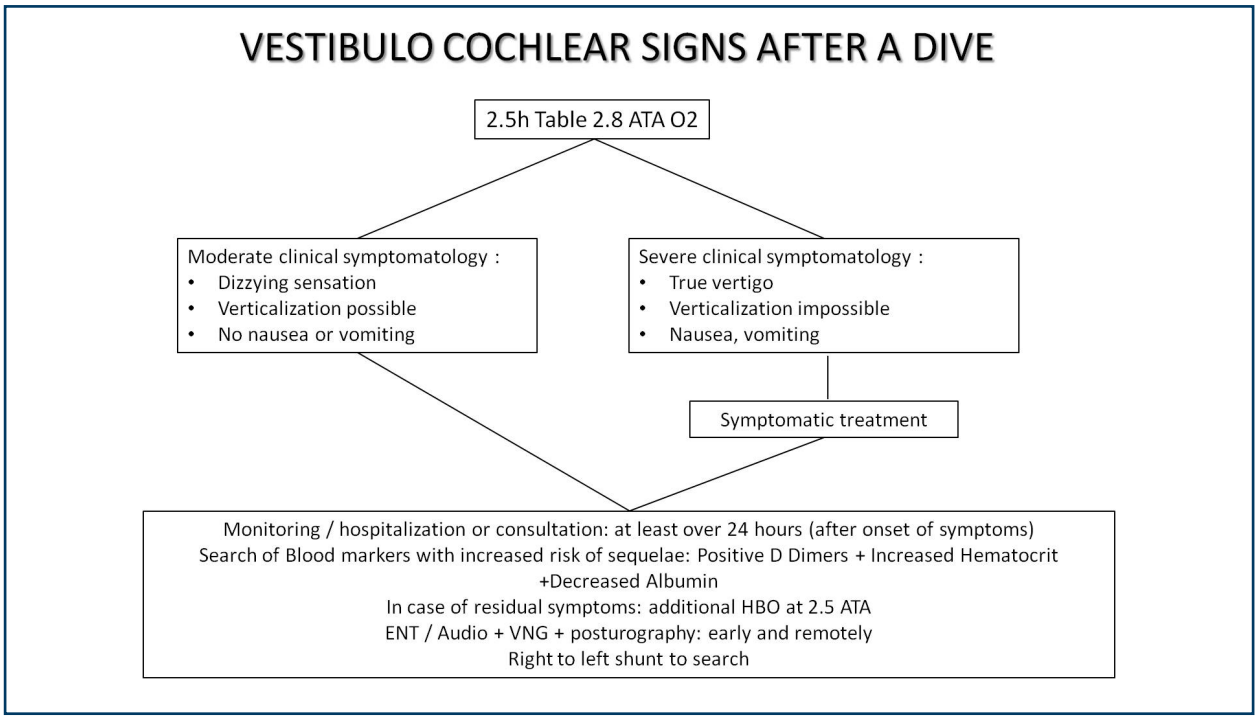



Figure 4. Treatment of vestibule-cochlear signs after a dive

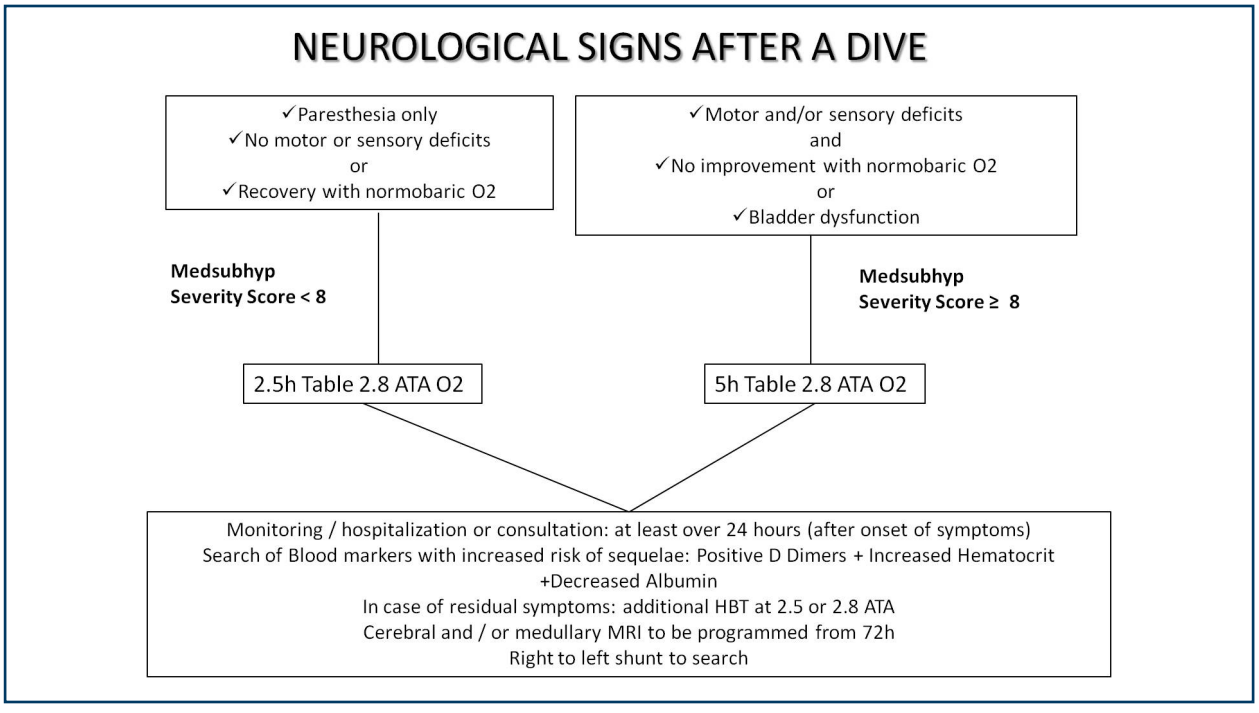
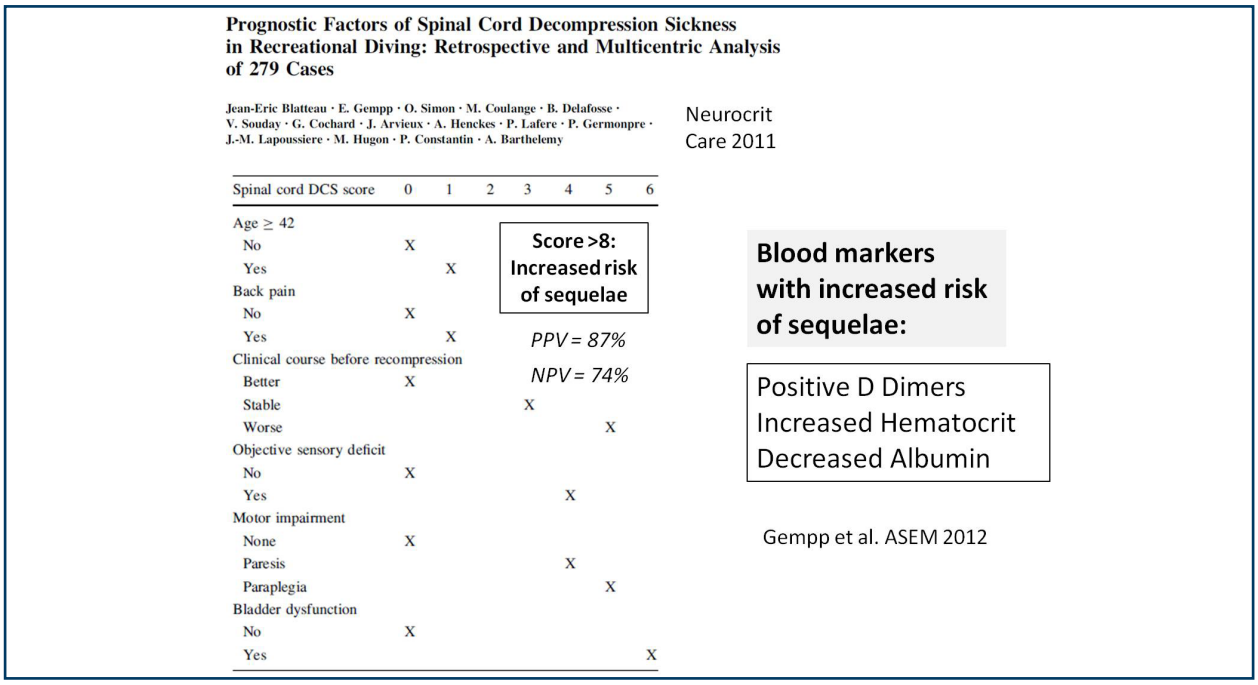



Figure 5. Treatment of neurological signs after a dive



**Prognostic Factors of Spinal Cord Decompression Sickness in Recreational Diving: Retrospective and Multicentric Analysis of 279 Cases**

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Neurocrit Care 2011

| Spinal cord DCS score | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Age ≥ 42 | | | | | | | |
| No | X | | | | | | |
| Yes | | X | | | | | |
| Back pain | | | | | | | |
| No | X | | | | | | |
| Yes | | X | | | | | |
| Clinical course before recompression | | | | | | | |
| Better | X | | | | | | |
| Stable | | | | X | | | |
| Worse | | | | | | X | |
| Objective sensory deficit | | | | | | | |
| No | X | | | | | | |
| Yes | | | | | X | | |
| Motor impairment | | | | | | | |
| None | X | | | | | | |
| Paresis | | | | | X | | |
| Paraplegia | | | | | | X | |
| Bladder dysfunction | | | | | | | |
| No | X | | | | | | |
| Yes | | | | | | | X |

**Score >8: Increased risk of sequelae**

*PPV = 87%*

*NPV = 74%*

**Blood markers with increased risk of sequelae:**

Positive D Dimers
Increased Hematocrit
Decreased Albumin

Gempp et al. ASEM 2012

Figure 6. Neurological DCS severity scores

Performing an emergency chest CT scan may be necessary. Neurological cerebral symptomatology may also correspond to ischemic or hemorrhagic stroke.

A 2.8 ATA oxygen table is performed in any case of neurological DCI (Figure 5). The spinal cord MRI, performed at least 72 hours later, shows, in severe forms, ischemic damage and sometimes the existence of anatomical compressive factors in relation to the spinal cord injury.

## RESPIRATORY SIGNS

In the presence of respiratory signs, cardiopulmonary DCS is exceptional. We must look for priority: immersion pulmonary edema (IPE), pulmonary barotrauma and drowning. Treatment is based on normobaric oxygen. Recompression is only performed in case of neurological signs i.e. CAGE from pulmonary barotrauma. Diagnosis is based on the chest CT scan.

## ARE PROTOCOLS SHORTER AND/OR SHALLOWER THAN TABLE 6 ACCEPTABLE?

USN TT5 and TT6 are the widespread hyperbaric treatments for DCI nowadays. No shallower protocols than USN TT6 are used in our center. Shorter protocols are usually used for DCS other than neurological DCI.

For neurological DCI, the first hyperbaric treatment depends on initial clinical severity (Figure 5). A 2.8 ATA oxygen table for 5 hours is performed in case of severe spinal cord DCS. The problem of spinal cord DCS is the diagnosis of its severity, which should be used to guide the choice of medication and hyperbaric treatment. Serious spinal cord DCS usually worsen in 12 to 24 hours. Blatteau et al. proposed a clinical severity score to predict the risk of sequelae, named MEDSUBHYP score (Figure 6). A score upper to 8 is at risk of sequelae.[5] We also identify blood marker. Elevations in hematocrit and D-dimer and albumin decrease are also associated with severity.[6]

### OXYGEN TABLES TO 2.8 ATA FOR 5 HOURS (USN TT6, RN62, C18)

Royal Navy 62 and French C18 tables derive from USN TT6.

Oxygen tables to 2.8 ATA for 5 hours are the standard of care for neurological DCS. Rate of success is high, over 80% after the first two sessions.[7] But these results are based only on retrospective studies. There is a lack of comparative data between recompression procedures.

### SHORT OXYGEN TABLES (USN TT5, RN 61, B18)

Royal Navy 61 and French B18 tables derive from USN TT5.

Short oxygen tables are not recommended in the current consensus guidelines.

In 1987, Green published a study based on twenty years of treating decompression sickness. He showed that serious DCS treated "inappropriately" with RN61 tend to present more residual deficits than DCS treated with RN62 although time to treatment was shorter.[8]

However some studies support efficacy of short oxygen table for the treatment of neurological DCS. Hart in 1986 and Cianci in 2006 found excellent healing rate in neurological DCS treated with USN 5 table.[9] In a meta analysis in 2011, Blatteau found a higher healing rate in neurological DCS treated with USN 5 table, even in the presence of a high severity score.[5]

## ARE DEEPER TABLES JUSTIFIABLE OR NECESSARY?

Due to hyperoxic risk, compression at a pressure higher than 2.8 ATA can't be made with pure oxygen breathing. Above 18 meters, gaseous mixtures containing a diluant gas (nitrogen or helium) have We don't use any more tables deeper than 18 m in our hyperbaric center.

However, the French Navy still use a 4 ATA nitrox table for 6 hours (named Emergency Recompression Table) in case of severe neurological DCS to be used. The oxygen content is adjusted to the maximum pressure of the table.

### TABLES > 2.8 ATA O2 < 100%: HISTORY

Deep tables were developed in the 1960s on the basis of experimental work of carotid air embolisms on anesthetized dogs.[10] Disappearance of visible bubbles were shown at 30 meters depth. Thereafter, many tables were developed at 30 and 50 meters. Even more "extreme" procedures were performed after that, like saturation tables[11] or tables up to 100 meters.

### DEEP AND SATURATION TABLES (HAWAIIAN TABLES, USN TT8, USN 6A, FRENCH GERS TABLES)

Concerning deep and saturation tables, numerous schedules exist depending on local facilities. These tables imply the availability of special technical and medical supplies. They are responsible for risks for carers (especially DCS) and the benefit ratio for the patient is not certain due to prolonged immobilization and oxygen toxicity. Their use is anecdotal with less than 1% of initial treatment delivered throughout the world.

Results are conflicting. Smerz et al. found good results with Hawaiian tables from 50 to 70 meters. However, they described some cases of DCS among carers and neurological oxygen toxicity.[12] Xu et al. related good results with Shangai tables from 50 to 70 meters.[13] Other authors did not find good results.[14, 15] In their multicenter study in 2011, Blatteau et al. didn't find any significant difference between standard and deep tables. With high initial clinical severity, results are not good whatever the initial hyperbaric treatment.[5]

## HOW DOES DELAY TO TREATMENT AFFECT DECISION TO TREAT?

Hyperbaric treatment has not only physical but also biological effects. Decompression accidents, especially those with neurological involvement, trigger well-identified ischemic and post-ischemic processes. The action of hyperbaric treatment is not limited to reperfusion by action on the bubbles. Hyperbaric therapy is part of a temporal process of ischemia-reperfusion (Figure 7). Thus, hyperbaric treatment has:

- Microcirculatory anti oedematous effects,
- Pro-fluidifying effects,
- Anti-inflammatory effects,
- Positive effects on reperfusion.

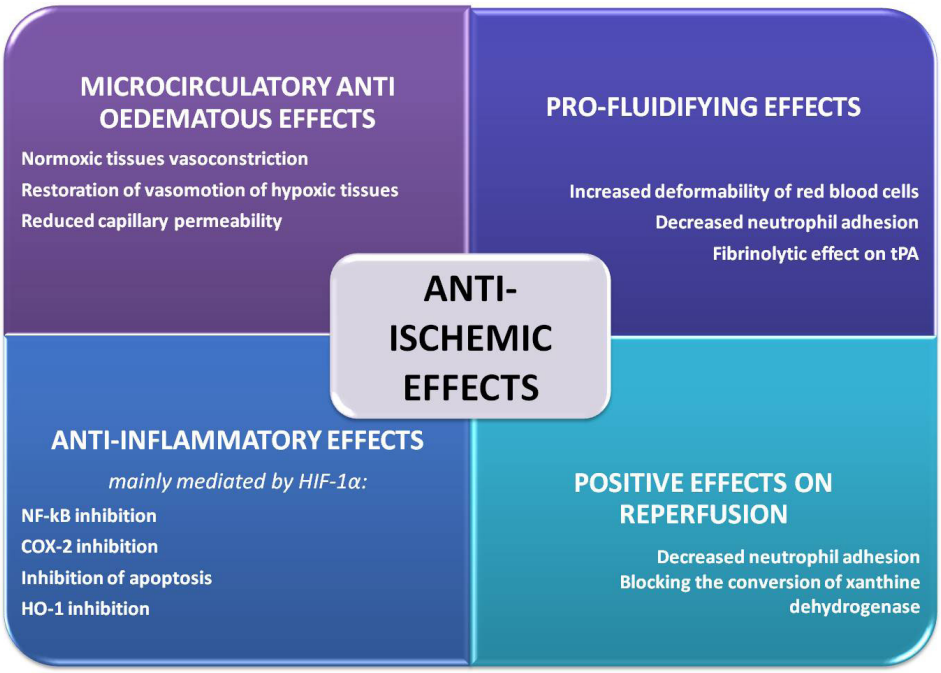


Figure 7. Utility of hyperbaric oxygen therapy beyond 24 hours

That's why hyperbaric oxygen therapy is of interest even beyond 24 hours. However initial hyperbaric treatment may be different from the one usually performed just after the first signs. Thus, beyond 24 hours, we use tables similar to those performed as complementary HBO sessions.

## FOLLOW-UP TREATMENT: WHEN, HOW AND FOR HOW LONG?

In our hyperbaric center, we used two sorts of tables as complementary sessions. A classic one at 2.5 ATA oxygen for 85 minutes. And a special one at 2.8 ATA heliox for 2.5 hours.

### FOLLOW-UP TREATMENT FOR JOINT PAIN

The risk of progression of a joint pain to dysbaric osteonecrosis is partly linked to increased pain during hyperbaric compression for HBO, that is in favor of an intraosseous form.[2, 3] Intraosseous forms should be confirmed by performing an initial joint MRI and repeating this examination to follow the evolution. In these bone forms, HBO sessions should be prolonged for several weeks to limit the risk of osteonecrosis.

### FOLLOW-UP TREATMENT FOR NEUROLOGICAL DCS

#### Re-treatment after initial recompression failure

In case of neurological residual deficit after initial recompression, we lack a successful method of follow-up treatments. Common practice is to repeat short courses of HBO (1-2 per day) until no step-wise improvement. Generally, 3-4 follow-up treatments are sufficient to obtain a clinical plateau and a maximum of 10 sessions has been statistically established.[7] Choice of procedure for re-treatment in unclear. According to Wilson, oxygen tables at 2.8 ATA seem superior to those using oxygen at 2.4 ATA.[16] According to Ball, there's no difference between various follow-up regimen.[17]

### HELIOX IN RECOMPRESSION PROCEDURE

Helium has theoretical benefits. Solubility and permeability are lower than nitrogen in the exchange of gas in fatty tissues.[18] Helium allows to maintain higher treatment pressure to increase mechanical reduction of bubble size.[19]

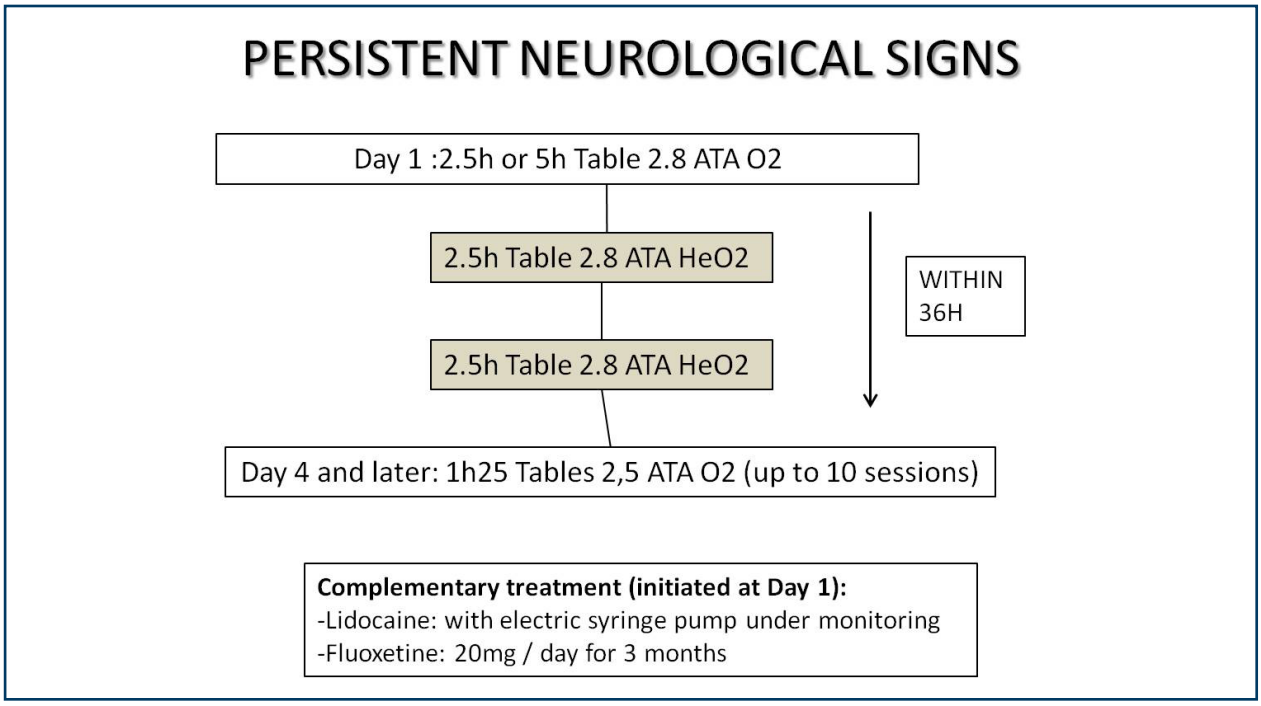


Figure 8. Treatment of persistent neurological signs

Experimental studies support evidence of beneficial effects.[20, 21]

Pharmacological effects of helium could be linked to neuroprotection and antiinflammatory effects.[22, 23]

There's anecdotal clinical evidence of beneficial effect from small case series.[24, 5, 18] In a Random Control Trial, Drewry found no difference in the final outcome but fewer patients were requiring multiple recompression with heliox.[26]

In our center, in case of residual neurological deficit after initial treatment, we perform 2 new HBO sessions with 2.8 ATA heliox for 2.5 hours within 36 hours (Figure 8). Complementary drug treatment is initiated at day 1 with lidocaine and fluoxetine. These sessions may be followed by up to 10 standard HBO sessions.

## HOW LONG DOES PATIENT NEED TO BE OBSERVED BEFORE DISCHARGE?

The evolution of decompression sickness is maximum during the first 24 hours.

Monitoring by hospitalization or consultation should be practiced at least over 24 hours after onset of symptoms.

# CONCLUSIONS

## STANDARDIZATION OF PRACTICES

We have tried to standardize our practices.

The choice of initial table depends of clinical form and severity. "Consolidation" sessions depends of the evolution. Initial short tables are well fitted to skin, joint, vestibulo cochlear DCS and low initial severity neurological DCS. Initial long tables are performed in case of high initial severity neurological DCS with adjunctive sessions during first 36 hours.

## PERSPECTIVES : OPTIMIZING HBO-BASED INHALATION THERAPY

What perspectives do we have to optimize HBO-based inhalation therapy?

One of these is to block post-ischemic processes. For that, we target the window of the first 24 hours after reperfusion by the initial table in the same way of Weaver protocol for carbon monoxide intoxication. We are already trying to associate helium with oxygen in the way to neuroprotection resulting from hypothermia. Others gases like argon and xenon should be taken under consideration.

## MEASURE THE EFFECTIVENESS OF TREATMENT

In the future, the challenge will be to measure the effectiveness of treatment.
It will require :

- to standardize data collection;
- to use clinical severity scores at admission;
- to monitor clinical recovery in hyperbaric center;
- to use sequelae scores at discharge.

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# THE CURRENT PRACTICE OF DECOMPRESSION ILLNESS TREATMENT IN CHINA

Weigang Xu, MD, PhD

## AN OVERVIEW OF THE DIVING AND DCI IN CHINA

On average, occupational and recreational diving in China started 30-60 years later than in the west.

Organized diving in new China began in the early 1950s, with mostly fishing and salvage diving and, of course, a certain amount of DCI cases occurred, but with little treatment. In 1959, a severe DCI case occurred due to fast ascent following a sub saturation exposure to 38 meters for 15 hours, and was successfully treated, being the only survivor of the submarine disaster.

In the early 1960s, during the investigation of the sinking of China's first 15,000-ton cargo ship and the construction of the Nanjing Yangtze River Bridge, near 600 dives, air to 66 meters and heliox to 83 meters, were performed, with no case of DCI. During 1977-1980, the "7713 project" salvaging the Japanese ship "Apo maru" sunk in the late WWII performed 13,604 dives to depth of 48-69 meters, 80 cases of DCI occurred, with an incidence rate of 59 in 10,000.

In 1995, when the government began liberalizing the marine fishery, a large number of divers without necessary training flooded into the industry, and diving accidents occurred frequently. We treated 5278 cases of DCI during the 11 years from 2000 to 2010 using a 12-seat hyperbaric chamber located in a small island in north China Sea. In 2000 alone, the chamber treated more than 1000 cases of DCI. Fortunately, since 2011, the local government strengthened the administration of fishery diving qualification, and the health awareness of participants has also been strengthened thanks to the development of general economy, and the occurrence of DCI has dropped sharply.[1]

In commercial and military, diving safety regulations have been well enforced and the overall incidence of DCI is less than 1 per 1000. In the field of recreational diving, there have been over one million recreational divers in China since the first club was operated in 1985, and the number is increasing by about 15% yearly. And DCI is also on the rise, but the overall cases are rare. Therefore, the experience in treating DCI mainly comes from fishery diving.

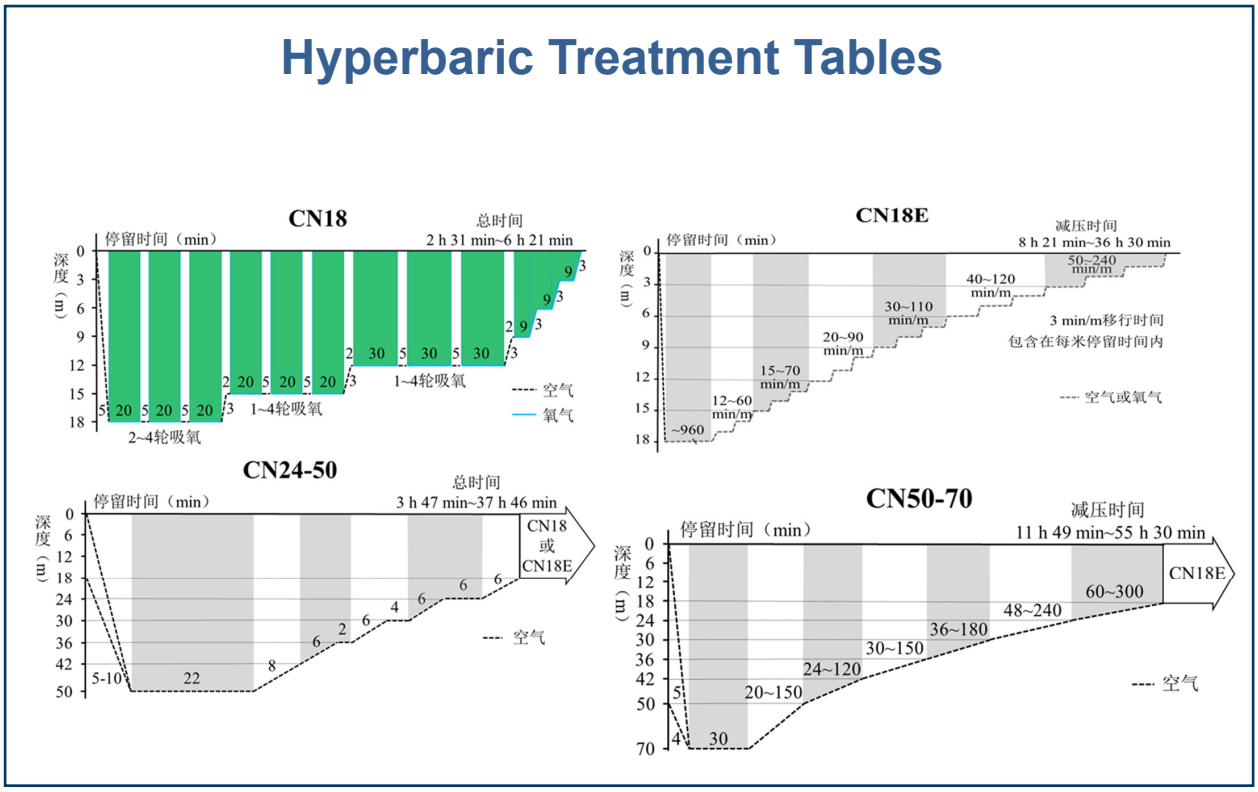


Figure 1. Newly developed set of treatment tables

## HYPERBARIC TREATMENT TABLES THAT HAVE BEEN USED IN CHINA

More than six tables have been used in treatment of DCI in China. The former Soviet Union table was the unique used before 1978. Three domestic treatment tables have been developed since 1980s, one in my university, and have been widely used. During 1980s-90s, the French Comex treatment table had been used in Shanghai salvage industry. In recent 20 years, many diving physicians use the USN table. Each of these tables has strength and weakness.

In view of the rare occurrence of DCI in general, hyperbaric physicians have little opportunity to gain experience in the treatment of DCI. The co-existence of multiple treatment tables further increases the difficulty in gaining experience.

Together with several physicians with experience of more than 1000 cases of DCI treatment, we just finished developing a set of treatment tables based on around 10,000 cases of DCI treatment. These tables combined the advantages of the previously used tables. The table includes 5 profiles, CN15, CN18, CN18E (enhanced, extended and extensive), CN24-50 and CN50-70, suit for chambers with the treatment pressure from 18 to 70 msw, respectively. The profiles can cover the treatment of all DCI cases.

We are now promoting the set of table to hyperbaric physicians in China, and hope they are suitable for inexperienced clinicians to follow in practice.

## ADJUNCTIVE TREATMENTS

In addition to optimizing the treatment tables, we keep exploring the prevention and treatment of DCI. Here, I recommend two drugs for adjuvant treatment of severe DCI.

1) **Ulinastatin:** it is a kind of glycoprotein that can inhibit the activity of a variety of proteolytic enzymes, and can stabilize lysosomes, scavenge oxygen free radicals and inhibit the release of inflammatory mediators. The experiment using a rabbit model proved that it can significantly reduce the incidence and all the determined injuries. Since steroids are no longer recommended for the treatment of severe DCI, ulinastatin can partially replace the role of glucocorticoids in treating sever and neurological DCI.

2) **Escin:** is the main component of the European chestnut seed extract, which has the effects of reducing vascular permeability, increasing vein tension and reflux, anti-oxidation, and inhibiting endothelial activation. Escin has been widely used in the treatment of chronic venous insufficiency, soft tissue edema and hemorrhoids. Experiments in rats and pigs proved that it protected against endothelial injury in DCI.[2,3]

## OTHER STRATEGIES FOR DCI

To carry out study alone is far from enough to implement the treatment of DCI. In China, for example, there are more than a million of medical institutions, among which, 31,700 are certificated hospitals, and at least 3,000 of them are equipped with hyperbaric oxygen chambers, but only around 20 hospitals are able to treat DCI, and only a dozen of doctors who have rich experience in treating DCI. The main problem is that most HBOT physicians do not know the treatment of DCI. In response to this situation, we established TAD, Treatment Alliance for DCI, to include hyperbaric treatment units in need of DCI treatment, train the hyperbaric physicians and provide guidance when treating complicated patients. Only in this way can we maintain the necessary skills to treat DCI and thus provide necessary support for various diving activities.

### TREATMENT ALLIANCE FOR DCI (TAD)

- To include hyperbaric treatment units in need of DCI treatment.
- To train the hyperbaric physicians.
- To provide guidance when treating complicated patients.

## CHARACTERISTICS OF DCI IN RECREATIONAL DIVING

As for the topic of this pre-course, treatment of DCI in recreational diving, I think it generally shares the characteristics of DCI in the other diving activities. However, DCI in recreational diving has the following aspects.

### THREE FEATURES

1. First, mild and moderate symptoms dominate, with little or mild violation of decompression rules, is often associated with heavy activity or poor physical or mental condition, panic or stress. A few severe cases are most possible related to arterial gas embolism caused by PFO or intrapulmonary shunts.
2. Second, many symptoms are associated with flying after diving. Disappeared symptom reoccurs, or new symptoms are triggered.
3. Third, since most recreational divers are well educated, they are often sensitive to subtle symptoms, and actively seek treatment, even excessive.

### TWO KEYS

1. First, pre-mishap plan, including emergency extraction, first aid, evacuation, and nearby chambers.
2. Second, prevention is always pivotal.

Therefore, the health and safety awareness of recreational divers is extremely important, and DAN's value will always be there!

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# AUSTRALIAN EXPERIENCE OF MANAGING DCS IN RECREATIONAL DIVERS

## David Wilkinson, MBChB, FRCP, PhD, DSc

Before describing how we manage DCS in recreational divers in Australia, I believe it is useful to understand something about the geography and the politics of healthcare in Australia. Geopolitical factors will undoubtedly influence the management of divers in most countries.

Australia is a very large country, it is a continent. When you overlay a map of Australia onto continental USA (ex-Alaska), there is very little difference in land area. What is striking is the difference in population. Australia recently passed 25 million while the USA is estimated to have 329 million people. The difference is even more glaring when you consider that close to half the Australian population live in Sydney or Melbourne alone.

Next, Australia has a universal healthcare system. Medibank started in 1975 although the system is now called Medicare. Very briefly, it is funded by a levy of 2% on taxable income plus government funding. It covers the treatment of people in well-resourced public hospitals for free. Importantly, it covers the treatment of DCI.

The map (Figure 1) shows eight significant hyperbaric facilities within big public hospitals around Australia. There are also three private hyperbaric facilities and two Navy recompression chambers which I am not going to include in further discussion. Each state has a hyperbaric facility; Queensland has two with the Townsville facility covering the Great Barrier Reef – a very popular dive location. As you can see, there are large distances between these facilities and Australia does have an effective medical retrieval system.

To give you an idea, I will describe my state – South Australia. It is far from being the biggest state but at 985,000 $km^2$ it is more than 30% bigger than Texas. It has a population of about 1.6 million with about 1.1 million living in the capital, Adelaide. I work at the Royal Adelaide Hospital, a hospital that has been around for about 160 years but which moved to a new location on the fringe of the city of Adelaide less than two years ago. It is a major quaternary hospital providing specialised medical services with a heavy trauma workload. We have a great hyperbaric facility with a state-of-the-art triple-lock hyperbaric chamber.

So, similar sophisticated facilities exist in these other locations around Australia. We all treat both divers and medical patients regularly; we cover both diving and hyperbaric medicine. Rather than give you my own personal approach to treating DCS, I took the

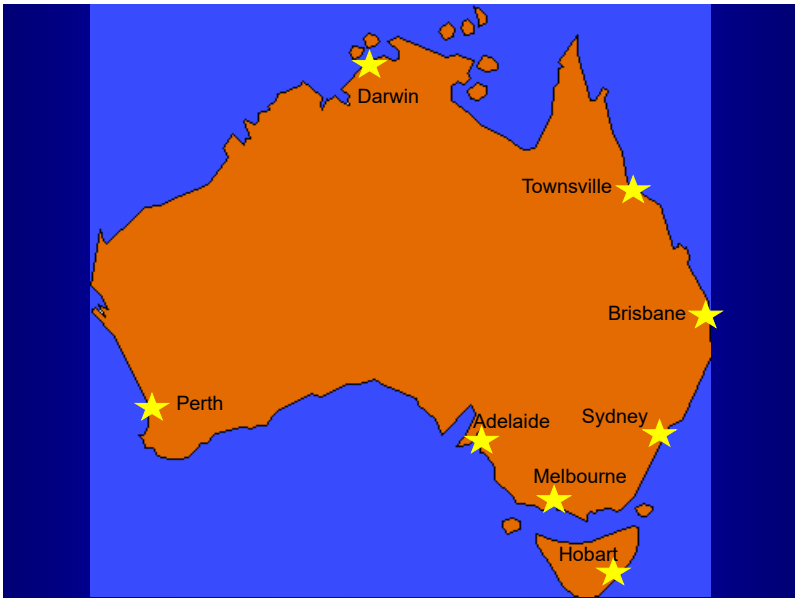


Figure 1. Major hyperbaric facilities in Australia

opportunity to survey these 8 major facilities. This was not a comprehensive survey. It was only sent to the medical director of each facility and I have assumed their response would be generalizable to the approach of that facility. There were six brief questions which asked their usual management strategies when treating DCS in recreational divers. I have collated their response in the following slides without naming particular facilities.

## PRIMARY RECOMPRESSION

When asked about the primary recompression of a diver, all facilities in general would not use a table shorter or shallower than a USN TT6. While one approach has been to differentiate the symptoms and signs into Type I or Type II DCS and provide a TT5 for Type I and a TT6 for Type II, we tend not to do this. It absolves us of potential uncertainty in discriminating between mild and severe symptoms and signs and makes allowance for delayed presentation, which is common and may be more difficult to treat.

People often talk about a "trial of pressure" while we have been brought up with the statement "a trial of pressure is a TT6". One of my maxims has been to make your first treatment the best treatment, so once you embark on recompressing a diver, you are committed to a TT6.

For the primary recompression of a diver, all facilities generally use a multiplace chamber. Five of the eight facilities have monoplace chambers. One facility has some experience of undertaking the primary recompression in a monoplace chamber but only in cases which are clearly very mild. While using the monoplace chamber has been promoted by a number of practitioners for many years, the Australian facilities had multiplace chamber from the outset and we have a very established practice within these multiplace chambers. The presence of an inside attendant does mitigate the risk of complications such as CNS oxygen toxicity and seizures. It also allows physical examination of the diver during the treatment to assess progress.

## ADJUNCTIVE THERAPIES

I also asked about adjunctive therapies to recompression. Oxygen first-aid and fluids are accepted as a given.

We broadly support the use of **Non-Steroidal Anti-Inflammatory Drugs (NSAIDs)** in appropriate cases. The evidence for this did come from our area of the world with the RCT by Bennett in 2003 in the management of mild DCS. Briefly, there was no difference in outcome for divers when assessed at six weeks for both arms of the study. However, one fewer recompressions was undertaken in the arm receiving the NSAID (average of two recompressions) compared to the placebo arm (average of three).

I also asked about **IV Lidocaine infusion**. This therapy had been suggested for severe DCS or CAGE, so I don't think it is particularly relevant for

the purposes of this workshop, but I was interested in the responses of my colleagues around the country and I'll share it with you. Of course, the evidence for this also came from our area of the world with an RCT on cardiac surgery patients (Mitchell 1999). Further work has not reinforced the initial findings and its use has diminished. While I recall using Lidocaine several times in the past, it appears that in Australia Lidocaine has not been used for many years.

## HOW MANY RECOMPRESSIONS?

When considering how many treatments we use and how we determine when to stop recompressions, the free text response was uniformly to treat to resolution or plateau. There was often reference to resolution or plateau +1, so-called "one for the road". No specific numbers were suggested; rather it was determined by the response of the diver. However, we are not talking about a lot of recompressions, as evidenced by Bennett's RCT of NSAIDs where mild DCS had an average of 2 or 3 treatments.

## FLYING AFTER TREATMENT

There was some variation in the suggested delay to flying after treatment for DCS. Most facilities suggested a period of 2, 3 or 4 weeks, depending largely on severity of presentation and duration of intended flight. One facility suggested a range of 4-6 weeks while one facility suggested 72 hours. With the size of Australia and the distance between hyperbaric chambers, flying is the standard way to get around this country. In particular, Townsville is the catchment for diving on the Great Barrier Reef and frequently treats tourists. In this regard, I present the following data which to the best of my knowledge have not been published. This is from a survey undertaken by the Townsville hyperbaric facility and presented as an oral presentation at the Hyperbaric Technicians and Nurses Association (HTNA) ASM in Townsville in 1998.

In follow up of divers treated by the Townsville facility, 28 divers reported flying after their treatment for DCS. Eight had a return or worsening of their symptoms while 20 flew without problem. Of the 8 with return or worsening of their symptoms, the interval between treatment and flying was a range of 5-35 days (mean 18.5 days). Of those flying without a problem, the interval was 5-98 days (mean 40 days). Bearing in mind the small numbers, there was no difference in the proportion that had residual symptoms at the time of discharge. While I don't have any more detail about these cases, the return/worsening of symptoms that occurred after an interval of 35 days is taken as evidence that while flying can be undertaken quite early, there still appears to be some risk even after waiting several weeks.

My final question presented the medical directors with the following scenario:
*"After provision of normobaric oxygen, all the symptoms of DCS had resolved over the few hours that the diver took to reach your facility (ie. the diver presented on the same day as his diving). How likely are you to recompress the diver?"*

I provided three responses: likely to recompress, likely not to recompress or "it depends". No one picked the rather ambivalent "it depends" option. Six facilities said they would probably recompress the diver. They cited the availability of a chamber, the proposed suppression of an inflammation process by HBO which is not achieved by normobaric oxygen and the potential for recurrence of symptoms later that could potentially force recompression with an even greater delay to "definitive" treatment. Two facilities suggested they probably wouldn't recompress the diver but would continue normobaric oxygen and a further period of observation. Those suggesting no recompression cited the workshop findings at the UHMS ASM in Sydney in 2004 – Management of mild or marginal DCI in remote locations.

Relevant to this discussion, I have been the co-ordinator of the Divers Emergency Service (DES) telephone for many years, providing advice to divers, many of whom described symptoms felt to reflect mild DCS. Often they have been in very remote areas of Asia and the Pacific where there may be no recompression chamber, limited medical resources and little chance of prompt retrieval. We have had considerable experience with advising normobaric oxygen in these cases. As the DES phone has been funded by DAN, we would pass the details of these divers over to DAN to follow up. I am aware that many of these cases resolved with only the normobaric oxygen treatment. So DAN does have some useful data about these divers with presumed mild DCS and their outcome which could further inform this debate. Their outcome would be interesting, not just for those divers in whom symptoms resolved, but also for those divers in whom the normobaric oxygen did not help, or the symptoms recurred sometime after an initial response.

Of course, suggesting that mild DCS can be treated by normobaric oxygen alone, on the basis of the remote locations workshop, must be tempered by recognising that the facilities in this survey are not in remote locations. It also requires the active

clinical decision to not recompress the diver when a chamber is available in the hospital. While the field experience has been encouraging, I believe better evidence is required before this question can be resolved.

Overall, I have found that the results of these survey questions do suggest that there is considerable similarity in how DCS in recreational divers is management throughout Australia. Finally, I would thank my colleagues who provided their answers, enabling me to construct this presentation.

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# COULD NORMOBARIC OXYGEN BE ACCEPTED AS A DEFINITIVE TREATMENT?

Richard Moon, MD

To address this question I will start by showing a slide that reflects the breakdown of symptoms of decompression illness in recreational divers. These data were put together by Petar Denoble some years ago. The pink bars represent the first symptom, and the black bars represent the prevalence of that particular symptom at any point.

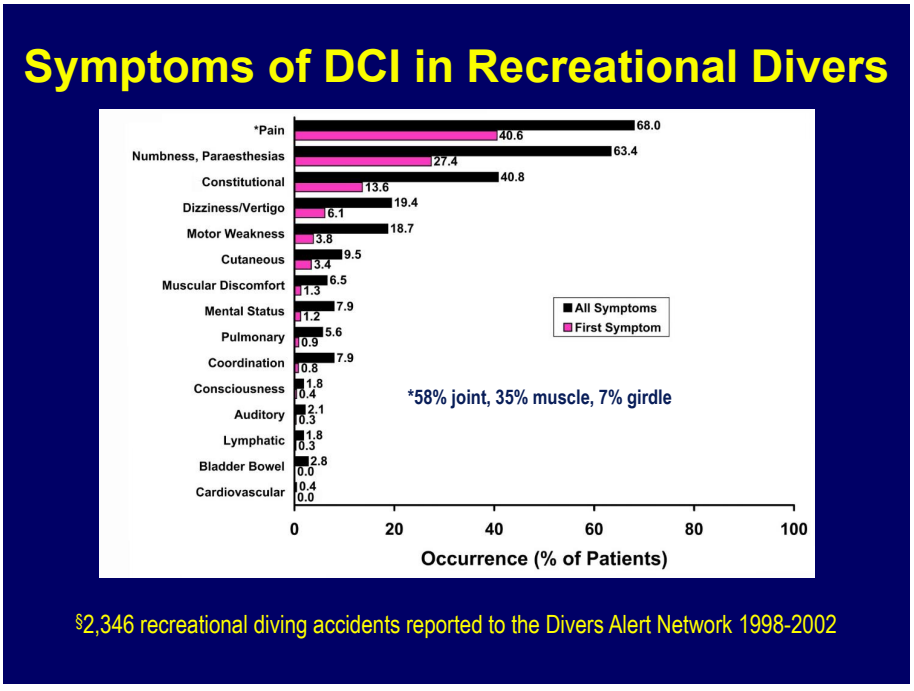


Figure 1. Symptoms of DCI in Recreational Divers

The vast majority of symptoms in recreational divers are pain, numbness, paresthesias, which are considered relatively minor. The other more serious manifestations are relatively rare, at least in this population. The prognosis of DCI varies. We can learn a lot from observations in the 19th century when there was no recompression treatment.

### SPONTANEOUS RESOLUTION OF NEUROLOGICAL DCS

With pains in his legs and thighs, a caisson worker was completely prostrated and unable to walk. His legs were cold and without sensation. He was *"...seated with his feet in the fire, so that several of his toes were burned without him feeling the heat. Two days later he was cured except for his burns."*[2]

In 1909, Graham Blick who was a Royal Naval medical officer spent some time in Broome, Australia and took care of a number of cases of decompression illness among pearl divers, and reported that a significant fraction of these were spinal cord hits and actually resolve spontaneously. Here he says:

> *"I have had patients who have been twice, thrice, or even oftener paralyzed, and who have more or less completely recovered. The treatment after the establishment of paralysis is that of all organic nervous disease - one can only wait on Nature's efforts, though in this disease Nature is kinder than usual....I have been often astonished at the way apparently hopeless paraplegics have recovered in the course of many months."*[3]

There is no guarantee that he did detailed neurological examinations on these people, but nevertheless they were back to work, back to diving.

So much for remote history. Let's refer to a couple of recent major efforts. In 2004, the Remote Management Workshop focused on whether there is another way of satisfactorily taking care of patients who experienced decompression illness, in the middle of the Pacific a long way from home. At the time, it was felt that the only way to deal with such individuals was to scramble a Learjet or other one-atmosphere aircraft to pick up the patient and bring typically to Australia for definitive treatment.

The idea of reconsidering this approach was, in part triggered by a case in Tahiti where an air ambulance arrived with two pilots and a nurse, picked up the diver, took off, and immediately crashed, killing everybody on board. The manifestations of diving injury, in this case, were mild, pain and or sensory changes. It appeared hardly worth risking air evacuation for a condition that would probably resolve spontaneously. And so, in the context of mild symptoms and signs defined as limb pain, constitutional symptoms, and maybe cutaneous sensory symptoms, rash, where the manifestations are static or remitting, not getting worse and with a normal neurological evaluation, it was felt from people's experience that untreated mild symptoms are unlikely to progress after 24 hours from the end of diving. In other words, if 24 hours has passed and the patient isn't getting worse, it's very unlikely that that person will progress to paraplegia, for example.

Level B, evidence suggests that a delay prior to re-compression for mild DCI is unlikely to be associated with any worsening of longterm outcome. It was felt that some patients with mild symptoms and signs of DCI, could be treated adequately without recompression, although it was pointed out that recovery may be slower in the absence of re-compression.

There is support for this in early 20th century experience. Dr. Keyes who attended caisson workers in New York City during the construction of the various tunnels and bridges, collected 3,278 cases of pain only decompression sickness, some of whom were recompressed with air. However, many were handled with medical means, which meant anything else but recompression.

While there was a statistically significant difference in outcome between treatments, whether it's clinically important or not is arguable.

## REMOTE MANAGEMENT WORKSHOP, SYDNEY, 2004[4]

With respect to decompression illness (DCI), **"mild" symptoms and signs are defined as follows:**

- limb pain
- constitutional symptoms
- some cutaneous sensory changes
- rash

Where these manifestations are static or remitting and associated objective **neurological dysfunction has been excluded by medical examination**

- Untreated mild symptoms and signs due to DCI are unlikely to progress after 24 hours from the end of diving
- Level B epidemiological evidence indicates that a delay prior to recompression for a patient with mild DCI is unlikely to be associated with any worsening of long term outcome
- Some patients with mild symptoms and signs after diving can be treated adequately without recompression. For those with DCI, recovery may be slower in the absence of recompression

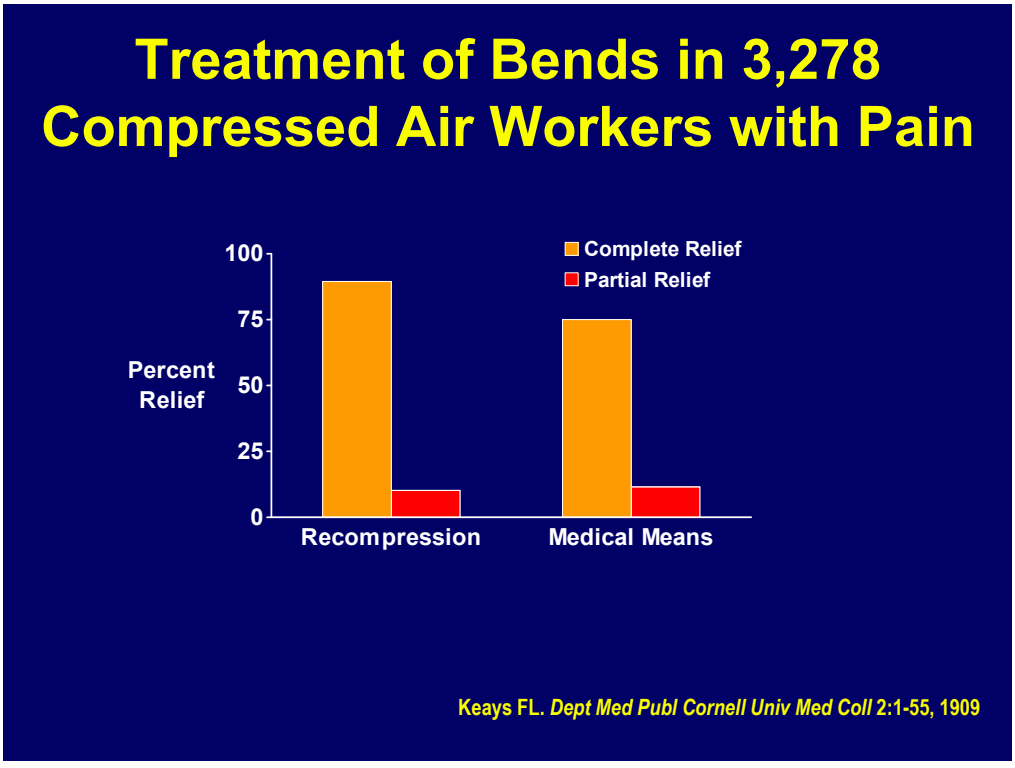


Figure 2. Treatment of Bends in 3,278 Compressed Air Workers with Pain[5]

Moving forward to the 1960s Dr. Workman reviewed the efficacy of the U.S. Navy air tables over 20 years and found that there was a significant failure rate of severe cases, but the ones who were mild actually did reasonably well.

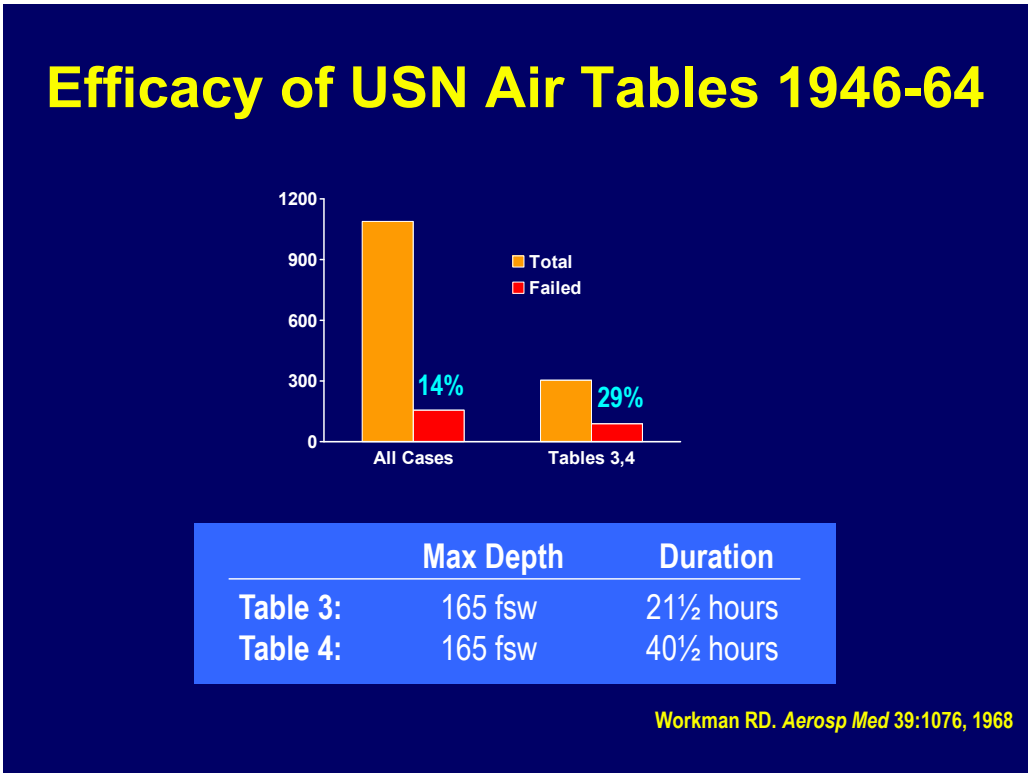


Figure 3. Efficacy of USN Air Tables 1946-64

In 2018, Simon Mitchell, Mike Bennett and others, put together a consensus group and reviewed key principles and controversies. They considered how to classify decompression illness as mild without a neurologic examination. In other words, what be done if there's no neurologist or a diving physician or even a doctor on site or, or a paramedic (a common scenario), how could such a patient be managed?

## REMOTE CLASSIFICATION OF DCI AS MILD WITHOUT A NEUROLOGICAL EXAMINATION[7]

### 'Mild' Symptoms and Signs

- Limb pain
- Constitutional symptoms such as fatigue
- Some cutaneous sensory changes *(subjective cutaneous sensory phenomena such as 'tingling' present in patchy or non-dermatomal distributions suggestive of non-spinal, non-specific, and benign processes. Subjective sensory changes in certain characteristic patterns such as in both feet, may predict evolution of spinal symptoms and should not be considered as 'mild')*

Importantly, it was pointed out that subjective sensory changes in both feet is probably not something that should be ignored because this is sometimes a harbinger of spinal cord decompression illness.

### Mild' Symptoms and Signs[7]

- Rash
- Subcutaneous swelling ('lymphatic DCI') where these manifestations are static or remitting
- Significant neurological dysfunction is excluded to the satisfaction of a diving medicine physician

It was further suggested that lymphatic decompression illness might be included with mild, if significant neurological dysfunction is excluded to the satisfaction of a diving medicine physician. It is very likely that a diving physician can be reached by phone, but how could he or she then exclude a significant neurological decompression illness? This is the issue before us.

> *"Significant": a problem that has the potential to leave the diver with functionally important sequelae.*
> *Exclusion of significant neurological signs is most reliably achieved by a neurological examination performed by a doctor. However, such examination may not be available, and there are plausible scenarios in which a global appraisal of other facts of the case renders significant neurological injury extremely unlikely.* ***In such scenarios it can be appropriate for a diving medicine physician to manage a case as 'mild' in the absence of a neurological examination.***[7]

'Significant' was defined as a problem that has the potential to leave the diver with functionally important sequelae, which means somebody who can't urinate, for example, or has balance disorders or motor weakness. It was pointed out that exclusion of significant neurological signs is most reliably achieved by neurological examination by a doctor, who may not be available. However, there are plausible scenarios, in which a global appraisal could render significant neurological injury extremely unlikely. In such scenarios, it can be appropriate for a diving medicine physician to assess a case as mild in the absence of a neurological examination.

I will describe a couple of examples of cases where mistakes were made. This is a scuba diver who called us complaining of nausea, vomiting and diarrhea, since making a series of recreational dives in Florida. His diving buddy had experienced exactly the same symptoms. They had both consumed fish a few hours before onset. On the phone, I was all set to conclude that the diver had gastroenteritis, and recommend fluids and anti-emetics. But, because he happened to be in a city with a very experienced hyperbaric facility, he was referred, and at the local hyperbaric facility, a detailed history and exam revealed that he had inner ear DCS. When I called the facility to follow up I was told he was in the chamber receiving USN Table 6.

If there had been no one at his location able to perform a neurological examination, he could indeed have suffered long term disability. Thankfully, the patient is now doing well.

If symptoms are relatively mild, but progressive, the diver must be continuously monitored to detect any appearance of new symptoms, and the mild designation must be repeatedly reviewed over at least 24 hours following diving, or the most recent decompression, the latter applying if there's been an ascent to altitude.

> *If symptoms are qualitatively mild but are progressive, then the diver must be continuously monitored to detect any appearance of symptoms not considered mild. The 'mild' status cannot be considered final until symptoms are static or remitting.*
>
> *The 'mild' designation must be repeatedly reviewed over at least 24 hours following diving or the most recent decompression, the latter applying if there has been an ascent to altitude. Untreated mild symptoms and signs due to DCI are unlikely to progress after 24 hours from completion of diving.*[7]

## So when could oxygen be acceptable as definitive treatment for decompression illness?

Using the recent consensus guideline, the answer is *"When manifestations are mild and unlikely to lead to permanent disability, and when the risk of transferring a patient to a hyperbaric facility exceeds the possible benefit."* Arguably, in this day and age the cost must be considered also.

*A proposed guideline:*
When a suitably trained or coached on-scene person can perform a neurological assessment sufficient to convince a diving physician that severe manifestations are absent.

*The issue:*
Is it possible to coach someone through an ad hoc neurological exam? I have specifically avoided specifics because they would depend on the individual situation. If reasonable assurance can be obtained that a symptomatic diver has a normal neurological exam it is reasonable to discuss whether surface oxygen (and maybe fluids ) alone might be sufficient for treatment of mild DCS.

### WHEN COULD OXYGEN BE ACCEPTABLE AS DEFINITIVE TREATMENT FOR DCI?

- When manifestations are mild and unlikely to lead to permanent disability Proposal: *When a suitably trained or coached on-scene person can perform a neurological assessment sufficient to convince a diving physician that severe manifestations are absent*
- When manifestations are mild and unlikely to lead to permanent disability
- When the risk (or cost?) of transferring a patient to a hyperbaric facility exceeds the possible benefit

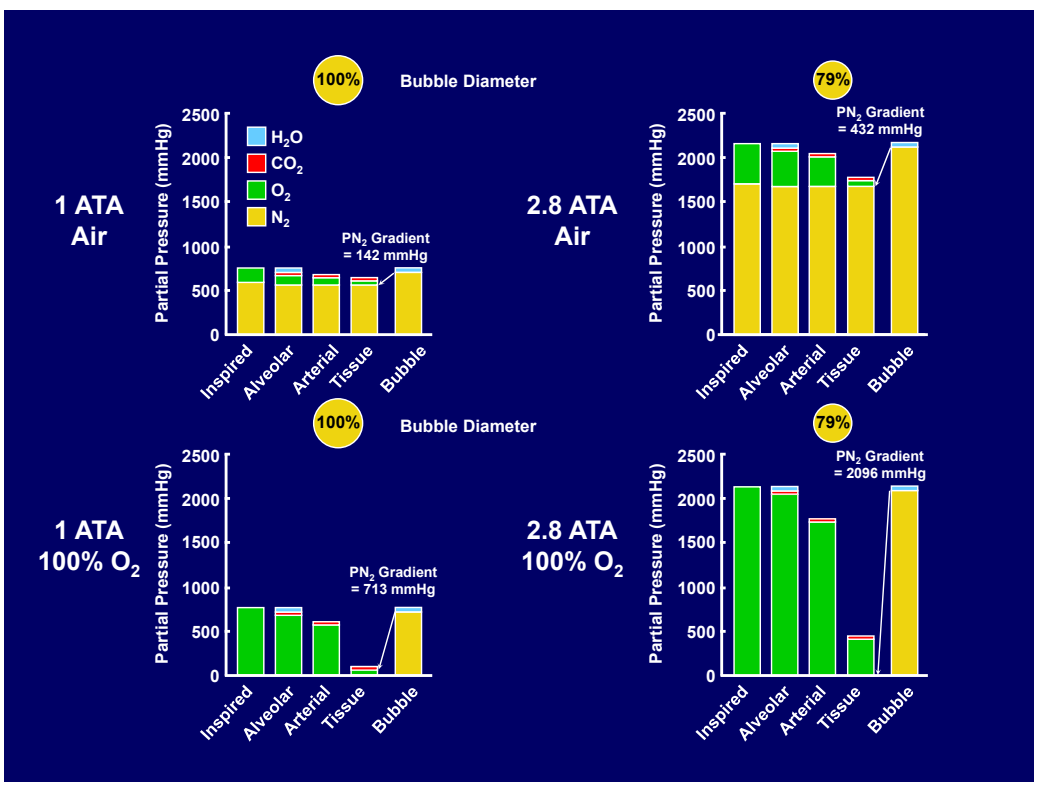


Figure 4. Partial pressures of nitrogen, oxygen, carbon dioxide and water vapor in various compartments. The effect of surface oxygen, hyperbaric air and hyperbaric oxygen (2.8 ATA) on bubble size and nitrogen diffusion gradient (bubble into tissue) is demonstrated.

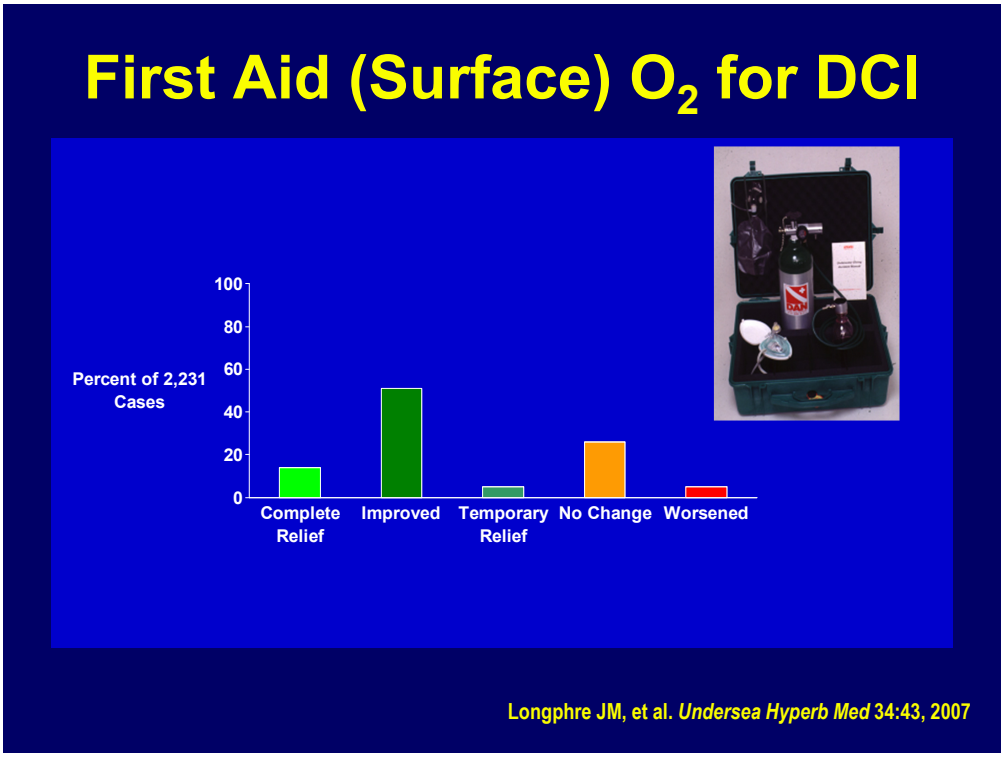


Figure 5. First Aid (Surface) Oxygen for DCI

The next topic in fact is oxygen. As Nick Bird pointed out this morning, Paul Bert who actually observed bubbles, also observed that in experimental animals, oxygen administration resolved bubbles and manifestations of DCS. Following this poignant observation it took almost a hundred years before hyperbaric oxygen became routine and recommended. The bar graphs in Figure 4 demonstrate the effect of oxygen breathing and increased ambient pressure on the diffusion gradient of nitrogen from bubbles to the surrounding tissue.

There is an intrinsic 140 mmHg gradient from the bubble to the surrounding tissue, which means that bubbles in tissues eventually resolve. Breathing 100% oxygen will reduce the partial pressure of nitrogen in the inspired gas and eventually the surrounding tissue increasing the diffusion gradient from 140 to greater than 700 mmHg. So oxygen administration resolves bubbles anywhere in the body for any reason. John Longphre, one of our former fellows, using data from DAN, looked retrospectively at outcomes of 2,231 cases of decompression illness and found that surface oxygen breathing was associated with complete relief of symptoms in 15% of cases and improvement in 50%. Surface oxygen administration also appeared to result in a higher likelihood of complete relief even after the first recompression.

2 Healthy Men Receiving 90% Oxygen at 1 ATA.[9] One reported:

- After the 2nd day my pulse rate and body temperature increased; there was a decrease in my vital capacity. Prickling and a numb sensation of the finger tips were experienced by Clamann at the end of the second test day, and also by me at the beginning of the third day
- FVC continued to decrease. Transitory pains in both knee joints occurred. In the night preceding the 4th day, my vital capacity decreased to 60% of initial value. There was also a distressing subjective feeling of dyspnea
- On the morning of the 4th day I noted sudden nausea and later vomited, after which the experiment was discontinued after a total duration of 65 h. Vomiting persisted for the whole day

A relevant question is therefore, how long should surface oxygen be administered? If you're in middle of the Pacific and you have an unlimited supply of oxygen, should oxygen be continuously administered until the patient reaches the chamber, perhaps 1-2 days away? What about oxygen toxicity? The following observations are from World War II German Air Force experience.

So, oxygen should probably not be administered for several days continuously.

In 1945 Julius Comroe reported a larger series and under various circumstances. He had 19 healthy men in this particular subset, where 34 subjects inhaled 100% oxygen continuously for 24 hours.

The most prominent symptom, not surprising, was substernal distress. Four out of six men in hoods, 24 out of 28 subjects in masks, complained of this. The onset was typically 14 hours after the start of oxygen although there was a range from 4-22 hours: 79% of those who did experience substernal stress first noticed the symptoms between hours 12 and 16. The

Healthy Men Receiving 100% Oxygen via Mask or head tent[10]

- 34 subjects (6 in hood and 28 wearing masks) inhaled 100% $O_2$ continuously for 24 h
- Most prominent symptom was substernal distress
- 4/6 men in the hood and 24/28 subjects wearing masks complained of this:
  - Slight N=4
  - Moderate N=18
  - Severe N=6
- Substernal distress noted an average of 14 h after start of $O_2$ (range 4-22 h)
- 79% of those developing substernal distress first noticed this symptom between hours 12-16

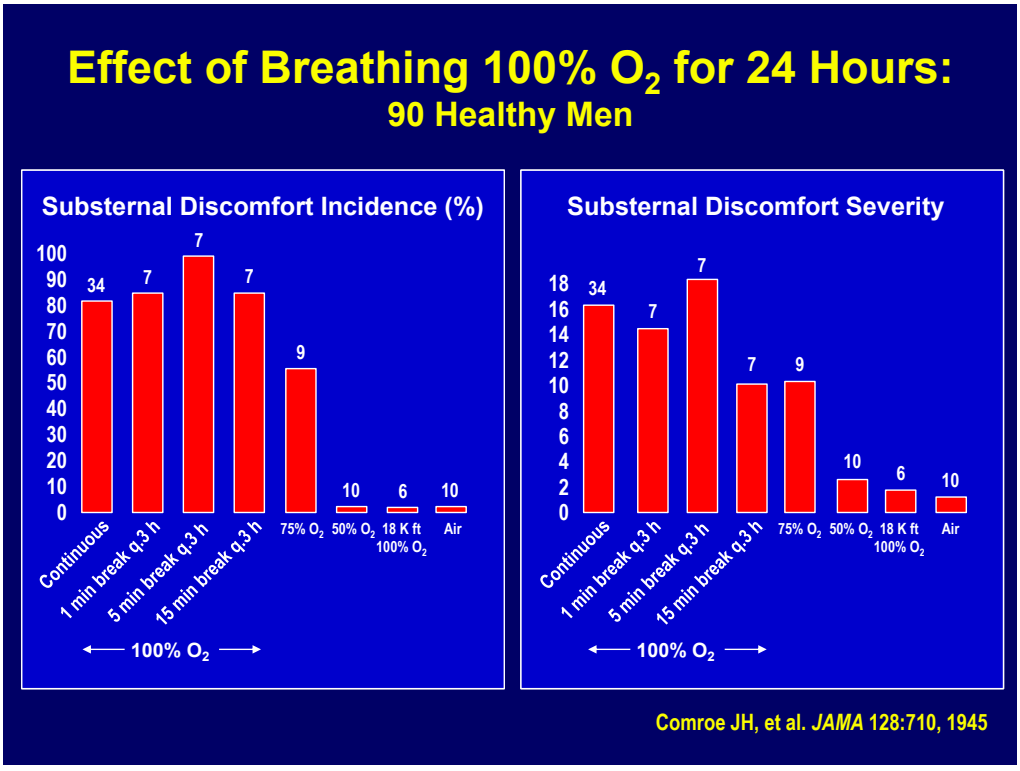


Figure 6. Effect of breathing different oxygen fractions and schedules on symptoms of pulmonary oxygen toxicity

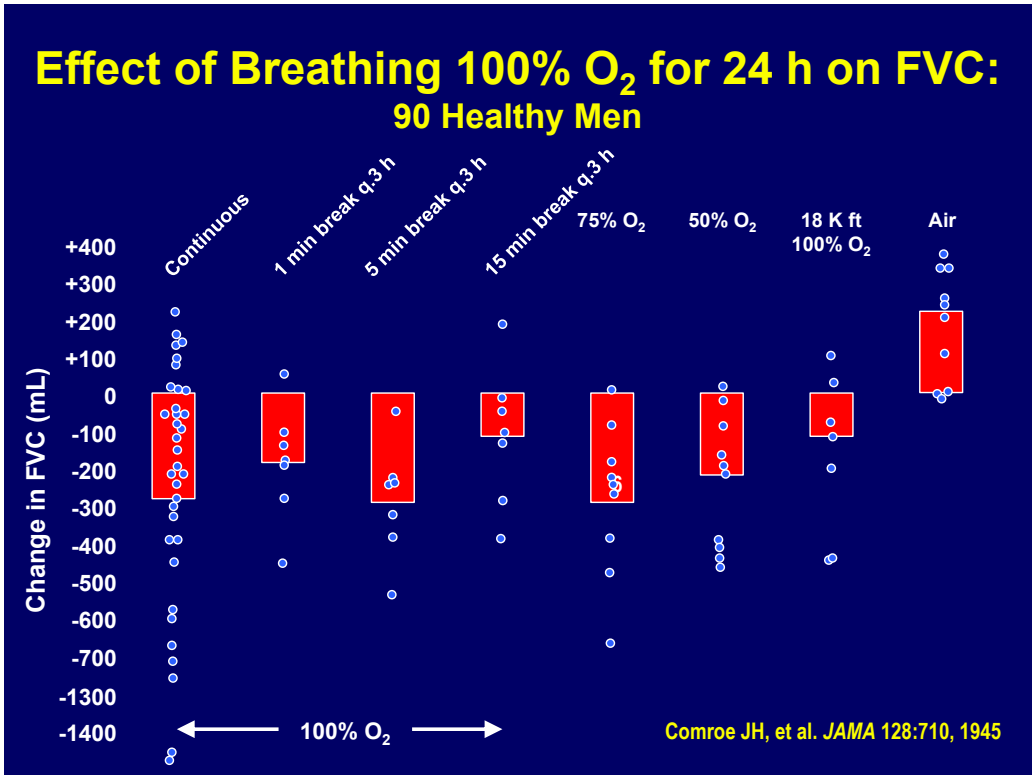


Figure 7. Effect of prolonged (24 hours) of breathing 100% oxygen on vital capacity

individual bar graphs represent different oxygen administration schedules. This work pre-dated Jim Clark's experiments at Penn.

Even 50% oxygen did result in some decrease in vital capacity. So, giving oxygen for long periods of time is not a good idea. In conclusion, I would suggest that mild decompression illness as defined by the 2018 consensus guideline, where the risk or cost of recovery referring to a recompression facility exceeds the benefit as determined by a qualified diving physician. Normobaric oxygen should be administered at a concentration as close as possible to 100% for 12 hours with 15 minute air breaks every four hours, which is a convenience factor. A person needs to eat and drink. After 12 hours the oxygen should be discontinued. If hyperbaric oxygen is to be administered at the end of that 12 hours, should the surface oxygen schedule be foreshortened? The answer is unknown except that a long period of surface oxygen is likely to result in pulmonary oxygen toxicity during the hyperbaric exposure. This should be the discretion of the diving physician.

For Discussion: Normobaric Oxygen can be accepted as a definitive treatment for DCI under the following circumstances:

- Mild DCI as defined by the 2018 consensus guideline, where the risk/cost of referring to a recompression facility exceeds the benefit as determined by a qualified diving physician
- Normobaric O2 should be administered at a concentration as close as possible to 100% for 12 hours with 15 minute air breaks every 4 hours, then stopped
- O2 may be interrupted/foreshortened if symptoms of O2 toxicity develop or in anticipation of hyperbaric oxygen therapy if it becomes available, at the discretion of a diving physician
- This recommendation should be reviewed and amended as additional evidence is obtained

## DISCUSSION:

Klaus Torp:
Richard, thanks for that great talk. I have had patients while I was traveling, and we stop the oxygen in anticipation for hyperbaric treatment that was in Guam. So they called and said "Hey, make sure you stop it before you send him. But my real question is, now we've heard that a few times, a few times about that limb pain and limb pain is not equal limb pain. You have periarticular one which arguably is a mild form and then you have the sharp, deep boring pain that presumably is some osseous hypoxia. And do we in the mild category, do we all lump them together? Or how do we deal with one that's, I would agree would be mild and the other one is probably not so much.

Richard Moon:
Klaus, that's a good question. We heard earlier that an MRI may be helpful in answering this question. Dysbaric osteonecrosis is arguably a serious complication, but in large series of dysbaric osteonecrosis, such as the North Sea experience, many of those affected were saturation divers. Outcomes were pretty good and very few actually required surgery. So, of scuba divers with limb pain only a small percentage will experience osteonecrosis, and of those who do most will be shaft lesions. Although a small percentage will have juxta-articular lesions with long-term complications, it is difficult or impossible to distinguish them in the field. Should MRI be performed after transfer to an advanced facility? Perhaps.

Speaker 3:
Or should you do hyperbaric oxygen? That's of course the other option.

Richard Moon:
I would agree with David's point that you know the guy arrives home and he's still got syafter arriving home with persistent symptoms, hyperbaric oxygen should be considered.

Simon Mitchell:
I'll just make a couple of comments, Simon Mitchell from Auckland, about your consensus class.
If you look at the face validity of the concern regaring the dysbaric osteonecrosis, Richard's kind of just alluded to that. There's an awful lot of untreated musculoskeletal decompression sickness out there in our community and we just don't see a problem with dysbaric osteonecrosis. I mean, we really do not, I can't remember the last case of dysbaric osteonecrosis I saw on a recreational diver. So, I get the idea that there's a potential problem, but the reality is we hardly ever see it. The other comment I want to make about that is that the sorts of cases we're considering here, particularly in remote locations, is pretty good evidence that undertaking an evacuation that's going to take 12 hours, 24 hours to get the patient to a hyperbaric facility is going to mean that after that duration of time, hyperbaric option is not going to change the prognosis of developing dysbaric osteonecrosis.

Now that evidence comes from some of the work that was done by Charlie Lehner or Alexi (Sobakin) but there's quite a bit of that, there's quite a lot of evidence that suggests that once you get beyond. around about 12 hours, hyperbaric options not going to change the prognosis anyway. So, you know, I think for the sorts of scenarios we're trying to consider here, actually it doesn't matter what kind of musculoskeletal pain they've got. I think we can still treat it as a mild symptom. I would say that if you do have access to a hyperbaric chamber and you've got one of these cases with mild syndromes, you shouldn't treat them, and none of the stuff that we've ever published about mild decompression sickness suggest otherwise. You know, if you do have access, you should treat them. So anyway, that's the comment about the disbaric osteonecrosis side of it.

Richard, I just wanted to make a comment about the neurological examination thing that you raised in your talk. This was something that we discussed a lot. You know, the idea that we can coach people to do neurological examinations and look, I'm not completely allergic to that concept except to say that we looked into it actually, there's quite a lot of literature about teaching to do neurological examinations and how accurate you can expect them to be if you teach them a sort of relatively superficial approach to a neurological examination. And the bottom line is the neurologists consider it extremely difficult to do. In other words to teach someone to do a neurological examination that you can rely on. And so I would say that if you really consider that a neurological examination is necessary based on the circumstances of the accident that you're dealing with, then if it's not available you should evacuate them.

But there are circumstances where quite plausible circumstances where all the facts of the case would lead you to believe that I can probably treat this as mild or consider this to be mild without doing

a neurological examination. It's not all cases; there are just some. I mean I could rattle off a couple of hypotheticals for you, but I won't bore the rest of the group with that right now unless you want to discuss it further. But I think that's quite a difficult thing to do. We did consider that, but we lifted out because of the published difficulty in doing it.

Richard Moon:
Yes, I totally agree with Simon. Doing a real neurologic exam is a hard thing even for a trained physician. But my thought was that you might be able to detect certain signs of seriousness that might push the decision to evacuate.

Jake Freiberger:
I want to reiterate that I agree with Simon about the dysbaric osteonecrosis issue that the animal evidence from sheep, and from Lehner's and Sobakin's work does show that it's really hard to generate those lesions, and hard to mitigate against those lesions if there's a long delay to treatment. The other thing is that, we really don't see clinical cases of that. I'm going to discuss some of these things in my talk after lunch, but the second point is that I think that the concept of treating or considering hyperbaric oxygen is completely benign, may need to be reexamined, because of the issues of oxidative stress and toxicities in animal experiments.

Petar Denoble:
Thank you Jake. Any more questions? I think discussions like this show that although we have defined what mild is, many other aspects of treatment will require further discussion.

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# SHORT TABLES FOR THE TREATMENT OF DECOMPRESSION SICKNESS

## Brenna Derksen, MD

Thank you so much for having me here today. I'm very honored to be able to speak in front of you all including many of the people who wrote articles I reference today. I'll be talking to you about use of short tables for treatment of decompression sickness. We will talk about the history of treatment and table development of short tables, and we will go over some of the standard tables; tables 5 and table 6, as well as some other tables.

Let's start off with defining what a short table is. I spent the whole year in fellowship treating divers in the middle of the night on treatment table 6, and it felt very long at times. Table 6 is actually considered a short table. But it is considered the standard treatment of DCS. So anything shorter than the U.S. Navy Treatment Table 6 (USN TT6) is what we're defining as a "short table." Short tables are not necessarily shallow, and shallow tables are not necessarily short.

Short tables can be used under certain circumstances to treat decompression sickness in divers. Some are also regularly used for other indications of hyperbarics, but today we'll only be talking about their use in divers. We'll be discussing the U.S. Navy tables 5, 6, and 9, as well as the Royal Navy tables 61 and 62, Comex tables 12 and 18, some Monoplace tables, and in-water recompression.

What are the advantages of short tables? Longer isn't always better. They are shorter, so they require fewer resources. They're cheaper to use, require less staff, and there's less interruption in your day-to-day workflow. Less time in the chamber also means that critically ill patients will go back to the ICU sooner; sick patients can get further medical workup that they may need. There's also decreased risk, potentially, of oxygen toxicity and barotrauma, and importantly, less risk to the tender. As you'll see some of these longer tables may result in a bent tender, and that's no good. Some studies have shown that short and shallow tables are highly effective for the treatment of mild decompression illness, especially when there are only short delays in treatment.

What are some of the shortcomings of short tables? Shorter tables may seem ideal, but there are some pitfalls when you compare them to the standard treatment table U.S. Navy treatment table 6, especially in regards to the treatment of severe decompression illness. Some studies have shown higher rates of treatment failure and higher rates of recurrence with the use of shorter tables. The data is all over the place, though. Some of the studies are very old, they looked at different treatment protocols in various tables. For example, some studies show improved outcomes with the use of short tables when compared to USN TT6 (Hart 1986, Green 1989, Cianci 2006) and some studies

showed worse outcomes (Goodman 1965, Wilson 1989). These studies were not standardized and had variable protocols and outcomes measured, so it's difficult to say whether or not there are truly different outcomes.

To understand a little bit more about why there is some confusion, let's talk about the history of how these short tables were developed, and that will give us some insight as to why things are the way they are today.

First a pop quiz. The first use of recompression for the treatment of DCS was in divers for the treatment of joint pain. Fact or fiction? As you all guessed, probably, fiction. Caisson workers were actually the first who utilized recompression for the treatment of decompression sickness. They used air as the primary gas and it wasn't until later that oxygen was utilized because it was not widely available for use.

What was initially used to treat DCS before the development of recompression? This was before diving became very technical. Usually in the navy, we saw symptoms that tended to be mild, pain only symptoms, but it could get severe at times. Early on in the history of DCI, the pathophysiology was not well understood and there were no widely established treatment protocols. Divers were pretty much living on a prayer. They were hoping for spontaneous recovery, and luckily, this worked most of the time. Decompression sickness does tend to get better on its own, over time. But sometimes it doesn't, and sometimes symptoms are severe.

Caisson workers paved the way for our modern treatment of decompression sickness. Back in the mid-1800s, symptoms were seen fairly commonly in caisson workers. Caisson workers were construction workers working in compressed air environments for hours and hours on end. They would surface and have severe joint pain. Reported mortality rates were up to 25% in some papers prior to recompression.

In 1896 recompression treatment was first developed by Moir and used to treat the Hudson River Tunnel workers. The protocol was actually the first true short table. The construction workers were treated on air and compressed to 1/2 or 2/3 their working pressure, and then slowly decompressed to the surface. They saw great success with symptom and mortality reduction these treatment tables, and they were modified to decrease decompression illness seen in caisson workers.

Divers were a little late to the party. They were far behind. Most diving-related cases of DCI were seen in navy divers often with mild symptoms and often in remote locations. Before the navy started using recompression as the primary protocol for treatment of DCI, they were largely using in-water recompression as well as supplemental surface oxygen, even though caisson workers were already using recompression treatment. It wasn't until 1924 that the U.S. Navy Diving Manual started making recompression the standard protocol for the treatment of DCI, and the tables were different than the ones we currently use today. Early protocols were not short or shallow compared to the current tables.

Once they started utilizing recompression, the navy ran wild with it. All sorts of tables were developed. There were long and short tables, air and oxygen tables, there are tons and tons of tables out there that you can look up. The early tables were fairly deep. Even "short" tables would go to a max depth of 100 feet or 30 meters of seawater, and the longer tables also went deep, up to 165 feet or 50 meters. But these tables seemed to show a high rate of recurrence (Van Der Aue 1947), and so the navy thought "let's go longer and deeper," and they developed tables 1, 1A, 2, 2A, 3, and 4. These were 30-hour tables. They were very long and cumbersome, and they were a 2 for 1: you had a bent diver and a bent tender from these tables. They also had pretty high failure rates, so then the navy went in the opposite direction and developed some short tables.

Figure 1 shows an example from a USN short oxygen table from 1944.

This is an example of an oxygen table used by the navy, no longer used today. It's sort of a hybrid between treatment table 5 and 5A, and it was used for the treatment of mild decompression sickness. As you can see, it went down to a depth of 100 feet on air, and then a step-wise ascent up to 80 feet then 60 feet, etc, eventually the patient was started on 100% oxygen at 60 feet for the remainder of the ascent, for a total run-time of 2 hours and 17 minutes. This table has further been modified into what we now know of as treatment table 5 and 6.

How did we eventually end up using table 5 and 6? These are the currently accepted standard treatment table protocols for DCI. To give you a little background on what these tables are, both tables utilize 100% oxygen at 60 feet and 30 feet with short air breaks that were implemented to decrease the risk of oxygen toxicity.

Why did they choose 60 feet? That seems to be the sweet spot. They looked at all these other tables and the outcomes that were associated with

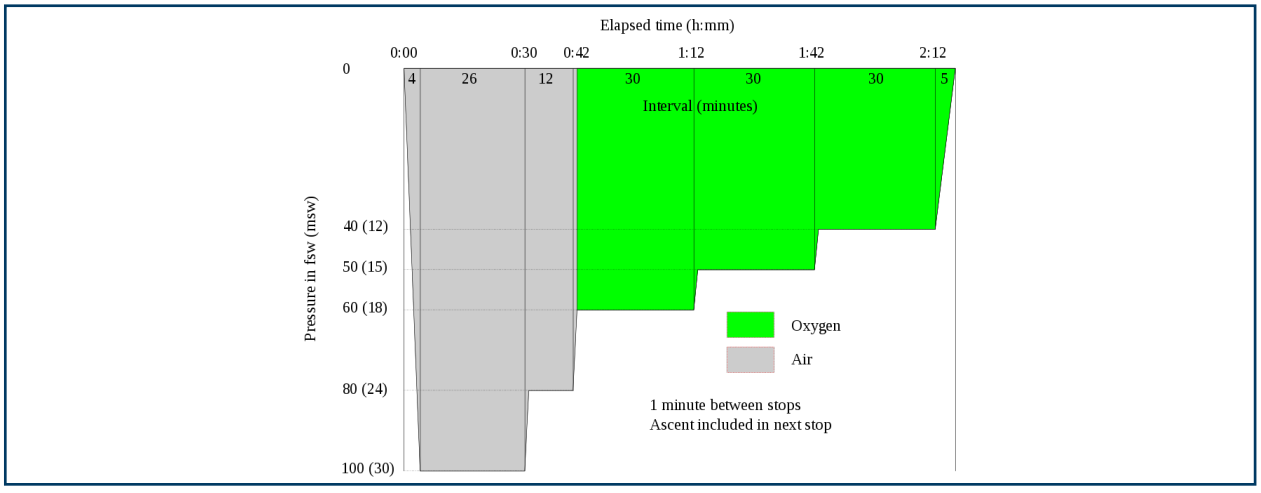



Figure 1. USN 1944 Short Oxygen Recompression Oxygen Table

treatment and came up with the best of both worlds in regards to safety and efficacy. They found that 60 feet had higher efficacy than 33 feet, so it was deep enough to get adequate treatment responses and less recurrence of symptoms. They also found that while it was deep enough to get good treatment responses, it was shallow enough where you had minimal increased risk of oxygen toxicity, especially with implementation of air breaks. It also, importantly, allowed for safer decompression of your tenders, so while it did require tenders to go on supplemental oxygen during treatment, it was a lot safer than the longer treatment protocols. Sixty feet tables are still commonly used, and they became the basis of modern recompression therapy. Shorter tables have been designed for use in monoplace chambers, as we'll discuss later.

Figure 2 shows the U.S. Navy Treatment Table 5 which is the currently accepted standard protocol for the treatment of mild or pain only decompression illness. It can also be used as a tailing treatment table, but alternatively, table 9 is also often used for tailing treatment. Table 5, similar to table 6, goes to 60 feet of seawater, which we'll see is a common theme for these tables, with 20 minute oxygen periods, with a gradual ascent to 30 feet of seawater while on 100% oxygen, for a total run time of 2 hours and 15 minutes. It's a relatively short table, but it is highly effective for the treatment of mild decompression sickness. Some studies have shown that U.S. Navy TT5 does show higher rates of treatment failure and symptom recurrence, especially when there are severe symptoms or significant delays in treatment. Then there is the question - What do you do if the patient is still having symptoms? This is why it is usually recommended, when unsure, go with a table 6. Table 5 can be extended, and there's also a 5-A deeper version that I'll show you in a bit but these are not widely utilized.

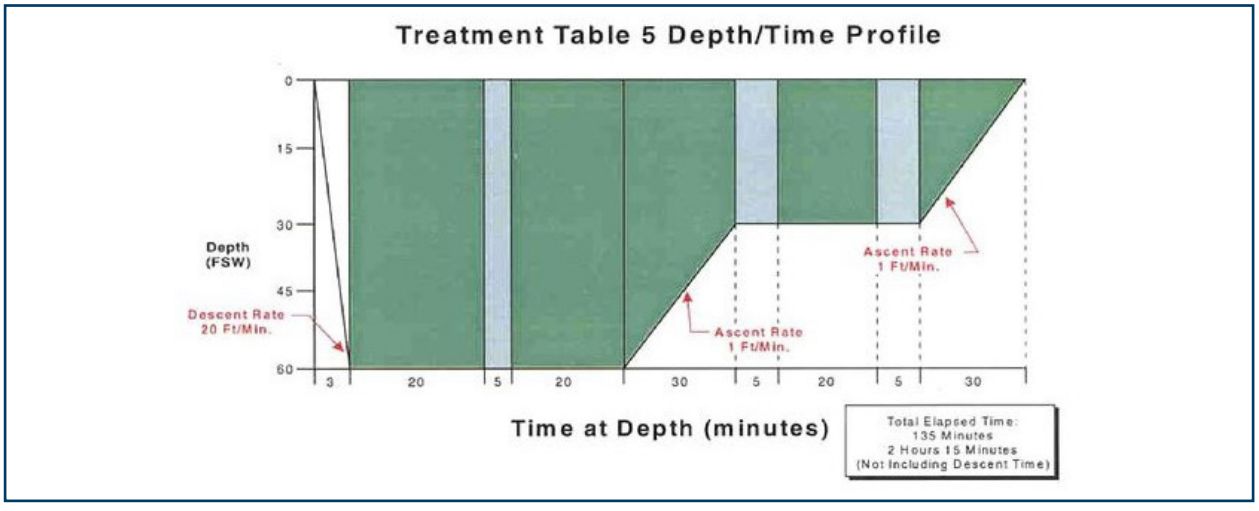



Figure 2. USN Treatment Table 5

Figure 3 shows U.S. the Navy Treatment Table 6 (USN TT6).

USN TT6 is the standard of care and almost never the wrong choice. If unsure, symptoms are unreliable, or if concern for more severe then treat with table 6. You can use it to treat any type of decompression illness. You can use it for AGE, severe DCS, ongoing mild symptoms that are progressing.

Again, descend to 60 feet with 20 minute oxygen periods and 5-minute air breaks, for a total run time of 4 hours and 45 minutes. Table 6 is longer than the table 5. Additionally, you can extend this table for severe symptoms or ongoing symptoms, which is nice, but it does incur more of an oxygen obligation for your tender, and it increases their risk of decompression sickness as well. Furthermore, table 6 has been utilized in monoplace chambers successfully for the treatment of divers.

Let's discuss the "A" versions of Tables 5 and 6. Tables 5A and 6A (Figure 4) are similar to the aforementioned tables except that the treatment starts by plunging down to 165 feet on air with a gradual ascent, and then followed by similar oxygen tables for the rest of the treatment. Although rarely utilized, the primary justification for their use is the treatment of early, severe decompression sickness and for arterial gas embolism. Table 5A is actually no longer approved for use, but table 6A, which is also known as "The Tender Bender" can be used in certain circumstances. The theory behind the initial descent down to 165 feet is to significantly decrease the size of bubbles by increasing the pressure.

Table 9 is another commonly used short treatment table; however, it is not indicated for the primary treatment of decompression sickness, but can be utilized for follow-on treatments in divers with residual symptoms. It's both shorter and shallower than treatment tables 5 and 6. It only goes to 45 feet and implements 30 minute oxygen periods instead of 20 minutes, with 5-minute air breaks for a total run time of 1 hour and 42 minutes. Table 9 is used regularly at HBO facilities for standard non-diving treatments, so you can add your divers into your regular hyperbaric treatments, which makes this table an ideal option for tailing treatments.

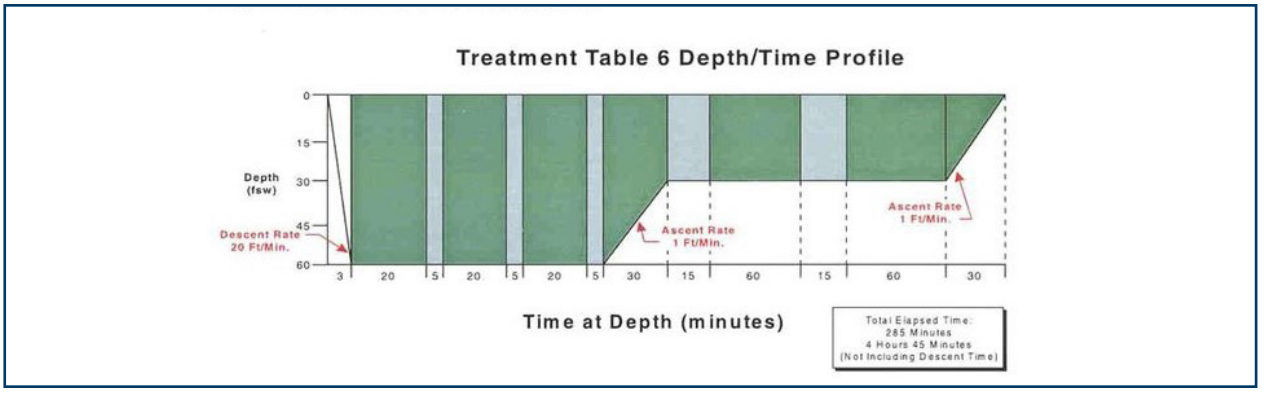



Figure 3. USN Treatment Table 6

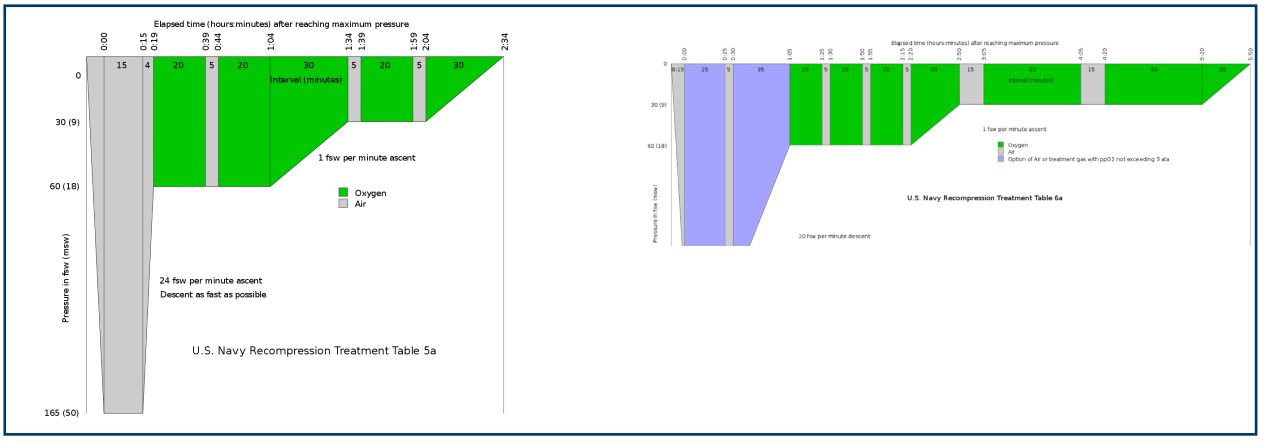



Figure 4. USN Treatment Tables 5A and 6A

The Royal Navy has a few tables that look familiar if you're familiar with tables 5 and 6 because they're essentially equivalent to the U.S. Navy tables. The Royal Navy table 61 is similar to table 5, which is used for the treatment of pain-only or mild decompression sickness, goes down to 60 feet for a run time of 2 hours 17 minutes. The Royal Navy table 62 is equivalent to the US Navy table 6, and is used for more severe symptoms or when pain-only is not relieved. Again, goes to 60 feet, total run time of 4 hours and 47 minutes.

Additionally, there are some "short" comex tables. The Comex tables are a little different than the U.S. Navy and the Royal Navy tables. Comex tables may be both short and long tables (CX 12, CX 18C, CX 18L, CX 30), but we will only discuss the short Comex tables today. Comex short tables include oxygen tables whereas Comex long tables utilize mixed gas: heliox or nitrox. Comex short tables are indicated for pain-only decompression sickness, and the way you choose which Comex table to use is based on how the patient is responding to recompression. You can have a shorter treatment if they're improving with treatment.

**Comex table 12** is the shortest of these tables. CX 12 is used for the treatment of musculoskeletal decompression sickness. You could compare it to USN treatment table 5. If within 4 minutes (<26 fsw) of recompressing the patient, they have complete resolution of their mild pain-only symptoms, you can continue with this short table and go down to 40 fsw for a total time of 2 hours and 10 minutes with intermittent 5 minute air breaks.

This short version of the table may only be utilized if their symptoms are relieved before they even reach maximum depth. If they do not have complete relief within 4 minutes or reaching 8 msw/24 fsw, then you continue descent to 60 feet, and then proceed with treatment using the Comex 18 table.

As you can see, there's a deeper portion added to this table when compared to the CX 12. This is for, again, musculoskeletal or mild DCS, when symptoms are not relieved within 4 minutes, but are relieved within 15 minutes. For CX 18C descent to 18 meters or 60 feet. If there is complete resolution of symptoms, carry on for 2 hours and 54 minutes with this table, and you call it a day. If there are persistent symptoms despite descending to 60 feet, then abort the short tables and proceed to treatment using a long Comex 30 table, which utilizes mixed gas, and is outside the scope of this discussion on short tables.

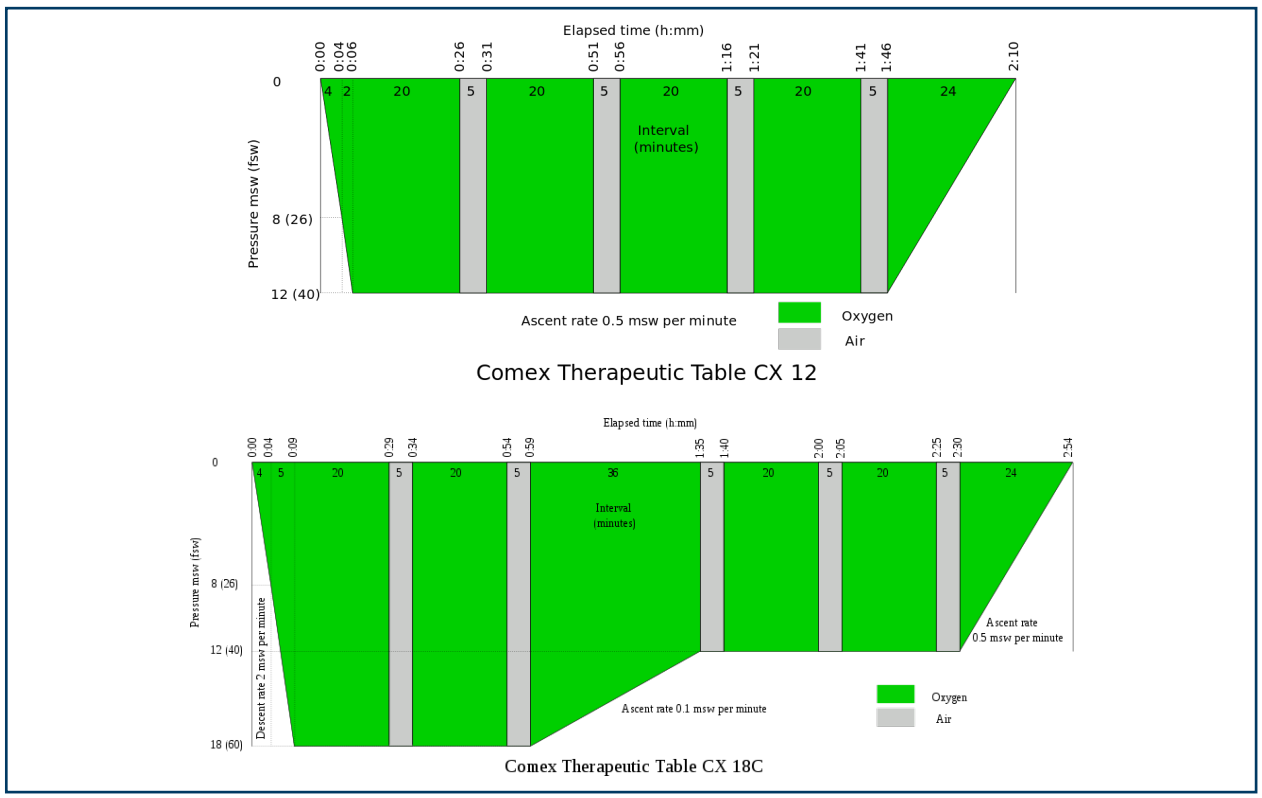



Figure 5. Comex tables CX 12 and CX 18C

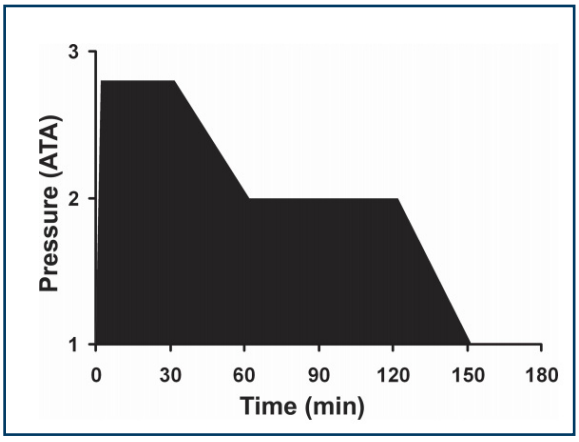
Monoplace chambers also came up with their own treatment table.

### Hart-Kindwall Table

Use: Monoplace, no air break treatment of DCS
Table Characteristics:

- 2.8 ATA (60 fsw) for 30 min
- Decompress to 1.9 ATA (30 fsw) over 30 min
- Maintain 1.9 ATA (30 fsw) for 60 min
- Decompress to surface over 30 min
- 100% $O_2$ continuously
- Time: 150 min
- Repeat after 30 min air break at surface if persistent symptoms

*** If Pain/skin only DCS resolved < 10 min of reaching depth can decrease decompression time to 15 min (instead of 30 min) when traveling from 60-30 fsw and 30 fsw to surface***

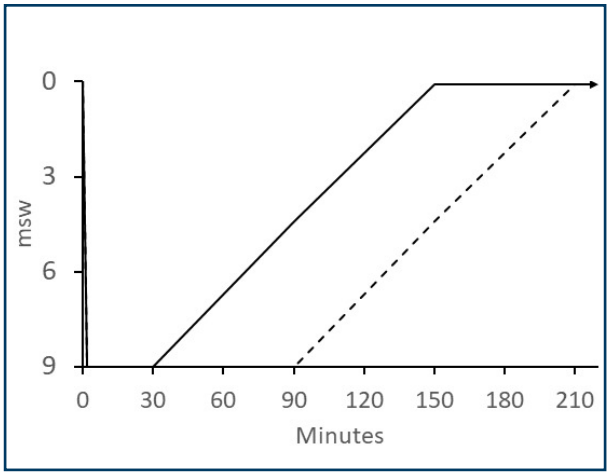



You have the Hart-Kindwall table, which again descends to 60' for a 30-minute O2 period, then ascends to 30', and then slowly to the surface. This monoplace table utilizes 100% oxygen the entire time for 150 minutes. If the diver still has symptoms after ascent, you take a 30-minute air break and repeat the treatment table. This allows for no-air-break treatments in monoplace chambers that do not have the capability to take air breaks.

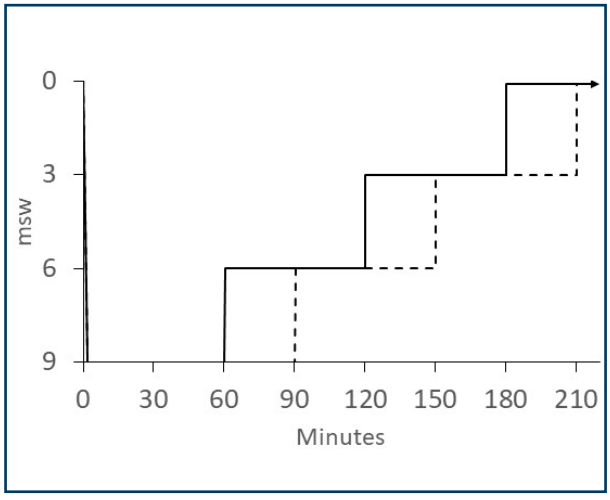
Developed in 1974 (Goodman & Workman). Monoplace treatment tables have actually been very successful in the treatment of DCS. High success rates have been seen in severe cases and cases with significant delay... with some caveats. One study by Cianci et al. 2006 looked at the use of short, no-air-break tables to treat DCS and many cases had a very significant delay in treatment over three days, and they found very high success rates, 87% improved with treatment using these no-air-break tables. Some studies have shown that monoplace tables are highly successful in the resolution of symptoms even in the treatment of severe DCS (Hart et al.1986, Cianci & Slade 2006). So this does show some promise with treatment in Monoplace Chambers, however, this does beg the question of whether or not these cases would have improved without treatment. Also, why was there such a delay, were these cases really DCS?

### In-water recompression (IWR)

In-water recompression DJ Doolette and SJ Mitchell Diving Hyperb Med. 2018 Jun; 48(2): 84–95. Published online 2018 Jun 27




Australian Schedule IWR: Mild: O2 for 30min, severe O2 for 60 min; max 90 min. Ascent over 120 min on O2 (4ft/min). At surface 1 hr O2, 1 hr air break x 6 cycles.




USN IWR: Mild: O2 for 60 min at 30 fsw, Neuro: O2 for 90 min. Step-wise ascent with 60 min at 20 fsw, 60 min at 10 fsw. O2 at surface x 3 hr IWR is also an interesting area that utilizes short tables. We don't

necessarily think of this when we're treating divers, but these tables are shorter and shallower than tables 5 and 6. There's an Australian table and a U.S. Navy table, the top and bottom table for reference. These tables only go to 30 feet, the divers remain on 100% oxygen the entire time, with a slow ascent, or a step-wise ascent if you're using the navy table, up to the surface, followed by periods of breathing 100% oxygen on the surface.

Some of the benefits of IWR are that you can immediately recompress. You just hop back in the water and you go. They're short and they can be done in remote locations where there's no access to a chamber; however, they should really only be used in certain circumstances because they are inherently risky.

You have the risk of oxygen toxicity, which, underwater can be fatal, because of seizures and drowning, the diver can deteriorate if their symptoms progress and they're underwater, additionally there are thermal and environmental risks, and you need a dive buddy and proper equipment. IWR has been discussed by Doolette and Mitchell. There's a tier-based system to determine if the diver is an appropriate candidate for IWR: the diver has to be sick enough to justify the risks of in-water recompression, but not so sick that they're not going to do well tolerating the treatment. Sx's must be clearly from DCS, diver must be willing and able, you must have appropriate equipment and a capable buddy, and symptoms must be a permanent injury threat. You also have to take into consideration environmental risks, like the thermal concerns and the marine environment, as well as have adequate equipment, and you have to kind of know what you're doing. Not just kind of, you have to really know what you're doing, because this can be more dangerous if you do it without knowing what you're doing. IWR has been shown to have decent success. 80% of cases looked at had symptom resolution within 3 hours of treatment.

Here's a case… There's a 28-year-old diver, he's got an itchy rash on his thigh after scuba diving, he's in the middle of nowhere. There's no other reason for him to have this rash. He has no paresthesias, he does not have any weakness. His wetsuit wasn't too tight, he wasn't stung, or bit, or scratched by anything, and he first noticed the symptoms about 30 minutes after surfacing. They initially became slightly worse, but are actually on their way to getting better and almost resolved.

Now that we've learned all this stuff about the different treatment protocols, what would you use to treat this patient? U.S. Navy treatment table 5, 6, in-water recompression, or just surface oxygen and monitoring?

First of all, what's his diagnosis? He's got Type 1 DCS, which is mild decompression sickness. You could use our tried and true U.S. Navy treatment table 5, which we can justify for the use of mild DCS. But remember this guy is in the middle of nowhere and there's probably not a U.S. Navy treatment table 5 capable facility anywhere nearby. You could also justify table 6. Remember, you can do no wrong with table 6, especially if his symptoms are getting worse, or you are concerned about anything with his dive profile or the characteristics of his symptoms.

In-water recompression? It sounds pretty mild, so you can't really justify in-water recompression with his mild rash only. However, if his symptoms do progress, or if there's no nearby chamber, then this could be a consideration under certain circumstances, probably not this one. Surface oxygen and monitoring is another very reasonable treatment option, especially in this case, he's in a remote location and evacuation would be very difficult.

Do all cases of decompression illness require recompression? It really depends on who you ask, so we'll give you both versions of the answer. The U.S. Navy Dive Manual says that hyperbarics is the definitive treatment of decompression sickness. You want to compress the bubbles and you want to increase the oxygen flow to that injured tissue. Any delay in treatment could result in significant increase in refractory disease or severe disease. You should try supplemental oxygen first, but that will not replace and should not replace hyperbaric oxygen as a treatment.

However, in the case of mild decompression sickness, such as a mild rash or pain, in remote locations you can attempt to manage with supplemental oxygen, observation, and discussion with a dive physician. Just because you're not utilizing hyperbaric oxygen, does not mean that you can defer work-up with a physician. You should still be thoroughly evaluated, thorough neural exam, and monitored very closely for progression of symptoms. That's the navy's take on things, but there's also the reality of the situation where sometimes decompression just isn't reasonable and not always necessary.

When can you justify NOT treating with recompression? Reality is more complex, especially when diving in remote locations with poor standardization of chambers, variable training, variable critical care capability, etc. You can almost always justify treating, because HBO is a pretty safe

treatment. Treatment is not required when there are: transient or mild symptoms, itching or a faint rash, lymphatic symptoms, or for ongoing pain if they're not really responding to symptoms after a few days.

Treatment is absolutely indicated and should be pursued in cases of severe decompression sickness. If there are any red flags that indicate spinal involvement, inner ear DCS, neurologic symptoms, or if there are concerning pain symptoms such as pain localized to abdominal or chest region, hip pain, or pain radiating in girdle distribution.

What is our ideal treatment table? Treatment table 6 is king. You can almost never go wrong using a treatment table 6, and if you're not sure, this is the one to use. But we are at a hyperbarics meeting, so I can't give you a simple answer like that with out justifying it, so [Antonelli 00:23:38] in 2009 said this very well, I think: "the main difference in expected outcome is not a consequence of the therapeutic table used, but is primarily due to other factors, especially the length and delay, and the initial symptom severity."

So what treatment table you use largely depends on the delay to treatment and illness severity if you're going to deviate from the standard protocols. So, early treatment... If you can get them in the chamber right away, bubble volume reduction is one of the critical components. You may consider a deeper table at this time. Otherwise, if you're treating later, the role of oxygen is more important. You should choose a less deep table, or your standard protocol table 5 and 6, because the oxygen is more important at that point.

It also depends on your illness severity, so mild pain-only symptoms, you can justify use of a short table, such as table 5; however, if there is any evidence of severe symptoms, a minimum treatment of 2.8 ATM is recommended. U.S. Navy treatment table 6 or equivalent is the only acceptable treatment.
Are shorter tables acceptable?

Yes, but only in certain circumstances, such as mild DCS, tailing treatments, or if there's no realistic or safe alternative.

We just spent all this time talking about how we should only use short tables under certain circumstances, but some studies show that 60' may be too deep, or deeper than we need. All of this can lead to some confusion. Behnke et al. showed that as shallow as 10 meters might be adequate. Other, older papers such as Goodman et al. and Wilson et al. showed higher rate of recurrence and higher rate of treatment failure with the use of shallower tables.

### Are protocols shorter and shallower than TT6 acceptable?

*YES but only for:*
- *Mild Type I DCS that improves with recompression*
- *Tailing treatments*
- *No realistic or safe alternative available*

What's the take-home? Treatment table 6 is the sweet spot. Shallow and short tables do run the risk, albeit small, of recurrence and treatment failure, and deeper tables, deeper than 60 feet, don't always offer a clear benefit in the majority of cases, except for extreme cases, and are associated with other risks, such as bending your tender or oxygen toxicity.

What about follow-up treatment? Residual symptoms should be treated with follow-up treatments. You can use U.S. Navy table 5, 6, of 9. We typically use table 9 for follow-on treatments, unless symptoms are severe, then you can justify table 6. You should treat daily until no improvement on consecutive treatments. Typically we treat for less than seven days, except in extreme cases or if there are severe symptoms.

### Some take-home pearls from the talk.

- Today we learned short tables are not always short and are not always shallow.
- Except when you're using treatment table 6, shorter tables are only acceptable for the treatment of mild or pain-only DCS and as tailing treatments.
- Treatment table 6 is the standard of care for all types of decompression illness.
- Treatment table 5 can be used for mild symptoms only.
- Table 9 can be used only for repeat treatments, and should not be the primary treatment modality for DCS although there is very limited data.
- Monoplace chambers have shown great success in the treatment of decompression sickness both with their Monoplace no air-break tables as well as treatment table 5 and 6.

- In-water recompression is an area that utilizes short tables; however, this is rarely the ideal treatment modality.
- If the symptoms are progressing, always lean toward treatment of the more severe symptoms, and most importantly, treatment delays appear to be the most consistent predictor of treatment failure, not so much the treatment table that you choose to use. Even when there are significant delays, patients tend to do just fine.

## DISCUSSION

Simon Mitchell:
Brenna, thanks for that. I just wanted to make a comment about an] issue that you raised in your presentation. It's this idea about whether or not you consider cutis marmorata to be a severe form of decompression sickness, which you kind of implied you should. The truth is that cutis fits the definition of mild decompression sickness, so long as it's the only thing that's present. I've never seen anyone die of cutis marmorata. I've seen people have cutis marmorata and have it relatively commonly associated with more severe symptoms.

So the key question, if someone is exhibiting cutis marmorata is "is there anything else present?" But if it occurs in isolation, true isolation, then there's no reason why it can't be considered a mild symptom. It has no prognostic significance of itself. But it is a sign that you should be diligent about looking for other manifestations.

For example, in discussing whether or not someone needs a neurological examination in a remote location for them to be called mild, if they had cutis marmorata, I would absolutely insist on that. If it wasn't available, I would want them to be evacuated because of that common association with more severe symptoms. But if is just cutis marmorata, on its own, I think you can actually see it as a mild symptom. It's just predictive of a higher likelihood of other symptoms.

Petar Denoble:
Thank you, Simon, for your comments. Yes, we see also that at least 20% of cutis marmorata is associated with neurological symptoms. And that's "at least" because we don't have all data. In cases when it's the only symptom, then it behaves as mild and has outcomes as mild.

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# TREATMENT OF PATIENTS WITH SEVERE DCS

Ian Grover, MD

"In many areas of endeavor, we tend to perpetuate ideas without fully understanding their origins or without seeking contrary opinions." One such area is recompression therapy for diving casualties.[1] This was true in 1978 when written, and it is also true today regarding the treatment of individuals with severe decompression sickness (DCS).

To discuss the management of patients with severe DCS, a definition of severe DCS must first be established, and the natural history of severe DCS understood. This then provides a basis to determine if the treatment provided improves patient outcomes.

Only once a case definition and the natural history of severe DCS have been agreed upon and understood, can the treatment and outcome of patients with severe DCS be meaningfully discussed. This review will also focus on treatment prior to recompression therapy, different treatment table options for severe DCS, and adjunctive therapy. Finally, the importance of continued research regarding decompression sickness and its treatment will be outlined. This will emphasize the importance of developing a suitable animal model for severe decompression sickness. If such an animal model can be developed, then this disease process can be adequately studied and appropriate treatment protocols for severe decompression sickness can be established.

For the purpose of this review, patients with severe DCS are those who have significant neurologic signs and symptoms, with objective findings of numbness and weakness, urinary retention, and mental status changes. Parasthesias alone will not be considered severe DCS. Inner ear DCS, also know as the "staggers," is also a severe form of DCS. These patients present with tinnitus, hearing loss, and vertigo, often associated with nausea and vomiting.

Severe decompression sickness also includes pulmonary symptoms or "chokes." These patients present with pleuritic chest pain, a cough often productive of pink and frothy sputum, cyanosis, and lung congestion. In many cases, these symptoms eventually lead to circulatory collapse. Although common during World War II when aviators flew in unpressurized aircraft, it is rather uncommon now.

Severe DCS can be quite devastating. In 1907, Zografidi published "Decompression accidents among divers." He described three forms of decompression related injury. "The outcome of a fulminating form is always death. The acute form is

fatal in 70% of the cases, according to my statistics. In the moderate form, recovery is the rule without exceptions."[2] The first type described probably represented arterial gas embolism. He reported in the moderate form, most divers recovered without severe sequelae.[2]

The natural history for decompression illness was also reported by Moon in SPUMS (2000).[3] He also noted although fatalities occurred (probably victims of AGE rather than DCS) most victims improved. Thus the efficacy of different treatment tables for severe DCS is difficult to evaluate when the natural history of the disease is patients' symptoms improve on their own and when comparable case definitions are not utilized.

When patients present with severe DCS, they must be first medically stabilized before being treated in a hyperbaric chamber. Prior to recompression therapy the patient should be immediately treated with the highest concentration of oxygen possible. Supplemental oxygen should be continued until recompression therapy can begin. A chest radiograph, if indicated, may be done prior to initiation of their hyperbaric oxygen therapy. If a pneumothorax is present, this should be treated with a chest tube. Patients may have to be intubated and placed on a ventilator in order to secure an airway, prior to recompression treatment. These patients should then receive the appropriate paralytics and sedation so they tolerate mechanical ventilation during hyperbaric treatment. A number of patients suffering severe DCS become hypotensive due to third spacing of fluids, dehydration, and possibly spinal shock. They require IV fluids and sometimes vasopressors to maintain an adequate blood pressure. If the patient requires multiple medications or vasopressors, a central line may have to be placed prior to the hyperbaric treatment. The patient's medical therapy should be maximized before placing them in a hyperbaric chamber for a prolonged period of time.

Different treatment table options for severe DCS abound. The U.S. Navy Dive Manual (rev 7) is often considered the gold standard for management of DCS, and states the primary treatment option for severe DCS is the Treatment Table 6 (TT6). (Figure 1)

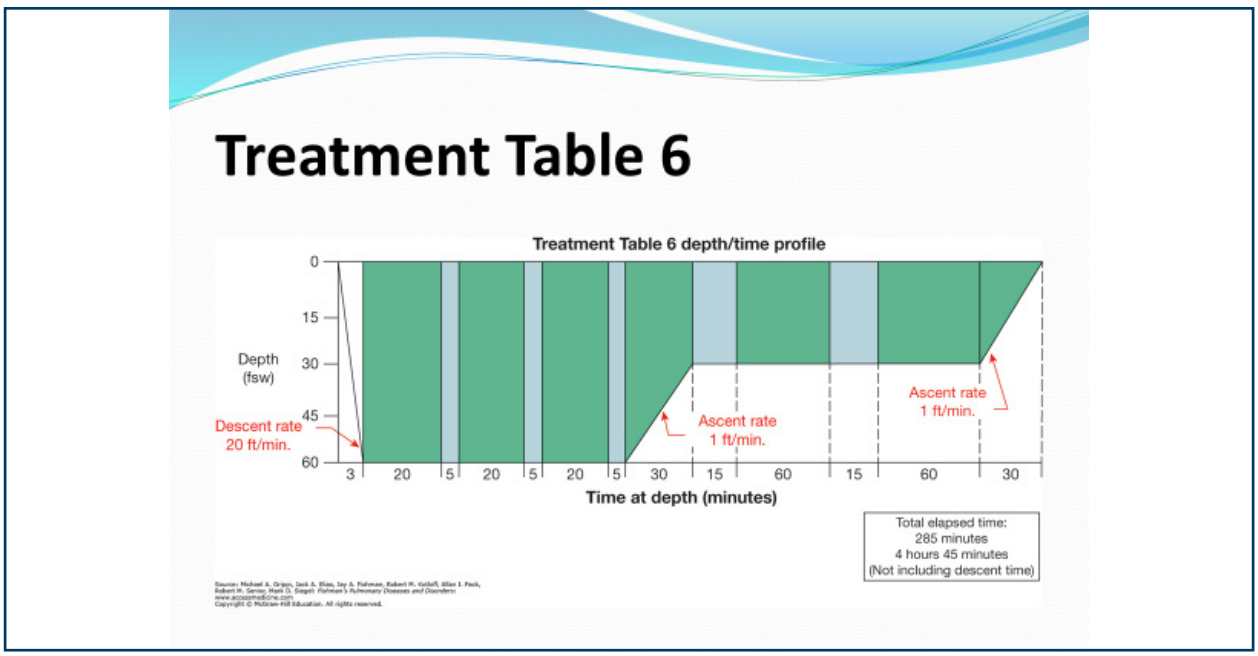


Figure 1. Treatment Table 6

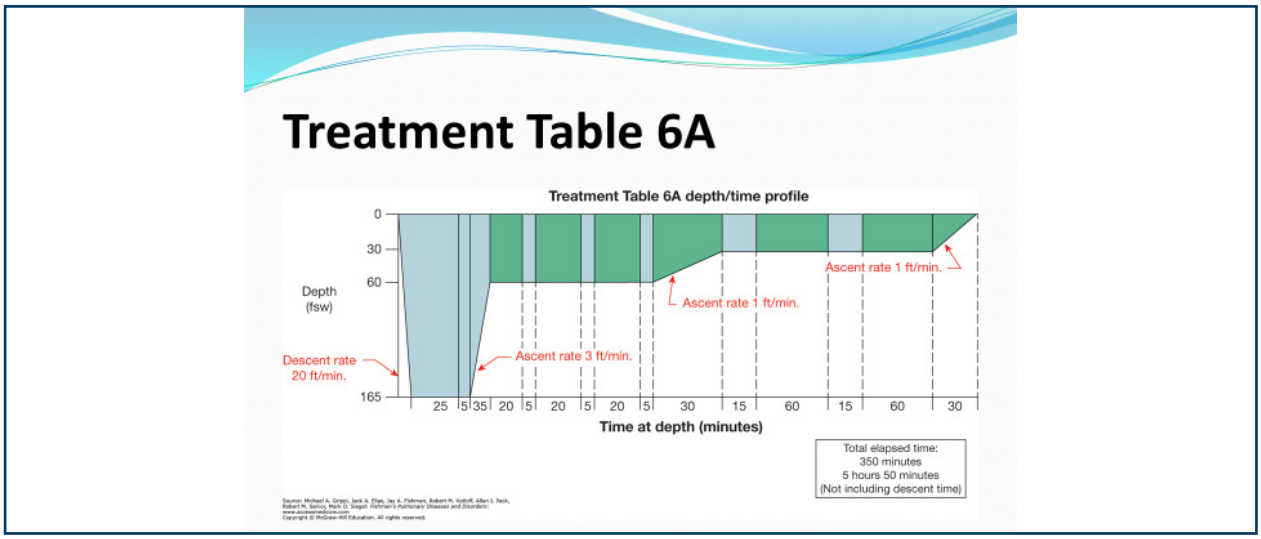


Figure 2. Treatment Table 6A

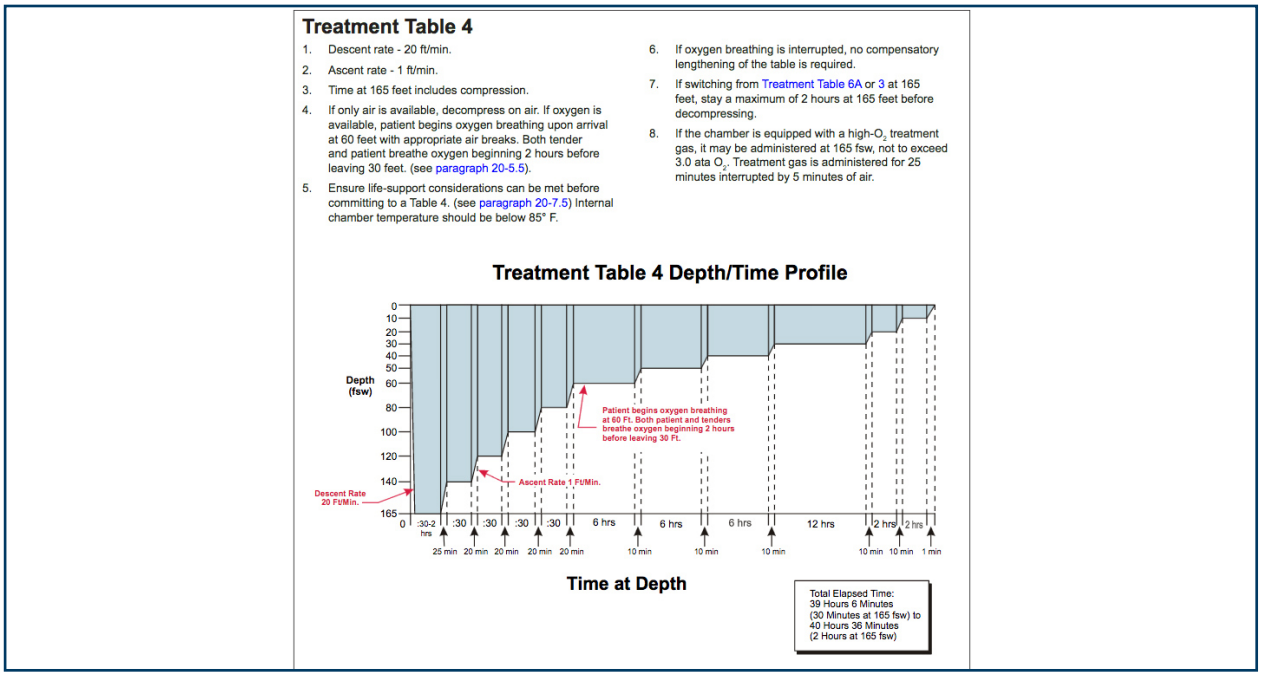


Figure 3. Treatment Table 4

A TT6 without extensions lasts four hours and 45 minutes. Should the patient not improve during the TT6, the U.S. Navy Dive Manual gives the option of transitioning to a Treatment Table 6A (TT6A). (Figure 2) The manual recommends compression until symptom resolution or improvement, not to exceed 165 feet of sea water (FSW).

If the patient is compressed to 165 FSW (6 ATA) the breathing gas should be a 50/50 mixture, usually oxygen enriched nitrogen (Nitrox). One hundred percent oxygen is not utilized until the patient has reached 60 FSW. However, treatment at 6 ATA increases the risk to both the patient and the hyperbaric staff, thus, this must be taken into consideration when determining the best treatment option. If the patient doesn't improve or requires additional time at the deeper treatment depth, the U.S. Navy Dive Manual states the patient can remain at that treatment depth for up to 120 minutes and then decompressed on Treatment Table 4 (TT4). (Figure 3)

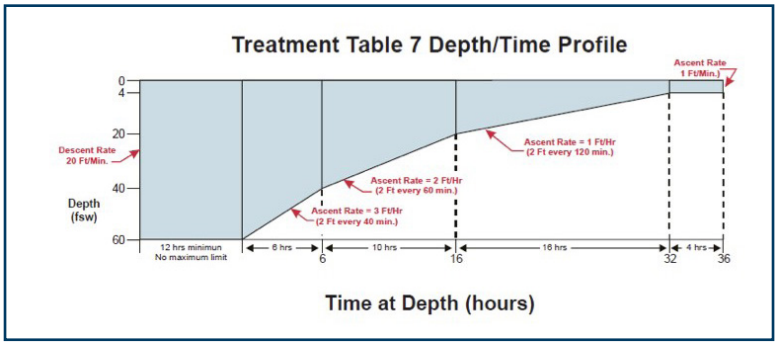


Figure 4. Treatment Table 7

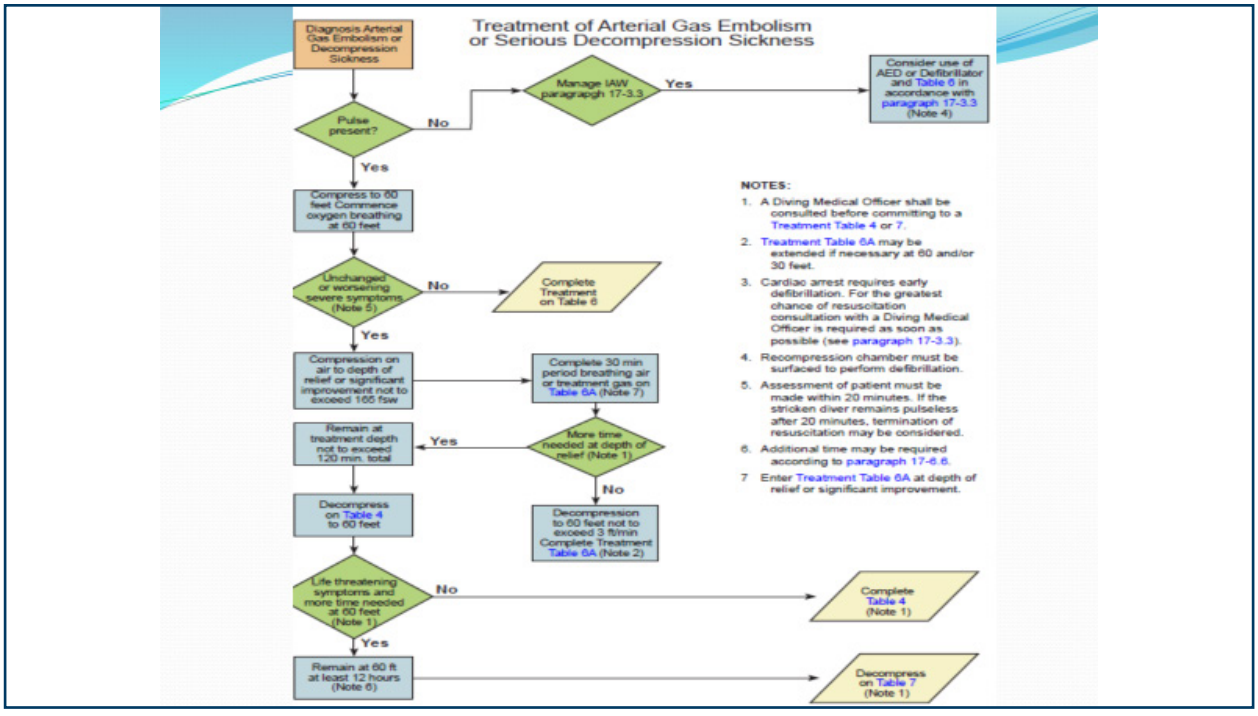


Figure 5. Treatment of arterial gas embolism or serious decompression sickness

The dive manual further states if the patient has life-threatening symptoms, another treatment option is to remain at 60 FSW for up to 12 hours and then decompress using Treatment Table 7 (TT 7). (Fig. 4)

Figure 5 is the algorithm from the U.S Navy Dive Manual with the different decision points.

In summary, the U.S. Navy Dive Manual (rev 7) recommends patients with severe DCS be recompressed to 60 FSW, and treated with a TT6. Treatment options for patients whose symptoms do not improve or worsen, would be compression to a depth of significant improvement or resolution not to exceed 165 FSW. Should that occur, a transition would be made to a TT6A. If the patient's symptoms persist and additional time is needed at the treatment depth, the patient can remain at 165 FSW or the depth of resolution for up to two hours and then be decompressed on a TT4. If there are still life-threatening symptoms, the patient can remain at 60 FSW for up to 12 hours and then be decompressed on a TT7.

The Undersea and Hyperbaric Medical Society (UHMS) published "best practice guidelines" in 2011. The UHMS treatment recommendations mirrored the U.S. Navy's recommendations with the TT6

being the primary treatment table for severe DCS. Patients could be treated at 165 FSW if there was no response at 60 FSW. (see Table 1)

Severe DCS warrants extensions at 60 FSW, when treating with a TT6. An extension is an extra 20 minute oxygen breathing period at 60 FSW and up to three extensions at 60 FSW can be made. For each 20 minute extension at 60 FSW, a 60 minute extension is made at 30 FSW. The treatment table 8 (Figure 6) is an option for patients with symptoms after uncontrolled ascents when more than 60 minutes of decompression were omitted.

Similar to the USN guidelines, if the patient's symptoms were unchanged or getting worse, then the treatment table could be converted to a TT6A, going to 165 FSW. It is possible to stay at 165 FSW or the depth of resolution for up to two hours and decompress on a TT4 (Figure 3) or stay at 60 feet for up to 12 hours and decompress on a TT7 (Figure 4).[4]

Table 1. Type II DCS

## TYPE II DCS

- TT-6 (option to go to 165 fsw if no response)
- Severe DCS warrants full extensions at 60 fsw
- TT-8 for deep uncontrolled ascents when more than 60 minutes of decompression have been missed
- Unchanged or worsening symptoms
  - TT-6A
  - May stay at 165 fsw up to 2 hours - decompress on TT-4
  - Persistent symptoms at 60 fsw - stay at 60 fsw up to 12 hours and decompress on TT-7

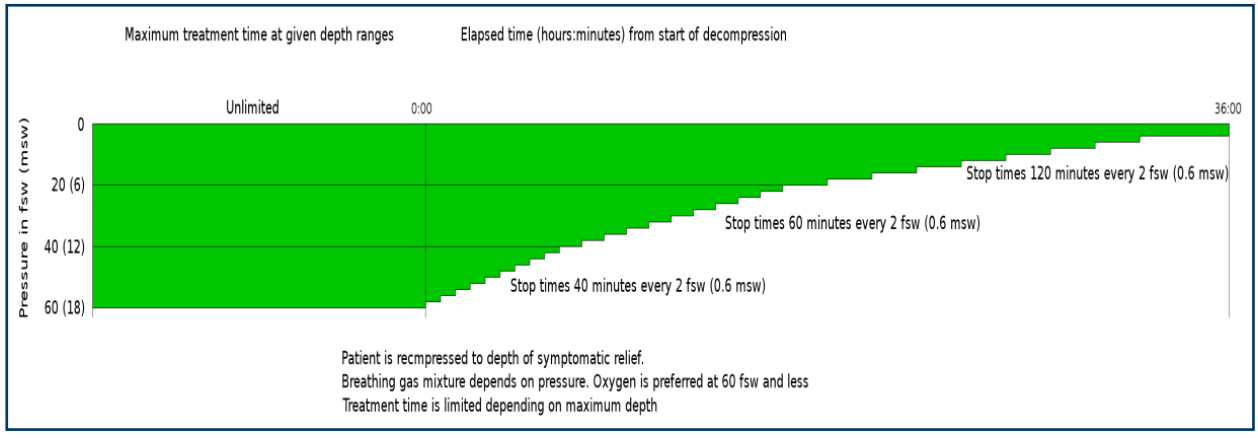


Figure 6. U.S. Navy Treatment Table 8 for 60 fsw (18 msw)

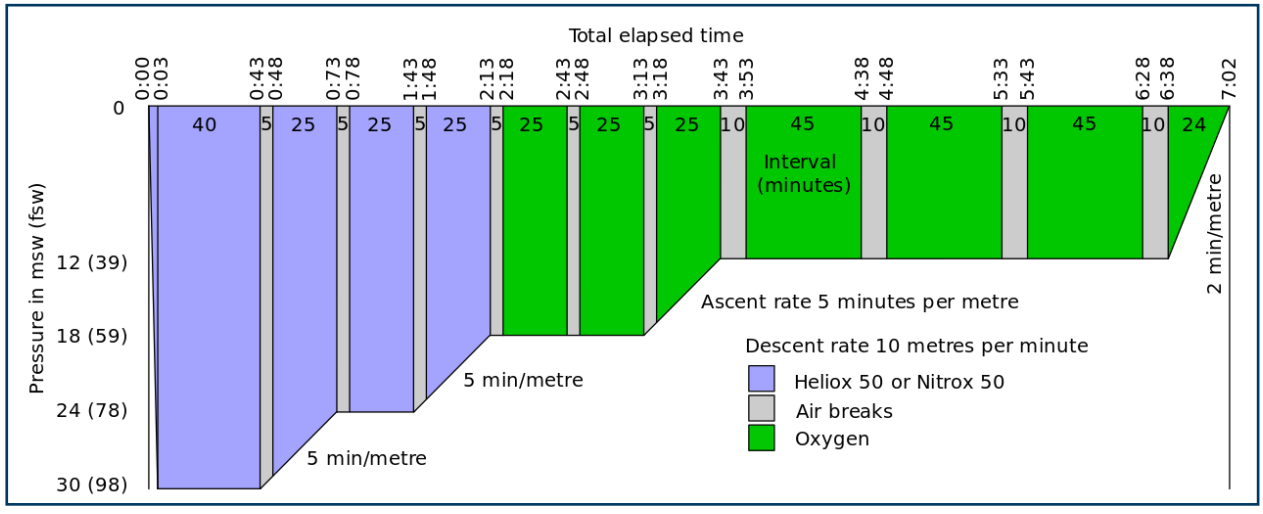


Figure 7. COMEX therapeutic table CX 30

The Canadian Navy recommendations are also very similar to the USN guidelines recommending a TT6 as the initial treatment table and then using a TT6A for severe or worsening symptoms, however in place of the TT6A the Canadian Navy provides the option of using a Comex 30 table (Figure 7).[5]

There is a great deal of experience associated with the use of the U.S. Navy TT6 and it has become widely used throughout the world, however, evidence proving its superiority to other treatment tables is limited. In a report published in 2006[6] using a short monoplace protocol (Hart-Kindwall protocol)[7], results were excellent. A 95% recovery rate for patients with Type II DCS was reported.[6] Additionally, many of the patients had significant delays to treatment, however the specific criteria for the diagnosis of DCS were not reported.

The UCSD experience also demonstrates the TT6 is an appropriate option for treating severe DCS. There, a modified TT6 is used. (Figure 8) The modifications utilized are the Air Force modifications to the TT6 and are used as there is an improvement in mask discipline with 20 minute oxygen breathing periods and five minute air breaks at 30 fsw compared to 60 minute oxygen breathing periods with 15 minute air breaks at 30 fsw. The continuity between oxygen breathing periods at 60 FSW and 30 fsw also provides uniformity for the chamber operators. Sadler in a retrospective review of UCSD's results using the modified TT6 found comparable results to other facilities.[8] There was a 90% improvement using the modified TT6 or modified TT6 with extensions as needed. These modifications consist of extensions at 60 fsw and then for every extension at 60 fsw, there are three extensions at 30 FSW. There is also the option of converting the modified TT6 to a TT6A for patients with severe DCS or for patients with AGE who arrive at the chamber quickly. However the TT6A is rarely used at UCSD due to the treatment success rate of the modified TT6 with or without extensions and the extra risk to staff associated with greater depth exposures.

Figure 8 is a depiction of the modified TT6 described above. There are three 20 minute oxygen breathing periods at 60 fsw. If the patient's symptoms don't completely resolve, then anywhere from 1 to 3 extensions at 60 fsw can be added. For every 20 minute extension at 60 fsw, three 20 minute extensions at 30 fsw are made. This modified TT6 can last anywhere from just under five hours to 12 hours with full extensions. The DCS cases seen and treated at UCSD are primarily recreational SCUBA divers, occasional technical divers, and aviation DCS due to the proximity to the Navy and the Marine Corps air stations in San Diego. Also treated are patients with severe DCS transferred in from remote locations.

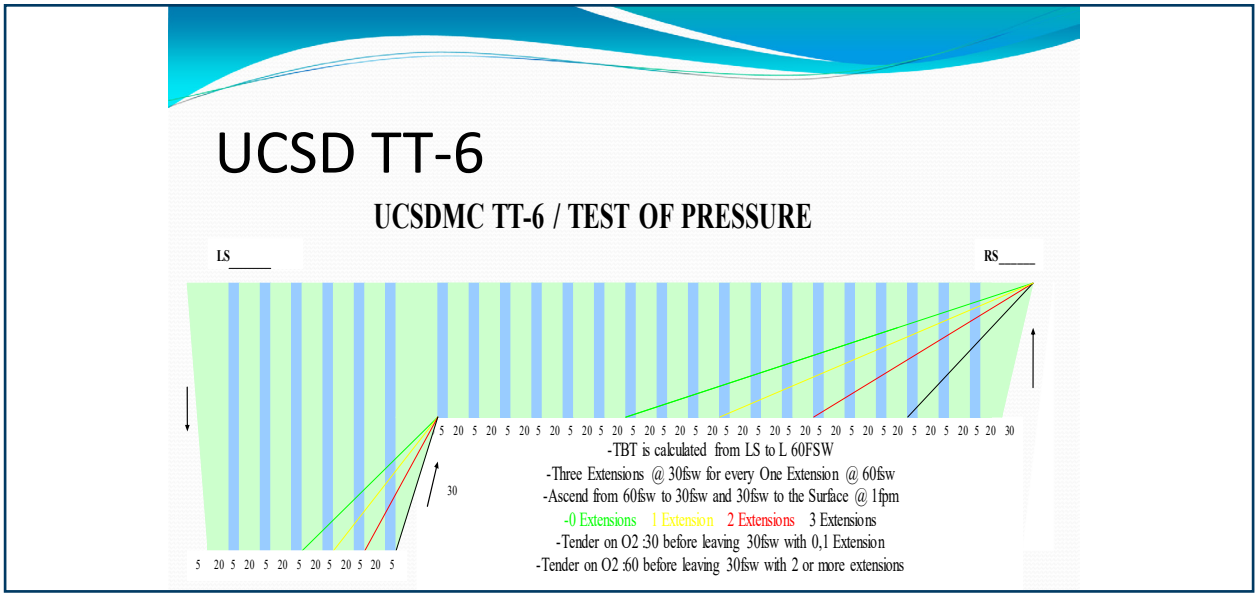


Figure 8. UCSD TT-6

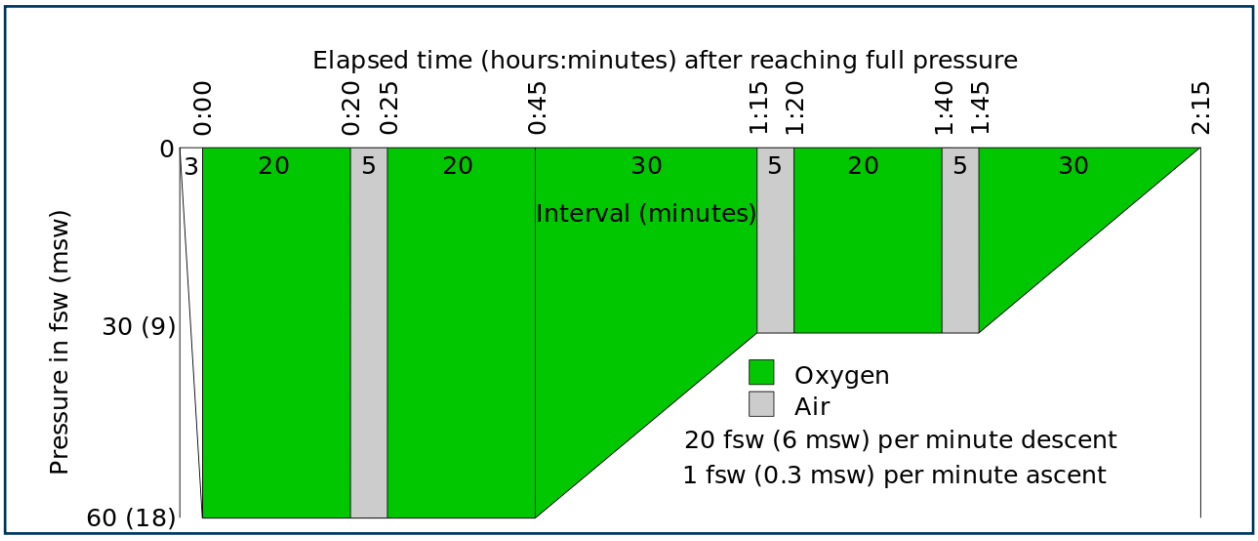


Figure 9. U.S. Navy Recompression Treatment Table 5

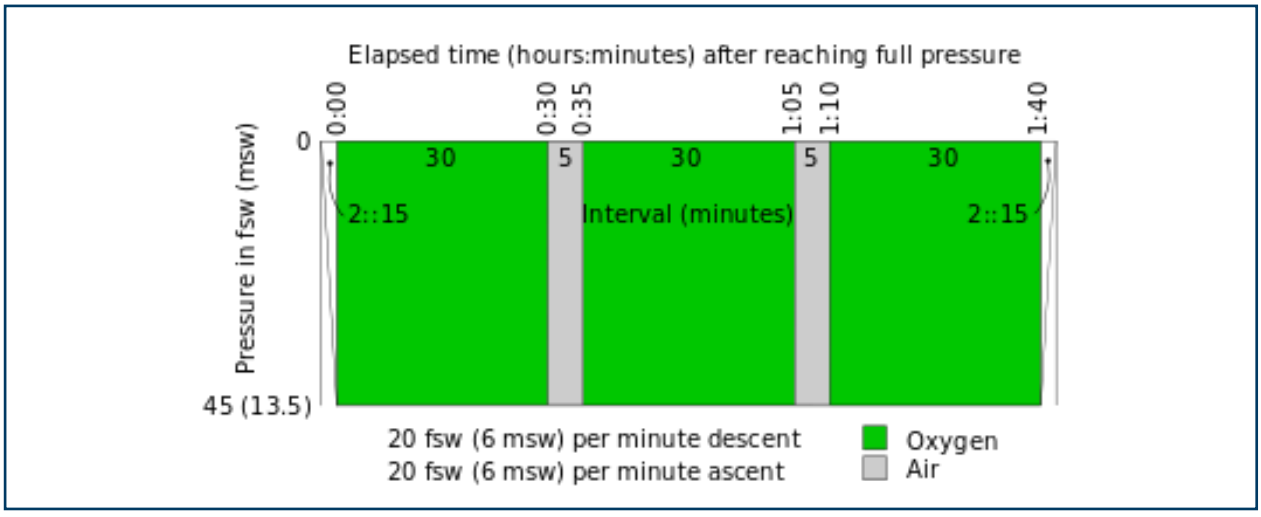


Figure 10. U.S. Navy Treatment Table 9

For patients with residual symptoms after an initial hyperbaric treatment, the treatment options vary significantly. Again, the scientific evidence proving superiority of one option over another is lacking. “Tailing” treatment options include repeating a TT6, a TT5 (Figure 9), or a standard wound treatment table, TT9 (Figure 10). These tailing treatments usually continue until the patient’s symptoms plateau and generally involve one to ten additional treatments. Rarely are more than ten additional treatments needed.

One size may not fit all when it comes to the treatment of severe decompression sickness. Currently almost all forms of decompression sickness are treated in a similar manner. Treatments which result in excellent outcomes in one location may not produce similar results in other locations as in different locations, divers have markedly different depth time profiles resulting in different syndromes of severe DCS. Thus it is vitally important for a good animal model for DCS to be developed. For clinical series, an agreed upon case definition is equally important.

There are few adjunctive measures for treating patients with severe decompression sickness. Many require either PO or IV fluids. If the patient's mobility is restricted, anticoagulation will reduce their risk of deep venous thrombosis (DVT) and pulmonary embolism (PE).

Currently there are no well controlled studies demonstrating aspirin, corticosteroids or lidocaine are indicated in the treatment of these patients. Lidocaine may be appropriate for patients with an arterial gas embolism, but it has not been demonstrated to be efficacious for patients with severe decompression sickness. Finally in a paper from 2015 it was suggested draining CSF via lumbar puncture might increase perfusion pressure of the spinal cord.[9] By increasing the perfusion pressure of the spinal cord, at risk portions of the spinal cord might be benifitted. Though an interesting hypothesis, lumbar punctures for patients with severe decompression sickness is not indicated at this time.

The historical record and data regarding the development and efficacy of the treatment tables currently in use are scant. Many of these tables were developed empirically and tested on small numbers of a select population. Some of the tables were considered "safe" if as few as four test subjects exposed to the table did not get DCS from the "treatment." This again emphasizes the need for continued research and the need for an appropriate animal model for decompression sickness. Equally important is the need for an agreed upon case definition of decompression sickness for future clinical series.

In summary, there are many treatment options available for managing victims with severe decompression sickness. First and foremost, the patient should be stabilized medically before treatment in a hyperbaric chamber. Currently TT6 is the preferred initial option for treating severe decompression sickness. These patients should receive fluids as they will be intravascularly depleted. DVT and PE prophylaxis should be given if their mobility is restricted. Finally, rigorous research studies and the development of a good animal model are paramount for advances in the treatment of decompression sickness.

I want to thank Dr. Tom Neuman for his guidance, editing of this manuscript, and the use of his extensive library for the research on this topic.

## DISCUSSION

Dick Sadler:
Thank you, sir. I am Dr. Dick Sadler from San Diego. Your thoughts on using a decompression spinal cord drainage is intriguing. We've had really good luck with that in American cardiac surgery. I'm wondering if we can get Dr. Mitchell to comment on possibly using that in the chamber. Is that a realistic option do you think?

Speaker 5:
And that's where the article kind of came from where they cited the evidence from cardiothoracic literature.

Speaker 7:
Yeah it's plainly an aortic syndrome.

Richard Moon :
I'm sure Simon has some thoughts on this, but when the aortic is clasped, the perfusion pressure distal to the client is extremely low and under those circumstances a small decrease in tissue pressure such as you might get with drainage of CSF could conceivably be worthwhile.

But in the setting of intact aorta, intact aortic or a spinal cord arterial flow there are numerous ways of increasing perfusion pressure. I think at the low end it wouldn't really make any difference. I mean to lower CSF pressure by a few millimeters of mercury would be easily trumped by, you know, a norepinephrine infusion for example or a fluid resuscitation or numerous other things one could do.

Pieter Bothma:
I happen to know about that case in the UK quite well. My colleagues were disgusted to have this, a paraplegic patient, sent to them after about eight hours lying in an A&E nearby. They are in hell and I think at that stage there was significant edema of the spinal cord and they thought that this may be an option.

In the end, the patient had a very bad outcome. Can I use this opportunity to ask you a different question please? Is there someone who wanted to talk about this issue further this time?

We have two units in the UK that can manage ventilated patients. They are far away from where the most popular diving sites are, and patients that do survive the initial injury and don't drown occasionally get into us ventilated which makes it very difficult to assess them in the chamber.

I prefer the U.S. Navy TT6 and the question always is are you going to give them extensions every time? Are you going to give them the maximum extensions? How frequently are you keeping them? Because these patients often are on sedation and difficult to assess neurologically. Do you have any views on that?

Ian Grover:
Well, that's the million-dollar question, and one of the beauties of working at UCSD is we have a number of different hyperbaric physicians and I think if you polled each one of us we probably would have a different answer. My take is if patients with a severe DCS come to me and they're that sick on a ventilator, I'm going to give them the best treatment that I know, which would be the TT6 with full extensions right off the bat.

Then as far as follow on treatments, again, that's a difficult decision. Many times we have to weigh in pulmonary oxygen toxicity there. So it depends on how their lungs are functioning. You know, we will talk with the ICU staff and see if they can wean sedation with any neurologic exam to guide us.

You know, just to try and answer your question, and again this is just a personal feeling and some of the other physicians here from UCSD may disagree with me, but I'd probably do a couple of more HBO treatments. Like, use a TT9 if they're still on a ventilator and sedated because they are that sick.

Pieter Bothma:
Yeah, just another comment about the very sick patients. There was a lot of emphasis in your presentation on your choice of treatment table and, and to be fair, what I'm about to say only really applies to a very small subset even of the very sick patients. So those patients who are, you know, hyportensive, in shock, coagulopathic, and hypoglycemic. You don't see them very often, thankfully.

But I just think the maybe narrative on the subject, so it's important to point out that that type of patient, it's more important to consider the stabilization procedures and the preparation for recompression than what the actual recompression's going to be. I mean that is an important question, but there is a sense out there in the community that just rushing people into a chamber is going to fix all these problems and it doesn't.

And if you take a patient like that into a chamber before they're properly stabilized and set up for an intensive care type treatment, then the outcome could be very bad. So my point is it's important in discussing very sick decompression sickness patients to mention that intensive care type care is important, not just recompressing them and choosing the right table.

Ian Grover:
You're absolutely correct. And I'm sorry that I didn't mention that. You bring up a great point and we saw that in one of the cases that we treated just recently. It was a young Navy gentleman who was vacationing in Guam. Had a severe arterial gas embolism, and was very, very sick. He was stabilized in Guam by the ICU physician there and I really believe he did more to save that patient than we did six days later when he got to us and we treated him with the treatment table six at our facility. So your point is well taken and I'm sorry that I didn't mention it.

Pieter Bothma:
To your point you probably remember when John Ross gave his presentation. We actually showed in Scotland it was more important to transport the patient to the acuity, high acuity, facility then to keep them somewhere to recompress.

Well that doesn't mean while the transport is arranged because as you mentioned earlier you can start them at 60 feet but when the transport shows up, you know like get them to a regular chamber and he has very nicely shown that there's better outcomes if the patient is treated in a treatment facility that is equipped like UCSD, Duke, near Rochester, those kinds of things rather than trying to make that happen yourself.

Ian Grover:
There was another question.

Jennifer Pitt:
I was working in Plymouth and we had a severely deep diver, 50 meters chap who actually came along and he was only, the treating doctor, was a surgeon. They gave him 10 liters of fluid during a Comex treatment including two more liters in the hospital afterwards.

He had gastric stasis and had his own [inaudible 00:28:11] the following day because he had no bowel sounds and he didn't get his second followup treatment 'til the third day. He had 29 treatments and was walking again at the end, but he had significant delight but the treatment was he couldn't get in [inaudible 00:28:25] or couldn't get on a trailer because the surgeon wasn't used to it and this is the other thing that Simon mentioned is adjunctive therapy as well as the treatment table.

Petar: Thank you for this discussion at the end. Probably I didn't provide enough hints that we would like you to talk about severe, severe cases, although they are rare. For example, how often you use your in-chamber ICU capability?

Ian Grover:
I'd say three or four times a year.

Petar Denoble:
These cases are what we were interested in. At DAN, when triaging cases that call our emergency line, we are trying to match a patient with a facility and in the case of a severe patient that may require ICU capabilities, we are referring them where such capability exists.. Of course we prefer to refer severe cases to the emergency room and ICU. But sometimes it's not always easy to predict who may need an ICU. However, out there people are trying to rush injured diver into the hyperbaric chamber regardless of the severity of their condition. So I think this discussion about severe and potentially severe cases, not just type two but severe, severe cases is necessary and perhaps will help people who are engaged in triage and field management of these cases.

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# U.S. NAVY TREATMENT TABLES - ACTUAL RULES OR “GUIDELINES”?

David Southerland, MD

My name is David Southerland. I work for the Supervisor of Salvage and Diving. We work at the headquarters of the the Naval Sea Systems Command. It is physically located on the Washington Navy Yard in Washington D.C.

I was asked to talk about U.S. treatment tables concerning recreational diving. I was allowed to take a little bit of a different look from what you’ve been seeing in this meeting because many people here already know about the U.S. Navy Treatment Tables. This presentation will touch on a smorgasbord of things.

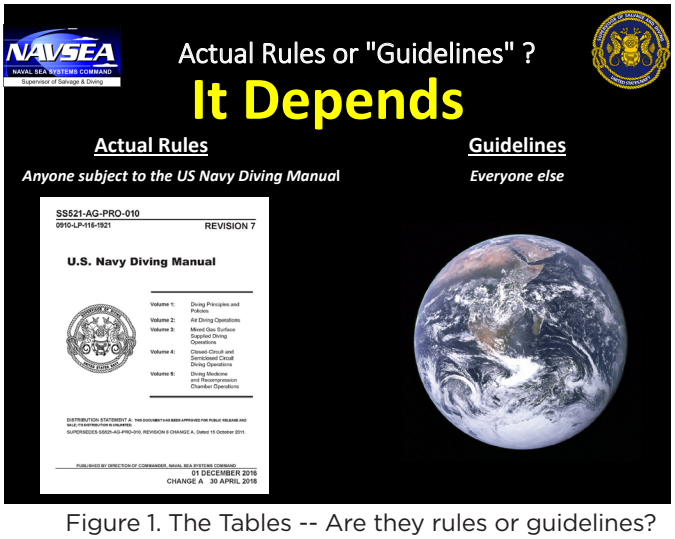



Figure 1. The Tables -- Are they rules or guidelines?

*Disclaimer: These are my own opinions. The wonderful people at the Naval Sea Systems Command had to look at the slides before they decided that I was allowed to express my opinion. I don’t have any relevant financial interest or commercial financial interest.*

## U.S. NAVY TREATMENT TABLES

"Are they actual rules or guidelines"?

The bottom line answer is: It depends.

So, it depends. For whom does this apply? These are actual rules for anyone who is subject to the U.S. Navy Diving Manual. The U.S. Navy Diving Manual is currently revision 7, change A. It has been out for a year. To find it, google for "U.S. Navy Diving Manual revision 7 change A" and look down the list and see one of the sites located at www.navsea.navy.mil. That's where you want to go and you can download your own copy. It's a 12 megabyte PDF file.

Who are the guidelines for? Basically, that's everybody else. This includes recreational diving, unless you're a recreational diver who's subject to the U.S. Navy Diving Manual. The U.S. Navy Treatment Tables are guidelines to use or not use as you see fit.

## NAVY DIVER

What is a navy diver? The term "navy diver" requires some explanation. "Navy diver" refers to the U.S. Navy Diver and not a diver in another country's navy. Until 2006, everyone who had successfully completed a U.S. Navy course in diving was considered a navy diver. In that year, the U.S. Navy created a specific rating for enlisted divers called the "Navy Diver" with a designation of "ND".

Until that time, enlisted navy divers had a rating in various fields with an additional qualification as a diver.

Now you hear people say, "I'm a diver in the navy, but I'm not a Navy Diver." Technically, the "Navy Diver" now refers to a subset of enlisted divers in the navy. However, I will use "navy diver" to include all navy personnel who have successfully completed a formal navy course in diving. Figure 2 a & b show some navy divers; 2b shows the real U.S. Navy divers.

The Mobile Diving Salvage Units go out and salvage stuff. There's a lot of things underwater that are not supposed to be there such as airplanes and ships. The divers will go in and salvage them. They are davy divers. They can also do some work underwater like welding. There are also divers involved with ship husbandry. You can save millions of dollars keeping a ship or submarine out of dry dock if you can do the repairs on it underwater. These are navy divers.

You might think that divers who deal with underwater mines are Navy Divers, but they're not. They don't have the ND rating. They are Explosive Ordance Disposal (EOD) personnel. Each is a Navy diver but not a "navy diver".

Seabees from an Underwater Construction Team build stuff underwater. They blow up stuff underwater, too. The diver in Figure 2b is inspecting a deep mooring chain - he would tell you he's just tugging on it to make sure it's still secure.

Then you have the Special Warfare guys - SEALs. They don't have the ND rating, but they're also divers in the navy.

I lump these groups together as Navy divers but they all have different jobs and different missions. If you ask, "What's a typical navy dive"? I have to ask "What group are you talking about?" Their jobs vary across the board.



Figure 2 a & b. The U.S. Navy Diver

## RECOMPRESSION CHAMBERS

We don't use monoplace chambers, but we do have have a few SOS Hyperlites that have been in storage for quite some time. I talked to the Navy's Director of Diving Programs and he said, "Well we could probably get them certified, but we'd have to replace the tube portion, the end caps are okay, but there's no demand for it, so we don't have any Hyperlites that are operational."

For those who didn't know, John Selby died not long ago. He was the father of the Hyperlite.

We don't use monoplace chambers; we use multiplace chambers. The Transportable Recompression Chamber (TRC) and the Standard Navy Double Lock Recompression Chamber are the two most common multiplace chambers that are used for operational diving not in any of the training or research chambers. These can be flown to different locations.

Here are two pictures of the TRC. The two compartments can be separated.

The picture below gives you an idea of the size. It's pretty cramped; it's small.

Figure 3 a & b. Transportable Recompression Chamber (TRC)

The Standard Navy Double Lock Recompression Chamber is larger and can accommodate 4 divers in the inner lock and 3 divers in the outer lock.

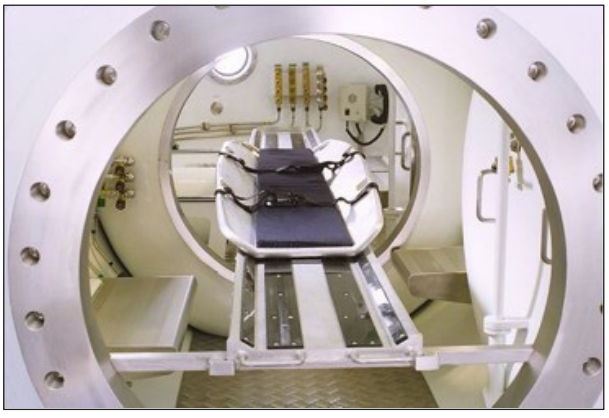


Figure 4 a & b. Standard Navy Double Lock Recompression Chamber

There is a big difference between how the U.S. Navy and most other people use decompression chambers if you're considering recreational diving or in a hospital. The important thing for the U.S. Navy is that multiplace chambers are multifunctional.

The U.S. Navy uses multiplace chambers for various purposes:

- Surface Decompression with Oxygen (SurD-O2)
- Multiple affected divers. (Symptomatic or Omitted Decompression)
- Medical access to stricken diver
- Industrial Workplace – Accidents happen

First, for surface supply diving, we do surface decompression. You must have a chamber because it can cut out a lot of the decompression time in the water if you can come to the surface quickly, get

into your chamber, get pressed back down, and get on oxygen. Depending on the bottom depth it may be possible to perform all of the decompression on the surface in the chamber. Surface decompression is desirable when the sea state is bad, the water is really cold, or you have a lot of decompression. You can do that decompression in a chamber on the surface. When the weather worsens, the vessel can be sailing back into port while the divers are undergoing the decompression in the chamber. In-water decompression requires the divers to remain in the water regardless of the weather.

In surface decompression, you are allowed five minutes to travel from 40 feet of seawater to the surface, strip out of your gear, climb into the chamber, and arrive at 50 fsw. Guess how far away your chamber is from your dive? A delay is called omitted decompression and requires extra decompression and likely a treatment table even if the divers have no symptoms. [A delay greater than two minutes requires the use of a treatment table.] The treatment table is a lot longer and thus there is an incentive to get in chamber within the five minute limit.

Second, treating multiple affected divers -- Here are two guys who are holding on to this platform called a stage. Normally, for that type of diving we use two divers. If something adverse happens to one, it can also happen to the other. In such cases, you have to treat two people at one time. While you can do that by having two chambers, it's easier to just have a multiplace chamber.

The third and fourth ones I will consider together. Sometimes you need to be able to get to the diver and perform various medical procedures, such as placing an IV. With a multiplace chamber you've got a way of getting in the chamber and do what is needed. This is rare, but it can happen. Also, remember that Navy divers perform operational work which is industrial work. Industrial accidents can happen underwater. Broken bones, lacerations, or whatnot can occur but the diver still requires decompression. You can multitask with a multiplace chamber. Multiplace chambers have multifunction capabilities.

We don't treat many cases of decompression sickness or AGE, but we use these chambers a lot for surface supply diving.

The Diving Manual is written for operators. It's not written for medical people. In your facility, if you wanted to do Treatment Table 6, are your chamber staff allowed to go ahead and initiate that treatment without hearing anything from a physician?

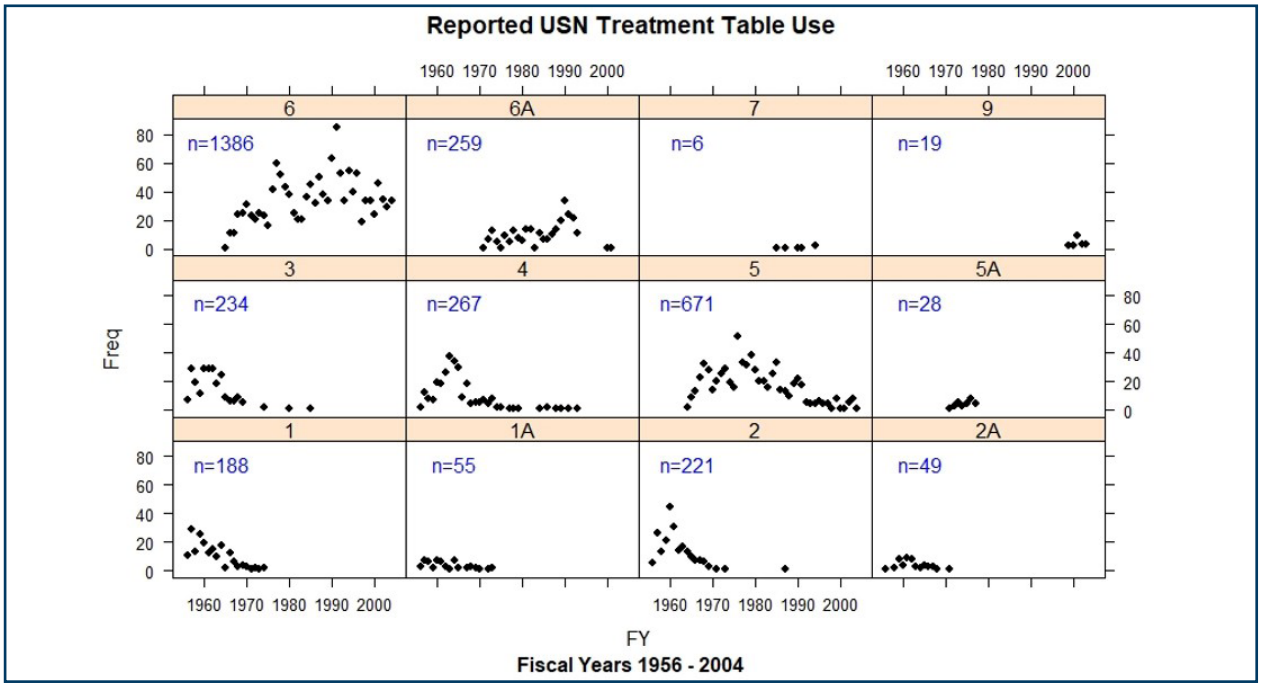



Figure 5. Reported use of USN Treatment Tables from 1956-2004

Many treatments in the United States Navy occur or start before the Medical Officer is contacted because the Dive Manual allows your dive crews to go ahead, make a decision, commence treatment, and complete it without notifying a physician. There are certain caveats and restrictions. However, these divers are operational. They may be operating a 1,000 miles from their base, where they don't have a physician and they don't have good communications.

## TREATMENT TYPES

The ones that we normally use are USN TT6, TT5, TT6A and then there's TT4. One thing I'll say is that we don't "start off on the TT6". We recompress to 60 feet and put them on oxygen. If their symptoms resolve in less than 10 min, you can come out on TT5 if you want. If they're getting worse during that time and it's been 20 minutes, you say, "hey, we need to go deeper". Then you can go deeper. You can go to TT6A. You don't have to go 165 feet, you can stop at 100 feet. It depends on where you're starting to see significant benefit. You can go ahead and stop there because everyone's always concerned about getting at 165 feet.

I guess the modus operandi is to avoid commitment till the last possible moment. Don't commit to a treatment table before you start out, except for maybe treatment table nine.

The other three treatment tables listed are TT7, TT8, TT9. TT8 is for deep blow up. It's based on a case that I can talk about afterward. TT9 was based on the Navy answer to the HBO treatments where you're treating non-diving injuries that might need hyperbaric oxygen treatment.

Figure 5 is a trellis plot or lattice plot of Treatment Table usage by fiscal year. The day before my slides were due I was able to grab data from 1956 to 2005 by fiscal year. Our fiscal year begins one October of the year before. Treatment tables are up here [displayed in the gold bars], 6, 6A, 7, 9 and then the frequency [y-axis], and the number of cases [blue text]. The points show at least one treatment for a fiscal year. This [x-axis] shows the years from 1956 to 2004. Most of these are initial treatments. Multiple treatments [for the same condition] weren't counted multiple times. Tables 1 through 4 haven't been used in recent years. The TT6 is our most common treatment table.

Table 1 below shows 2016 data from the Naval Safety Center. I'm just throwing this up because I thought it was curious. In 2016 we had 145,000 dives. Student training accounted for 22% (31,483).

I would have thought student training would have accounted for most of the dives but that's not the case.

The only accident I checked was this rebreather AGE. This was actually in a student, who was on an oxygen rebreather. He came to the surface and ended up embolizing.

Table 1. 2016 Data from the Naval Safety Center

| Dive Apparatus | Number | DCS II | AGE |
|---|---|---|---|
| **Scuba** | 71,419 | | 2 |
| **Surf-supplied** | 29,947 | 2 | 2 |
| **Rebreather** | 37,854 | | 1 |
| **Other** | 5,567 | 1 | 1 |
| **Total** | 144,787 | 3 | 6 |

## DISCUSSION

Speaker 4:
Yes, sir, on your last slide where you're discussing the number of injuries reported, I wonder is that also skewed to where the Air Force guys are that they ... You're not gonna get flight pay unless you're flying. You're not going to get dive pay unless you're diving? Do they mask their reporting symptoms?

David Southerland:
Good question. I would say that, unlike in the Air Force the dive pay is not related to reporting dives. You don't get more money for having symptoms or not. In fact, we probably have under-reporting both of those because entering the data into the system we have to use is painful.

Speaker 4:
I guess I should clarify my question, a pilot doesn't get paid flight pay unless they're on flight status, so if they get taken off flight status, they are losing pay. Does the same thing happen in the Navy?

David Southerland:
Almost always, no. You're required to make so many dives per each six month period. During that time, if just you do a SAT dive, then that counts for the whole period. A diver with a permanent or prolonged disqualification can lose dive pay. Speaking of which, one thing I forgot to mention is when I'm talking about eight treatment tables, I'm not talking about saturation.

Petar Denoble:
How confident are you in the ability of a master diver to do a neuro exam, but since this is small number and treatment starts practically immediately, maybe in the case of the Navy, the neuro exam doesn't play a role?

David Southerland:
It plays a definite role. Not every case is treated quickly. If you don't do a full neurological exam before you start the treatment, you are obligated to do one in the chamber; and by the way, you're placed on a TT6 even if it was for mild elbow pain. The rules penalize you if you don't do a decent neurological exam. All divers are trained to do the neuro exam, but the Master Divers are all pretty good. They recognize significant abnormalities and while many divers have been evaluated for suspicion of DCS, only a few were treated. In those cases, there was value in a neurological exam -- confidence that the diver didn't have DCS.

Petar Denoble:
You had mentioned some caveats where the Diving Medical Officer has to be involved with treatment or decision making, what would it be?

David Southerland:
The Diving Medical Officer or the Undersea Medical Officer can modify any treatment tables that he or she wants, but he has to have the permission of the commanding officer. You can't just decide to shift tables, you have get permission. Getting back to your question, the number one treatment table would be treatment table nine. You cannot do a hyperbaric treatment for a non-diving related injury without having a medical office involved. If someone comes in carbon monoxide poisoning, they're not not supposed to treat those people without having a Medical Officer involved.

If you're doing a TT7, TT4, or even a TT6A, it is strongly recommended that you get a Medical Officer involved. If the chamber can't support those types of treatments, then you're not going to do them. Generally, for the routine Type I or uncomplicated Type II DCS, they will attempt to call you but they may already be into the second O2 period before they get in touch with you. If something is really gone badly or if they are expecting something to go badly, that's when they'll be more active in calling.

It also depends on the command and how good the command is.

# FLYING AFTER TREATMENT (FAT)

James Chimiak, MD

I have no conflict of interest to report for this presentation. But as we have all learned, there is considerable conflict when we mix altitude with diving. Unfortunately, there are often more questions than there are definitive answers when dealing with altitude especially for this topic, Flying After Treatment (FAT). This presentation will review related topics, prior studies and workshops that will help you better understand the complexity of this subject and help physicians determine a suitable Pre-Flight Surface Interval (PFSI) after treating a patient for Decompression Illness (DCI). In addition, a discussion of the alphabet soup of effects that flying or altitude exposure has on the diver suffering from DCI will be given. These effects include FAT (Flying After Treatment), PFSI (Pre-Flight Surface Interval), FAD (Flying After Diving), FBT (Flying Before Treatment) and Diving with Symptoms (DWS). They share this same underlying complicating factor, altitude.

One of the main concerns after a diver is treated for DCI is when can they fly home commercially. The PFSI is generally understood to be the time interval between the last treatment until they take off.

World-wide Diving Injuries


Remote Treatment Facilities

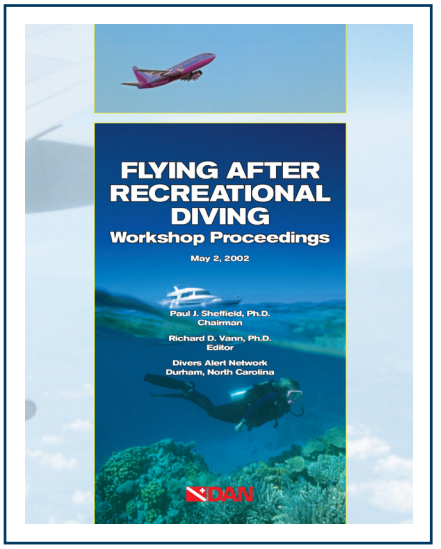
Flying after Treatment (FAT)

Most of the diving table development and research was conducted at sea level without exposure to elevated atmospheric conditions. Altitude exposure became increasingly important and accounting for its impact on the diver has been the focus of investigation especially with increased air travel, space exploration, special operations activity, technical diving, high performance aircraft, etc. These areas of study include:

- Altitude DCS
- Flying After diving (FAD)
- Diving at altitude
- Space Exploration
- Diving With Symptoms (DWS)
- Flying Before Treatment (FBT)
- Flying After Treatment (FAT)

Recognition and proper management/prevention of altitude DCS in high flying aircraft pilots has been refined over the years. Manned studies were conducted to form practical guidelines for FAD. Tables and computer algorithms have been developed to make diving at altitude safer.

leading to efficient methods to manage the low-pressure exposure risk. NASA investigations have confirmed the benefits of oxygen breathing both before exposure and for treatment. The benefits of surface level oxygen breathing not only before treatment but also during flight supports future investigation for its application. One airline did support the practice of delivering oxygen to injured divers during their commercial flight, but the practice has been curtailed. The reason this practice has never been widely adopted may have multiple factors including the overall patient's health/stability with general reluctance to allow embarkation by any passenger with an acute illness that may deteriorate inflight and require emergent flight diversion. Other issues raised have been fire safety, expert opinion consensus, adequate supply

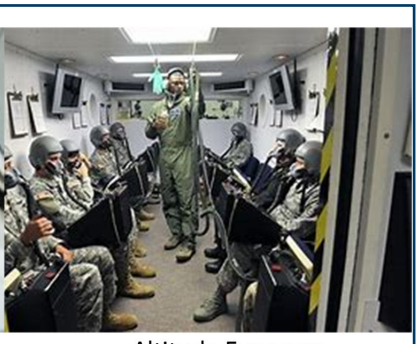



The need for efficient procedures to prevent and treat DCS for space exploration inspired research for the continuous high flow oxygen need of the diver(s) in addition to the large reserve oxygen requirement for inflight loss of cabin pressure emergency for all onboard, oxygen management, training, assignment of responsibility, etc.

Controlled man studies have been important in understanding and planning for altitude exposures. These are manned studies that require very specialized facilities, resources, and expert manning to complete. This was made apparent when we tested and validated the safety of an operational pressure check for the P-3 Orion aircraft that commanders needed just before take-off, a specific FAD profile.

P-3 (Orion) test

P-3 Pressure Check



Altitude Exposure

The point to be made is that these studies are costly, test specific profiles and are needed for guideline development directly or incorporated into algorithms. Despite the difficulty, there is considerable control of the variables involved in these studies. The subjects are screened. A variety of factors such as medications, medical conditions and lifestyle during the study are controlled or recorded. Time, pressure, even bubble doppler scoring can be precisely observed. With trained diving medical staff routinely involved in such studies, the onset time and intensity of DCS symptoms can be annotated with considerable precision. The subjects are briefed on DCS concerns and barriers to report symptoms are removed.

Contrast such studies when studying FAT in real patients occurring randomly around the world. Control of experimental conditions are not practical when studying either FBT and FAT and make them both challenging to study with precision. Unlike diving procedure development that involves healthy subjects studied at altitude, we are trying to study unknown divers, injured in the field with DCI or DCI-like symptoms, undergoing uncontrolled, often poorly documented treatment courses. Even the partial pressure of the oxygen and its duration of application can be suspect. To get to the point, we have to identify divers who definitively have DCS and then precisely record treatment delay and altitude exposure to determine the limits of negative impact. In addition, we still struggle with the definition of DCS especially if very mild or when only constitutional or subjective symptoms are expressed. A subjective improvement of these questionable symptoms over several days involving recompression treatment is sometimes used solely to confirm the diagnosis of DCS. Indeed, a common concern expressed by dive medicine experts conducting manned table development is the diagnosis DCS. Any study will involve cases occurring in a range of medical facilities with information that can be self-reported or even second hand. Not surprisingly, the actual onset, symptoms, diagnosis, diving medical expertise, preexisting conditions and even treatment results including recurrences can be suspect or not recorded. Dive operations and treatment facilities are under no obligation to report injuries. Privacy regulations, communications difficulties, legal concerns impede this vital component for accurate study. This problem when collecting field data is not unique to the study of FAT. For instance, use of monitors that had depth-time recording capability for field dive table testing would be highly efficient and yield considerable precision to table development but suffers from these same dive medicine concerns for accurate data collection.

Diving with Symptoms (DWS) is an unusual practice that has no rational advocacy. It is the diver's personal decision to continue diving even though symptoms of DCI exist. It may be part denial, the desire to push through injury, fear to speak up or jeopardize the diving operation/tempo, or ignorance of the symptoms themselves. Some may be under the grossly mistaken impression that a subsequent, less provocative, nitrox dive with slower decompression/ascent rate may be curative. This is not in-water recompression but a possible method to convert a mild case of DCI to a severe permanent injury. DWS may not be freely reported by the diver when presenting to the physician for definitive recompression therapy unless asked directly about symptoms on previous dives in that series.

Flying Before Treatment is a special category of altitude exposure and perhaps the most distressing for the physician. It is the diver with acute, symptomatic bubble disease going to altitude after onset and theoretically expanding bubbles in tissue as well as decreasing ambient oxygen partial pressure. Yet, Macris has reported the lack of clinically relevant deterioration on short interval commercial flights of less than 2 hours (Mitchell). One could then make the argument that FAT is a less provocative maneuver than FBT since the diver would have received at least one hyperbaric oxygen treatment and a longer PFSI prior to flight and therefore FAT would be less problematic.

Summary of difficulties in studying FAT:

- Proper diagnosis
- Inaccurate timeline
  - Symptom development
  - Treatment delivery
- Prior Diving with Symptoms (DWS)
- Reporting biases-diver, dive operator, associated problems, physicians, etc.
  - Determining a recurrence
- Underlying medical conditions
- Psychologic overlay/internet consultation
- F/u after treatment, flight, recurrence
- Socio-economic factors to get home
- Treatment variability - tables, surface oxygen, medico legal concern to "maximize" treatment
- Agreement difficulties
  - Incomplete/flawed/2nd hand reporting
  - Anecdotal
  - Expert opinion varies
  - Length of flight
  - Actual aircraft ambient pressure

This has led to multiple expert FAT recommendations that range from no delay to six weeks before flying commercially. This startling range has vexed diving medical physicians and best stated by one chamber operator who specifically called for "...some order to this madness."[1] It would be the goal to completely resolve this question but that may not be possible at this time. Instead, describing the factors impacting the injured diver and outlining the pertinent studies should shed some light on the "madness" and help physicians give reasonable advice. But as we all know, patients will sometimes choose not to follow our advice. I was struck by a morbidly obese diver who developed Type 2 DCS who refused treatment in a monoplace chamber, and despite strong advice against leaving, flew on a 14-hour flight back home for treatment that required multiple treatments and permanent neurologic deficit. The recreational diver is burdened by other factors that impact the diver's objectivity when flying after treatment and include:

The emergency during vacation and away from home

1. Need to get back home on time
2. Separation from travel companions
3. Lack of confidence in treatment with a new, unfamiliar health care system
4. Dr. Google's ability to quickly deliver to the patient the most extremes of advice (6 weeks delay FAT) in addition to other lay prognostic information; and torment the traveler "did I wait long enough before flying"
5. Flying commercially can be uncomfortable; sitting, confined and ruminating for hours in flight
6. Preexisting underlying chronic medical conditions (neuro/psych, cardiovascular, musculoskeletal etc.)

Edmonds believed some suffer from a psychoneurotic disorder and Elliot had called "DCS syndrome".[2]

## FLYING AFTER TREATMENT FACTORS IMPACTING PHYSICIAN CONSIDERATIONS

### ALTITUDE

Cabin pressure in a commercial aircraft can be 0.74 atmospheres (8000 ft/2440 m of elevation). Altitude introduces two troubling effects for those with DCI, both decreased pressure and oxygenation. The decrease in pressure may negatively affect bubble size as well as safe, "orderly" inert gas off-loading. That can equate to 35% and 10.6% increases in theoretical spherical bubble volume and radius respectively. The reduction in oxygen partial pressure affects oxygen delivery to the tissues especially in those with certain cardiopulmonary conditions. The positive effects of oxygen that include edema reduction, inert gas off-gassing, tissue oxygenation, neutrophil adhesion inhibition, etc. are reduced.[3]

### CABIN ENVIRONMENT

The cramped seating when traveling can cause anxiety and impact circulatory stasis, especially the lower extremities. Edema, venous thrombosis, nerve compression, etc. has been reported. The full impact and duration of effect of venous gas emboli on the vascular endothelium has not been fully elucidated but may prove to be a factor in thrombus development. The dry cabin air and disruption of daily routine may lead to dehydration. Factors impacted by the duration of flight.

### SEVERITY OF INITIAL SYMPTOMS

A patient with severe DCI who has made recovery after a difficult course, may receive the more conservative FAT recommendation.

### RESIDUAL SYMPTOMS

The hyperbaric oxygen treatment itself may introduce confusion. There is often a slight residual complaint that does not resolve (treatment plateau) or is quite subjective. Flying with such complaint may seem to reappear or worsen during flight and be confused with a recurrence upon landing.

### ALTERNATIVE SEA LEVEL TRANSPORTATION

It seems reasonable that the longer one waits before altitude exposure after treatment for DCS, the better. If there is no compelling reason to fly and the patient can remain or use alternative sea level transportation, then this would be a wise option. Such transportation when feasible can include boat, train, vehicle (may require longer travel routes to limit higher elevations). The desire to

return home and not engaging in "non-productive" vacation time often drives the desire to fly as soon as possible. Increasingly, extended world travel may include a diving expedition followed by travel to higher elevations for hiking adventure.

## FLYING AFTER TREATMENT, RARE

With billions of passengers traveling annually, it is no surprise that there are almost 44,000 in flight emergencies (1 per 604 flights) for a wide range of medical problems. Hypoxia is often implicated in these in-flight medical emergencies. An additional factor is hyperventilation and may be a response mechanism by the victim.[4]

## LENGTHY COURSE

If mild symptoms are treated over several days, one may consider starting the PFSI after the initial treatment.

## DIAGNOSTIC/NEUROLOGIC EXAM

Severe injury noted on exams could be considered in choosing PFSI.

A crucial element in determining the appropriate FAT interval is recognizing actual recurrence. Preventing recurrence drives the determination for minimum PFSI after treatment. There are several important confounding factors to consider:

- Residual symptoms can remain after treatment or plateau, even after repeat follow-on or tailing treatments. These symptoms can improve with the "tincture of time" and so during the PFSI one may observe improvement prior to the flight. Hyperbaric physicians will sometimes break an extended treatment course for a day or two to observe if these mild subjective symptoms improve with time alone before resumption. It also affords a break for pulmonary oxygen toxicity concerns.
- Actual trivial altitude DCS symptoms have plagued research in this area. It has been described that the milder profiles generated the more trivial symptoms, often found to be postural and imaginary even in early studies.[5] It is possible this may occur with a diver recently treated for DCS, been subjected to a relatively eventful experience prior to flight (first aid, medevac, ER in unfamiliar health care system, may be alone, recompression chamber, follow-up, conflicting advice, etc.) and experiencing mild subjective symptoms.
- There is research that is demonstrating symptoms secondary to the effects of hyperoxia on the mitochondria that may manifest as subjective symptoms such as fatigue, mental fogginess, myalgias etc. that resolve with time and could be confused with residual symptoms and inappropriately treated with additional hyperoxia in the chamber (conversation Dr. Piantadosi, ongoing research).
- Hyperventilation does occur to the general flying population for psychologic reasons that include anxiety/phobias and less often, cardiopulmonary response. The manifestations are varied and can range widely from euphoria, unreality, lightheadedness, paresthesia, muscular incoordination, spasm, etc.[6]
- The natural course for the resolution of mild residual symptoms may overlap the flight period and possibly interpreted by physician back home as recurrence.
- Functional symptoms that have been described in aviation personnel in response to traumatic or distressing circumstances. Functional chest pain symptoms have been reported in even air crew that resulted in unnecessary diversions, cardiac catheterization and even self-administered precordial cardiac thump.[7]
- During a 5-year period, 2042 medical incidents occurred. Surprisingly 31% of these calls were neurologic and resulting in over 1/3 of all diversions. Dizziness, vertigo, pain, headache and sensory/motor deficits predominated as presenting symptoms. None were related to a diving injury.[8]
- A condition termed "airplane headache" was coined to describe new onset headache in air travelers thought to be a result of inflammation or reversible barotrauma. Volunteers who experienced such headache also had changes in salivary prostaglandin, cortisol levels and oxygen saturation.[9]
- Actual DCS recurrence during flight has never been definitively explained. Theories include:
  - Edema formation in the injured tissue
  - Hypoxia of marginally oxygenated tissue secondary due to lower ambient pressure
  - Bubble persistence, although unlikely especially after treatment or prolonged surface oxygen breathing.

- The length of the PFSI prior to commercial flight has varied from no delay to 6 weeks.[10] Much is based often based on specific expert opinion that influences chambers around the world. Surveys appear to reflect the influence of that expert opinion and therefore affects expert opinion survey outcomes. Also, those locations requiring the longest flights to return home tend to favor longer PFSI. As discussed earlier, there does seem to be evidence that flights less the 3 hours for those FBT may be acceptable. One might consider the longer the PFSI in an asymptomatic treated diver, the greater confidence that any questionable symptom development would not require recompression therapy. Gorman found that brain function as measured by EEG recovered fully in most divers by one week. Other conditions such as mild pulmonary edema could impact oxygenation while breathing ambient air at altitude. Townsend found that air travel resulted in diurnal rhythm changes for as much as 2 days.

A summary of recommendations from several surveys were summarized.[11]

- DAN interviewed 17 chambers; recommendation ranged 1-7 days with an additional day added for serious DCI cases.
- A DDRC center survey found a range of guidelines, with 1/3 opinion based.
- A DAN anonymous survey of divers found actual PFSI to be 1-3 days other than FAT with symptoms had a significant increase in relapse rate and symptoms lasted longer.
- A study of over 150 cases demonstrated no significant increase in relapse rate at 3 days.[12]
- Three days to seven weeks were found in another study. All were unsatisfied with their recommendation and desired better guidance.[13]
- A 2009 DAN survey of 56 chambers, found that over half advocated a 3 day wait with 11% advocating 1 week. In addition, recommendation for treatment of recurrence was recommended with almost 40% recommending treatment only if symptoms persisted after landing.
- The Standards Association of Australia recommends at least 7 days.
- Four weeks has been advocated with a report of no recurrences after 6 week.[14]
- Even 16 relapses occurring in 89 patients traveling from Thailand, only 2 required recompression and over 50% traveled with residual symptoms.[15]

None of these studies looked at the relapse rate in those that did not have an altitude exposure after treatment.

The survey results of diving medical physicians at this workshop felt that 24 hours was too short an interval even if asymptomatic with most advising 72 hours. One week was the limit of even the most conservative.

## SUMMARY

Determining FAT guidelines is challenging. Factors such as precise diagnosis, treatment outcome, flight related issues, recurrence determination, time interval, remote chamber capabilities and follow-up plague studies. Information from FBT or FAD although quite different may help understand issues involved. Three days appears to be the most widely used interval by diving medical physicians with 1 week still used by some, with evidence that 2 days is the minimum. Length of flight, destination (home) to significant higher elevation, severity of injury and residual symptoms seem to influence recommended stays greater than 3 days. Formal testing (despite well researched tools to quantify relevant personality traits/disorders) of the diver's psychologic make-up was not addressed by any guidelines but may be a factor in some PFSI determination.

There is evidence that FBT commercial flights of 2-3 hours duration have been utilized with success and therefore may have application to FAT. One might consider flight recommendations for urgent FBT to be more concerning than FAT. But, the desire to avoid recurrence after successful treatment is an important consideration and may explain why FAT (an "elective" transport situation) has influenced some treating physicians to elect alternative, sea level transportation.

If the diver is asymptomatic following the use of surface level oxygen only (no recompression) for mild DCS, delaying flight for at least as long as if the diver had been recompressed (FAT) appears to be a rational approach.

Significant residual central neurologic symptoms after treatment might influence the decision by some for a longer period before flying.

Flying in a pressurize aircraft does address the altitude concern but the evac process may be delayed and must be considered as part of the interval before recompression treatment. Providing surface level oxygen or transporting with a hyperbaric stretcher may be of benefit during this interval.

Since surface oxygen is recommended after injury, it seems rational that even a chamber capable of providing only a short shallow oxygen treatment should be considered prior to evacuation. Subsequent necessary, follow-on treatments should be continued and coordinated with the arrival of the evacuation.

The use of inflight oxygen administration for FAT has been used in the past without clear evidence of benefit if normoxic. There is a strong argument for its use when FBT. There is difficulty arranging it through most airlines. FAT as in FBT might be the time to aggressively push hydration. The excess fluid will be dealt with by the kidneys, compel the traveler to get up often and avoid a prolonged seated position with the frequent ambulation required. This will optimize perfusion and possibly oxygenation as well as psychologic well-being.

In conclusion, flying after treatment is a complex evolution with multiple factors to consider. With increased air travel for the purpose of aggressively dive in pristine yet remote dive locations, DCI will continue to occur. Air travel will play an important role in evacuation to receive treatment and safe return home afterwards. As more information is obtained, refinement of flight recommendations for the management of the injured diver will occur. DAN has a formal IRB approved study underway to study Flying After Treatment (FAT) and provide answers to these important issues.

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# WHEN TO RETURN TO DIVING AFTER DCI

John J. Freiberger, MD

This talk is about when a diver should return to diving after experiencing Decompression Illness. To properly discuss this issue I will present the published medical fitness to dive and return to diving after injury guidelines used by the U.S. military, the Association of Diving Contractors International (ADCI), and the International Marine Contractors Association (IMCA). Recreational training agencies, dive trip operators and diving club practices are usually based on a composite of the military and commercial practices, but there is no strict regulatory framework or means of enforcement in the U.S. We will also briefly review some of the statutory issues that concern working divers and their employers because secondary consequences of fitness to dive examinations may have both significant economic as well as career altering consequences. For physicians, The topic of when to return to diving after DCI should be seen as a starting point for developing an overall understanding of the fitness to dive evaluation process and a strategy for appropriate care for candidates who wish to dive.


Figure 1. Organizations impacting diving regulations and recreational diving practices


Figure 2. Categories of rules and regulations

The specific rules that a physician must apply to determine fitness to dive depends on the type of diving and the type of dive candidate that is being evaluated. There are many organizations that either set rules or make recommendations for diving (Figure 1), but in general there are 4 main categories (Figure 2). Due to their different working environments each has slightly different rules and regulations, diver objectives and tasks. Military diving consists of both ship's husbandry and military missions involving underwater operations. Commercial diving is comprised of underwater construction, repair, inspection, and decommissioning of existing oil and gas facilities. Scientific diving is observational and used for data collection from experimentation and marine environmental surveys. Professional divers in the recreational arena perform training and guiding, but, recreational divers themselves perform functions that range from simple to highly complex that may require knowledge and abilities that vary from moderate to extreme when technical, wreck or cave diving is included under the recreational umbrella.

Figure 1 shows some of the groups that make fitness rules. These rules can be described as either descriptive and inclusive or proscriptive and exclusive. Military and commercial fitness to dive standards are proscriptive and exclusive, meaning that there are lists of yes or no questions, boxes to check, and non-negotiable prohibitions. These rules are exclusive and their goal is to simplify, give the best chance for mission success, and to protect companies from liability (Figure 3). In contrast, the recreational fitness to dive process is descriptive. There are no rules or regulations that have the force of statute that apply to recreational divers. Recreational fitness to dive is best practiced when the physician uses the opportunity to discuss with his patient their personal suite of medical risks in the diving environment and a physician's aim should be to teach the diver how to properly evaluate his own personal medical risks. If asked during a recreational fitness to dive examination "am I fit to dive?" an appropriate answer would be "it's always going to be your choice. I can't prevent you from doing whatever you decide is best, however, I can explain how your cardiac disease, your pulmonary disease, your carcinoma, (or other medical condition) impacts on your medical risk. The goal is to educate not regulate.

Performing a useful recreational fitness to dive examination can be challenging. Because of the lack of specific guidelines and the wide range of recreational diver skills and aspirations the spectrum of physical fitness for recreational divers is much wider than that of military or commercial divers. For the most part people with significant medical problems do not choose to dive. However, many do. The percentage of older and less fit recreational divers is expanding as divers certified earlier in life age. At the far end of that less physically fit pole of the spectrum are the divers who dive with the Handicapped Scuba Association (HCA), Diveheart, and other adaptive diving groups. These groups successfully push the fitness envelope and train people whom without their careful support would be entirely unfit to dive. However, with the proper support, and by leveraging the skills of their extensively trained dive buddies, many people with serious medical problems can become "fit to safely dive" as long as they stay within the confines of these well controlled systems. When these candidates actually make it into the water it is life affirming and very gratifying to see the growth in self-image, social confidence and overall physical fitness these programs provide for their participants. Conversely, many technical divers pride themselves on their superior levels of physical fitness and mental prowess. Although this is usually a good thing for challenging high current, cold, closed overhead environments using complex equipment and decompression practices, this attitude may result in a technical diver's grasp exceeding their reach and them becoming exposed to conditions beyond their ability to cope. Therefore a fitness to dive examination for a recreational diver who wishes to experience extreme conditions may require more extensive fitness evaluations than for those planning on diving in more forgiving venues. These divers may also be more likely to have previously experienced DCI requiring a careful review of both past and present physical examinations and medical tests to properly assess the future diving risks for these candidates. Finally, the evaluation physician should make sure he/she is familiar with the scientific basis of the challenges the technical diver will confront to be able to give accurate and relevant advice.


Figure 3. Types of standards for fitness to dive

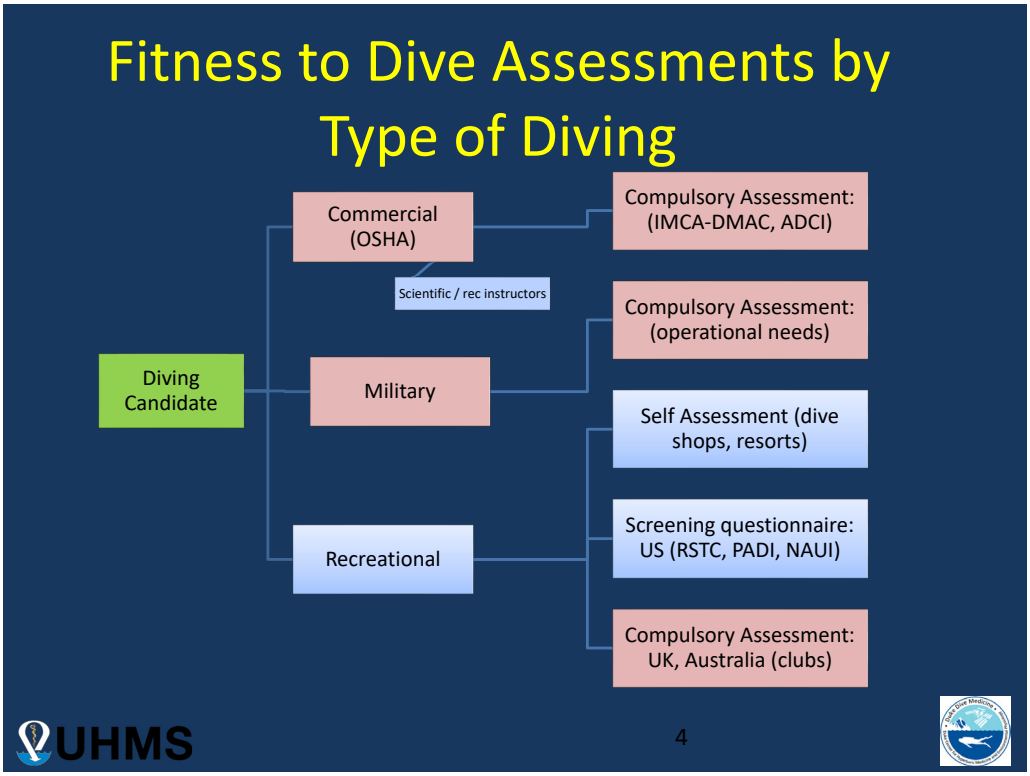


Figure 4. Fitness to dive assessments by the type of diving

No matter how complex their medical histories or their diving aspirations, recreational divers are self-assessed and they are not required to have a medical fitness assessment under U.S. law. This is not the case for OSHA regulated commercial or military divers. To perform a military or commercial fitness to dive evaluation the physician must adjudicate within a specific and well defined standard of care. Figure 4 shows the types of diving candidates categorized by their initial medical evaluation requirements.

Commercial and military divers, (shown in the coral color on Figure 4), require medical assessment both for their initial fitness to dive and for clearance to return to diving after an injury such as DCI. In contrast, because there are no formal rules divers represented by the light blue, (recreational, public safety and scientific divers) are essentially self-assessed. Please note that both scientific divers and recreation dive instructors and guides are exempt from OSHA requirements for any formal medical examinations. Scientific divers and recreational dive instructors all fall under a 50 year old OSHA variance which allows them to avoid taking the yearly dive physicals that are required for commercial divers. Presently, there is a debate about where aquarium workers and public safety divers should fit in this system of categorization. Some liability experts would like to put them under commercial rules meaning that they would be required to spend $500 to $1000 a year to get a commercial diving physical exam, an expense which would be difficult for dive instructors, public safety and scientific candidates to meet. This expense could have the unintended consequence of reducing the pool of available participants or pushing any currently helpful evaluation/education processes under the table. It should be stated that instructors, public safety and scientific organizations are always free to decide whether someone is at too much medical risk to train or participate in diving activities with them.

Military and commercial rules and regulations. For military or commercial divers, the initial and follow up examination and most return to diving decisions after DCI must strictly follow their published guidelines. The process is proscriptive and the candidate must not have any of the conditions defined by the proscriptive list of disqualification questions. The U.S. Navy Diving Manual and USN Manual of the Medical Department (MANMED) are the official sources for the Navy. Because of the large number of candidates available ,the medical fitness rules are strict, but the military may accept

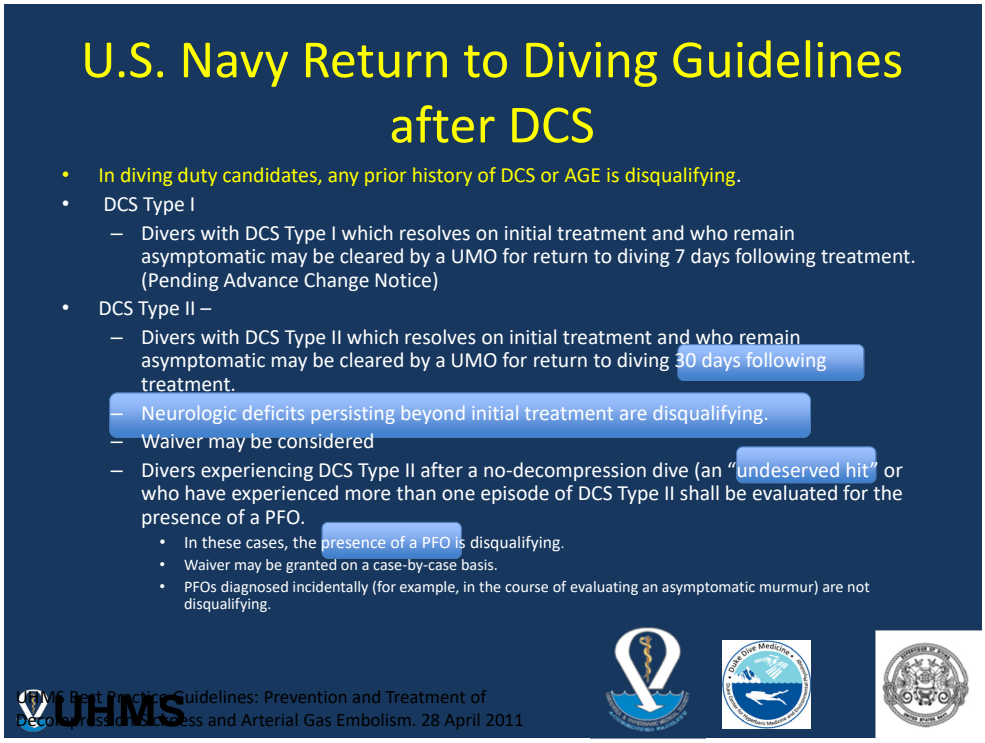


Figure 5a. U.S. Navy return to diving guidelines after DCS

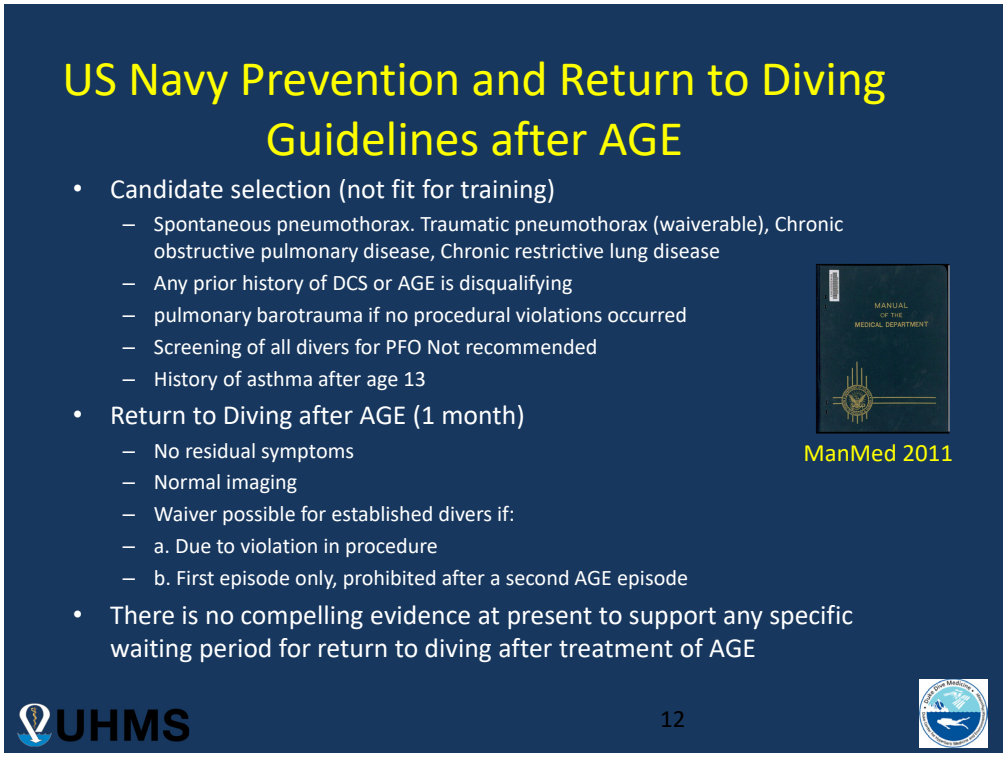


Figure 5b. U.S. Navy return to diving guidelines after DCS and after AGE

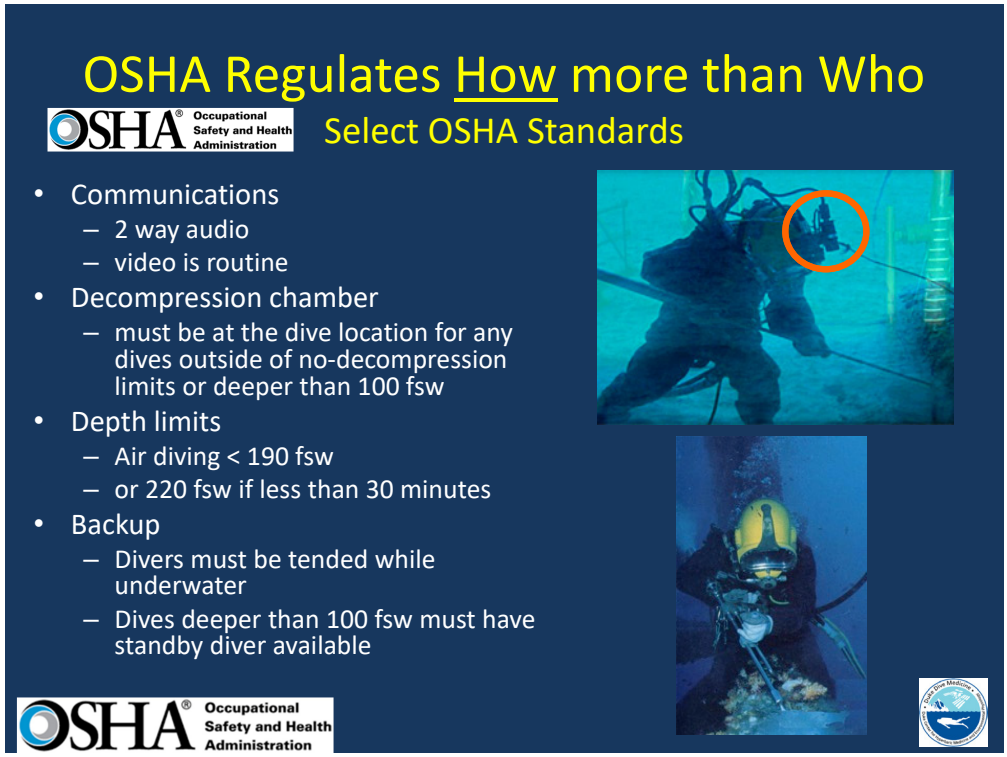


Figure 6. OSHA standards for commercial divers

a higher than allowable medical risk depending on the specific needs of a mission. Figure 5 lists some of the military selection for training and return to diving after DCI rules. Note that diving duty candidates with any prior history of DCS are not accepted for training, even if he/she was injured as a recreational diver long before joining the Navy. However, once the diver is trained, if he/she were to develop DCS they would not be disqualified. Type 1 DCS simply requires a wait of seven days before returning to diving as long as no residual symptoms are present. For Type 2 DCS, the limits are no residuals after treatment and no diving for 30 days. Once symptoms completely resolve, they must also be cleared by a qualified undersea medical officer. Any neurological defects persisting beyond initial treatment are disqualifying. Moreover, divers who experience an undeserved case of DCS (unexpected is a probably fairer way describing it) they must be examined for a Patient Foramen Ovale (PFO). This could be a career-altering test so the assignment of "expected" versus "unexpected" bends cases is critical. Waivers may be available under certain circumstances. Also disqualifying are: a prior history of a spontaneous pneumothorax, prior history of AGE or pulmonary barotrauma and a history of asthma that begins or persists after age 13. Military diver candidates are not routinely screened for PFO. The US Navy's rules regarding return to diving after an AGE are lenient because they recognize that an AGE is primarily an operational error. The US Navy rule published in the 2011 UHMS best practices guideline (https://www.uhms.org/images/DCS-AGE-Committee/dcsandage_prevandmgt_uhms-fi.pdf) states ..."*there is no compelling evidence to support any specific waiting period for return to diving after the treatment of an AGE*." therefore, as long as there are: no residual symptoms and no persistent or intrinsic abnormalities on pulmonary imaging (blebs) the diver may immediately return to duty. This waiver applies for the first AGE episode only. If a second AGE is diagnosed then the diver's military diving career is over.

Commercial diving trade organizations, the ADC and IMCA, the Association of Diving Contractors International and The International Marine Contractors Association ADCI and IMCA publish their rules and regulations in their International Consensus Standards for Commercial Diving and Underwater Operations (https://www.adc-int.org) and in the Diving Medical Advisory Committee (DMAC) proceedings (http://www.dmac-diving.org/) respectively. They work together on regulatory and medical matters, and help their members meet national workplace regulations in member companies. They have no legal regulatory jurisdiction whatsoever, but, their practices, along with those of OSHA, and

## Association of Diving Contractors International (ADCI)

- Consensus Standards for US commercial Diving and Underwater operations
- ADCI hosts the Physician's diving committee
  - No official regulatory jurisdiction
  - But the association ensures that its member companies fully comply with national regulations in effect.
- Medical exam forms used by commercial companies (found online)

*https://www.adcint.org/files/C12181_International%20Consensus%20Standards.pdf*

UHMS

## International Commercial Diving

### International Marine Contractors Association (IMCA)

- International trade association representing 490 offshore, marine and underwater engineering companies.
- Promotes good practice in:
  - health, safety and environmental standards
  - quality and efficiency and technical standards
- Hosts DMAC (Diving Medical Advisory Committee)

IMCA

UHMS

Figure 7 a & b. ADCI and IMCA commercial diving standards


Figures 8. Standards of practice for medical fitness

the US Coast Guard, are used to set the standard of care. Excellent summaries of the Navy, ADCI and IMCA rules can also be found in 2011 UHMS Best Practice Guidelines Prevention and Treatment of Decompression Sickness and Gas Embolism (https://www.uhms.org/images/DCS-AGE-Committee/dcsandage_prevandmgt_uhms-fi.pdf).

OSHA has very little to do with medical issues for divers (Figure 6). OSHA primarily regulates how commercial divers dive more so than who dives. There is little guidance about medical fitness, only about two pages in total length and they don't have much to say about return to diving after DCS, or medical fitness in general.

The ADCI and IMCA are diving industry trade groups. They set the commercial standards of practice for medical fitness. They do that not by lobbying their congressman to write medical fitness laws, but through their practices. "This is what we do with our divers, and we have this safety record, and so we have a standard of care." (Figures 7,8).

Finally, there are some important laws that pertain to liability in the commercial diving setting that should be mentioned. The following is an incomplete a list of statutes that protect commercial divers: The Jones Act, general maritime law of longshore harbor workers, the outer continental shelf lands act, Americans with Disability Act and numerous state laws (Figure 9a)

The Jones Act (Figure 9b) is probably the best known. It's a real benefit for commercial divers, but sometimes causes contention between dive companies and their divers. The Jones Act is 100 years old was originally drafted to protect divers working off the coasts of a foreign countries. It was intended to ensure that these divers would be subject to a consistent set of the laws (including the various coastal U.S. state laws) of the United States and not the laws of the foreign country where the diving occurred. Under the Jones Act any injured sailor is entitled to "maintenance and cure". Maintenance means that full wages, not 60% like disability, but 100% full wages. Cure refers to all medical expenses. This sets up the potential for abuse by both sides. An aging commercial diver without a good retirement plan might be tempted to claim an insignificant injury under the Jones Act. A company that suspects that an employee diver might submit a Jones Act claim might try to unjustly terminate his employment. Situations such as this are not very good for either group. The Jones Act also guarantees the right to a jury trial in Federal

## Liability for Worker's Injuries is Based on Both Statutes and Standards of Practice

- Statutes
  - Jones Act
  - General Maritime Law
  - Long-shore and Harbor Workers' Compensation Act
  - Outer Continental Shelf Lands Act
  - State Law
  - Americans with Disabilities Act

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From B. Delise, JD, 2009

## Jones Act

**Merchant Marine Act of 1920** (P.L. 66-261)

- Maritime Law where US Seaman are covered by US Federal, not local (state or other country) regulations
- Any sailor injured at sea is entitled to maintenance and cure (wages and health care expenses)
  - 100% (not 66% as in workers comp) of past and future medical expenses, lost wages, and pain and suffering
- Guarantees the right to a jury trial in Federal Court
- Applies worldwide even if the accident occurred on land or while the vessel was docked
- Requires negligence (failure of normal ordinary care) that caused damages

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Figures 9 a & b. Liability laws for commercial divers

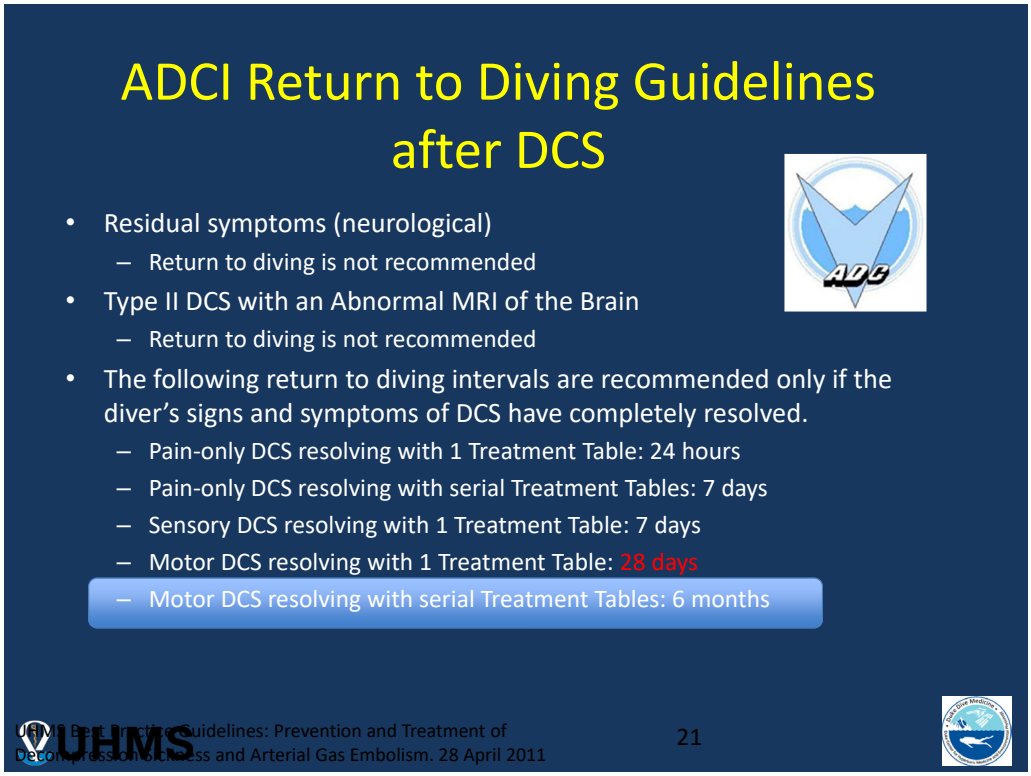

Figure 10. Standard of care determination

court raising the economic stakes for everybody who is involved. Moreover, the Jones Act applies worldwide, even if the accident occurred in land or while the vessel was docked. Therefore, if the sailor gets injured in a bar fight the Jones Act applies. To prevail in a Jones Act claim requires that the company (defendant) be shown to be negligent. Negligence is loosely defined as failure of ordinary care that resulted damages. Usually the degree of deviations from ordinary and reasonable conduct rise to being negligent if it is a deviation from the accepted Standard practices. See Figure 10. What is wrong with this picture? Is that a standard practice? No, it's not. A commercial diver would never be allowed to jump off of a boat or a dock, he would be lowered safely on the diving stage. I put that in as an example of non-standard practice. The determination of standard practice comes from U.S. Coast Guard standards, company operations manuals, industry protocols, and general medical standards. If these are not followed, and argument can be made that there was negligence. Note that the final entry on the list is common sense. Because industry standards are mostly set by the ADCI, or IMCA the circle closes.

Commercial diving consensus standards for diving and underwater operations and diving medical examinations are listed in the previously mentioned ADCI and IMCA publications. Figures 11 and 7 describe some of the functions and attributes of the ADCI and IMCA. Figures 8-13 summarize the return to diving consensus standards.

Note that for neither commercial nor military divers is an examination for PFO is required, initially or annually. Moreover, neither IMCA nor ADCI require PFO evaluations for simple bends cases. However, similar to the Navy, an ultrasound is justified in the case of neuro-decompression sickness without a provocative profile. IMCA rules state that a positive finding is not grounds for disqualification. ADC rules that finding a PFO is grounds for disqualification. This is the only, and probably the biggest different I've found between the two trade organizations. For some reason, ADCI is more restrictive than IMCA there. MANMED says that finding a PFO is grounds for disqualifications, but DMO consultation recommended, and some divers are able to obtain waivers.

A final word. Physicians should read the ADCI and IMCA publications in their original form. The urls are included in this text. The UHMS gives an annual medical fitness to dive course each September in New Orleans. Participants who pass the examination receive a DMAC (IMCA) level 1 certification.



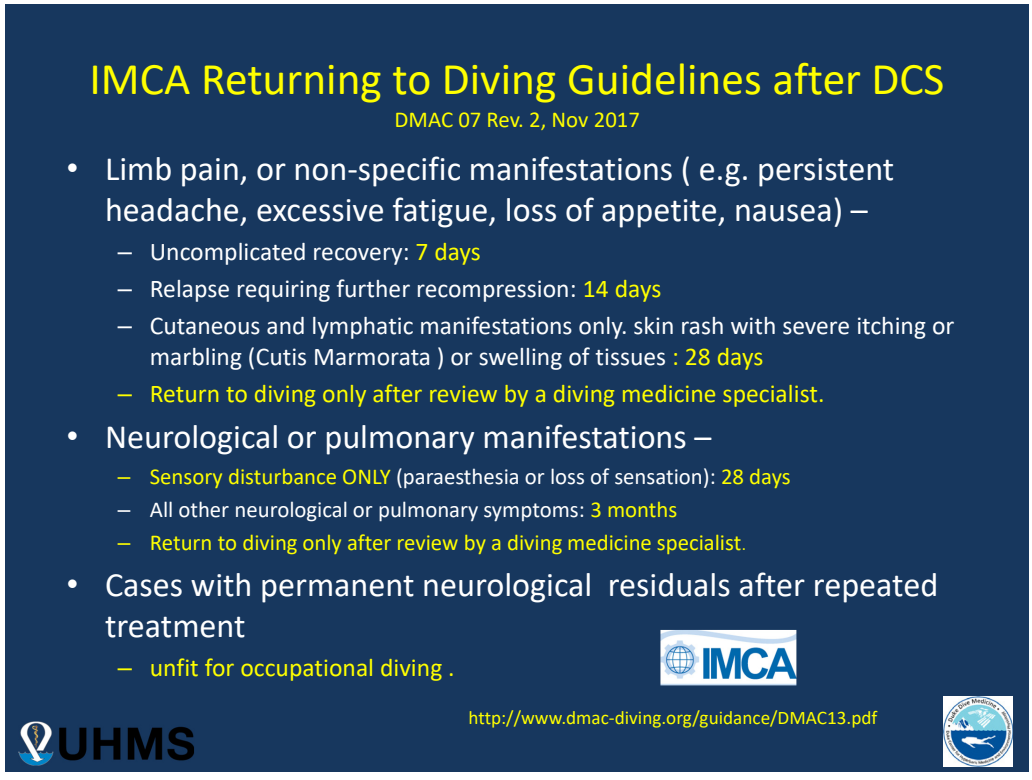




Figure 11. Return to diving guidelines after DCS

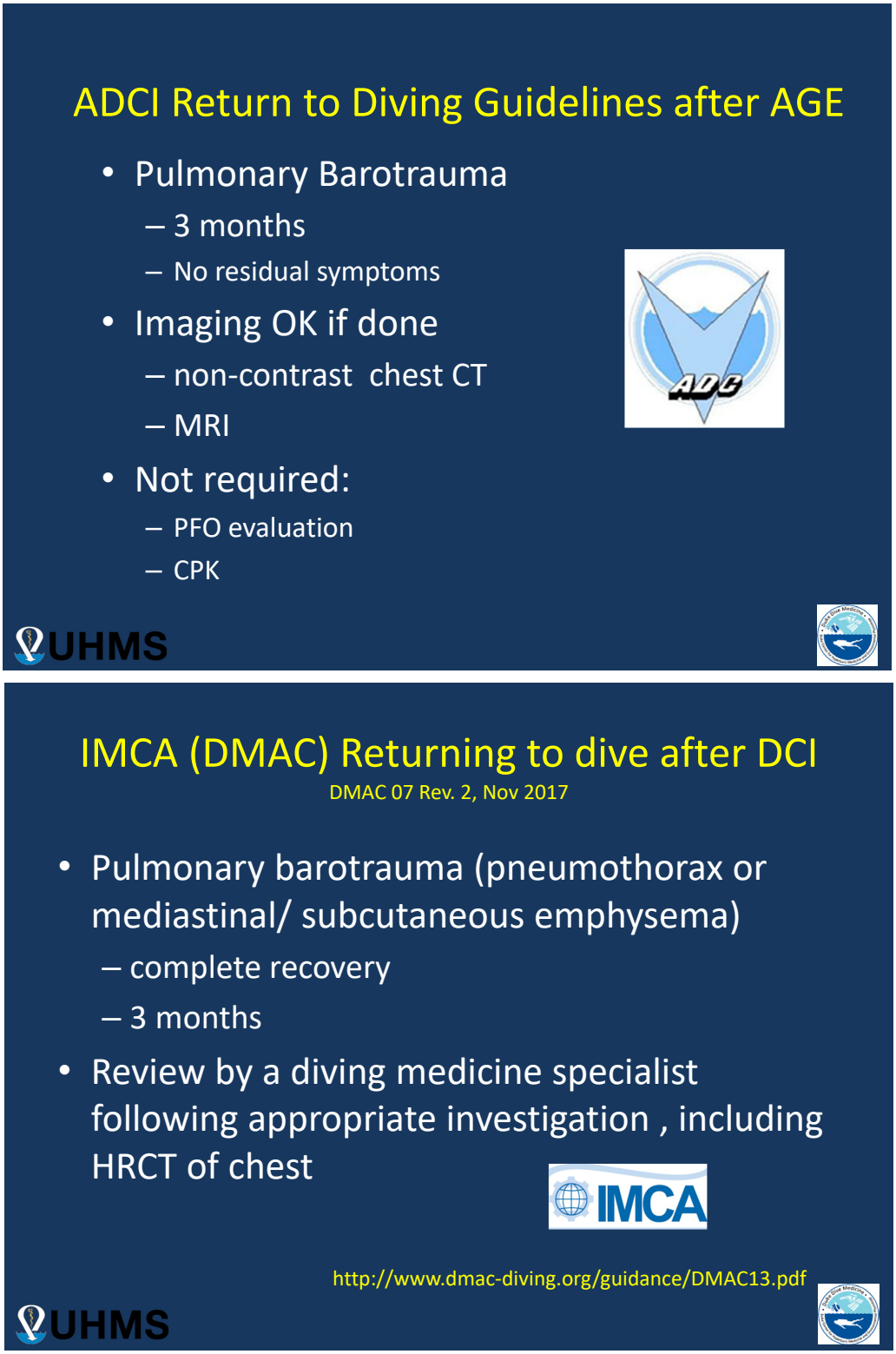



Figure 12 a & b. Return to diving guidelines after AGE

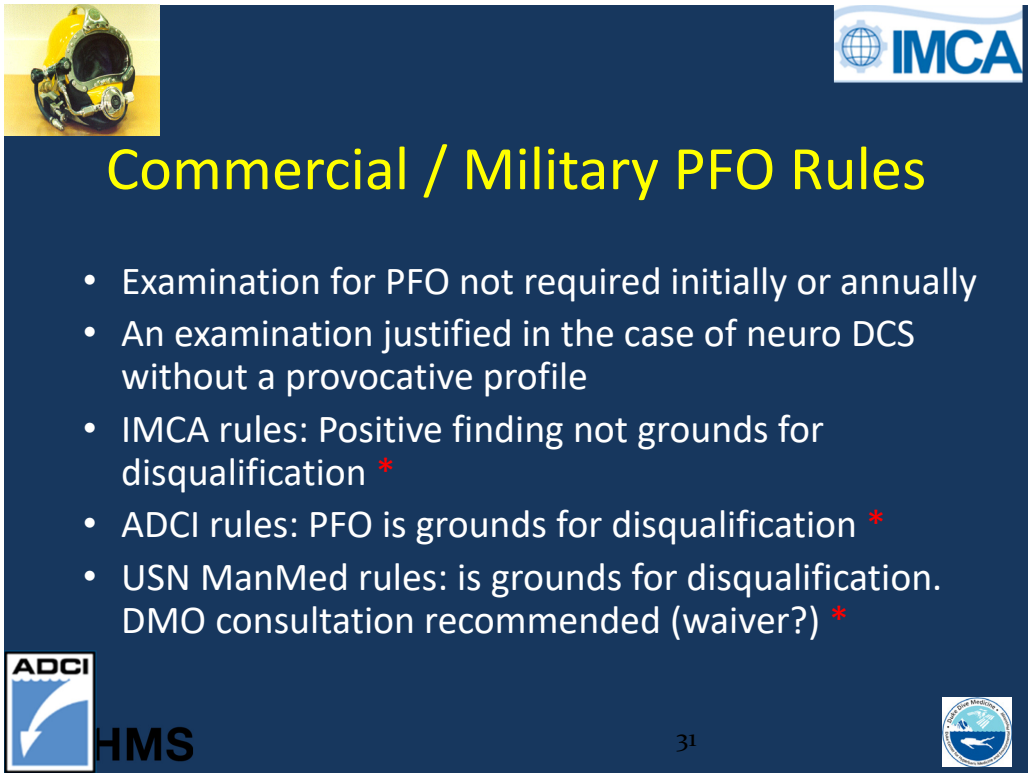



Figure 13 a & B. PFO rules

# DISCUSSION/CONCLUDING REMARKS

## Petar Denoble,MD, DSc, Nick Bird, MD, MMM, FAAFP, FUHM

Petar Denoble:

We are not trying to establish any new consensus because there is still current guidance out there. We are going to collect more data before we can make suggestions for changes. Let us summarize the discussion that we had here. We will try to provide, at minimum a summary, and later with a small working group, maybe to produce the final draft.

Nick Bird:

Thank you to all the speakers and attendees. Petar and I have tried to summarize a few of the take-home points. These are not published consensus guidelines at present. We just wanted to have a summary of the day and hope to encapsulat some of the key points.

At baseline, we have to assume that any treatment process that we talk about is based upon the presumption that we have an accurate diagnosis of DCI.

## CONCENSUS STATEMENTS:

- When available, appropriate, and safe, hyperbaric oxygen therapy ($HBO_2$)should be initiated as close to symptom onset as possible.
- When safe, appropriate, and possible (excluding the scenario where shorter $HBO_2$ table is used prior to evacuation), the initial $HBO_2$ exposure should be a treatment table 6 or its equivalent, with or without extensions. The goal is to achieve optimal treatment results with the first treatment.
- In the case of incomplete resolution upon the first $HBO_2$, consider follow-up treatments with $HBO_2$ up to a clinical plateau. US Navy guidelines recommend treatment to 'plateau plus one' to assure that you've reached a steady clinical state.
    - UHMS guidelines require utilization review for decompression sickness at 10 treatments.
    - In severe decompression sickness, the emphasis should be on lifesaving stabilization and ICU level treatment versus $HBO_2$.

## Summary of Key Points

- Initiate $HBO_2$ as close to symptom onset as is reasonable and safe
- Treat aggressively upfront (TT6 +/- extensions)
- If tailing treatments provided, treat to clinical plateau…+1 to confirm plateau
- In severe DCS, there should be an emphasis on life saving, stabilization, ICU treatment over $HBO_2$

## Summary of Key Points

- Mild, non progressive DCI in remote locations (as defined by 2018 paper on remote mgt of mild/mod DCI), can be treated effectively with $O_2$ and fluids
  - Risks and expenses associated with evacuation exceed the likely benefit from HBO2 after prolonged travel, altitude exposure, and delayed treatment
- If symptoms of suspected AGE resolve with or without surface $O_2$/fluids, most would prefer to treat that person with $HBO_2$ (within ~24h of sx initiation)
- Moderate → severe DCI
  - Consensus opinion is that cases should be treated with $HBO_2$

I hope you will all read these statements with an appreciation that each case is unique. We can all come up with exceptions. For example, a case of mild non-progressive DCI in a remote location can likely be treated effectively with normobaric oxygen and fluids. But I think it's been well expressed in other consensus forums, that in this clinical setting the expense and/or risk associated with evacuation may exceed the potential benefit of $HBO_2$.

If symptoms resolve with or without normobaric oxygen or fluids, but the person still presents to a hospital stating, "Hey, I had some symptoms, but now they have resolved", the consensus opinion is that most of you would be in favor of initiating $HBO_2$, provided that presentation was within a reasonable time frame. Probably somewhere within 24 hours as opposed to, "Last month I had symptoms or six years ago I had symptoms would you treat me today?"

For moderate to severe symptoms, the consensus opinion is that if $HBO_2$ is available, the goal is to urgently initiate treatment or evacuation.

The U.S. Navy Diving Manual has a slightly different approach, but it's important that we provide some balance to the U.S. Navy Dive Manual, which was not written as a guide for civilian chamber operations which may have some flexibility with respect to how patients are evaluated, treated, and potentially evacuated.

Flying after treatment? I hope that provided a reasonable summation of this topic this this morning, and did some justice to the subsequent talks. This is apparent agreement that in the case of moderate to severe DCI, with the plan to evacuate to a definitive treatment center, that the provision of some initial treatment which may include surface level oxygen and fluids, or an abridged hyperbaric treatment, that such interventions should be initiated as soon as possible and appropriate. For people who have achieved clinical plateau and/or resolution with mild-moderate initial symptoms, waiting 3-4 days prior to flying is appropriate and consistent with the current literature. A more challenging area relates to when it is safe to fly following a severe case of DCI where either resolution or stabilization/plateau has been achieved. Timeframes discussed today ranged from about a week to out to about a month. Just recognize that operationally, longer timelines are associated with increased resistance and patient borne expense. It's pretty tough for anybody to spend a month in Australia and provide an evidence based risk/benefit justification when people have mortgages and employment responsibilities.

## Summary of Key Points

- Treatment and evacuation urgency is related to symptom severity
- US Navy Dive Manual provides instructions for USN Diving Operations
- The USN Dive Manual is not written for civilians, but can be used as a guideline
  - The USN Diving Manual provides instructions for USN operators to treat injured divers without a physician present

## When is it Safe to Fly After DCI Tx?

- Following single $HBO_2$ in preparation for evacuation -- fly immediately
- Following clinical plateau / resolution of mild/moderate DCI -- wait 3 - 4 days[1]
- Following clinical plateau with residual symptoms -- wait ~7 - 28 days

1. Slight modification of the wording from Bove and Davis' Diving Medicine (2004) Treatment of DCI, Richard Moon.

Tom Newman:
I like to get a couple of cents into this work. I think Jake said it and our colleague from Japan said it, you said it, but it cannot be emphasized strongly enough unless we're relatively sure of the diagnosis of decompression sickness and or arterial gas embolism, trying to make predictions, trying to make suggestions, trying to make recommendations about what to do with our group of patients. If we don't know who's in that group of patients represents, I don't want to say wasted effort, but near wasted effort.

We simply as a group, and I've said it before, you've said it before, it's been said, but we need to take it to heart now that unless we establish a wicket that we have to go through to get into this whole process, we're going to be stumbling around in the dark for many, many more years.

The other very small point that I would like to make is the business of potentially not treating someone who gets better. I'm very happy with all of those recommendations. As long as we're sure it's decompression sickness, and so to say, "Oh, somebody who's got DCI and they got better, they're completely normal now. I don't need to treat them." I'm very concerned. Somebody who has an arterial gas embolism, showers their brain with balls becomes unconscious and then wakes up and is seemingly normal and six months down the road has a bunch of holes in his brain from those little bubbles that were basically undetectable but in common detectable when higher executive function and personality and things like that aren't working quite right. So I'd be a little nervous about throwing the term DCI in there. As long as it's decompression sickness, no argument there. I'm a little bit nervous about arterial gas embolism under those circumstances. We can agree to disagree.

Nick Bird:
No, no. I just want to be sure that I'm actually the idea that this-

Speaker 5:
Go to the next slide right there. Mild amount progressive DCI in remote locations? No-

Nick Bird:
That was not what you were talking about. Were you talking about the person who …

Tom Newman:
No, it wasn't flying. Okay look … I'm pretty sure you said DCI, but if you …. Have not spoken necessarily …

Nick Bird:
I wanted to be sure that I was clear about this because I've certainly seen and I'm sure what else has people who have had a history which sounds a whole lot like AGE where they have that neurological compromise and suddenly resolved. They walk in right as rain and

we're like, it's certainly concerning and I would rather treat you now versus not treat you. And that was the case that I had in my mind is as I was trying to scribble the summary point. Decompression sickness gives me a little bit more … not quite sure. When did that resolve, what was it, how do you describe, and if it was that mild …

Petar Denoble:
Take, for example, a diver with symptoms that would qualify as a DCS or AGE or DCI, but all symptoms resolved entirely, and the diver has been free of symptoms for a certain time. Now he admits to your hospital, what do you do? I guess, many physicians consider how long patient has been symptom-free, but it is risky to set any specific time limit.

We know of a case where the patient who was treated somewhere and felt back to normal, called to inquire about her insurance policy. Two days later she called again because when she returned to her office, she did not know how to do her job. Her executive functions were affected. But that was not noticed in the initial exam. However, we assumed that the initial exam in qualified hospitals should detect things like that. Maybe not?

Tom Newman:
In general, I don't think it will, but the question is having that person presented initially and so you have the person who comes up from a dive clinical setting that's compatible with the material via symbolism. They lose consciousness for 10, 15, 20, 30 seconds come around, cough up some blood, and then they go to the hospital and you do a pretty thorough motor sensory exam, and it works normal. Again, that to me is somebody who needs to be treated and I wouldn't lump that person in with the same person who comes up from the dive has shoulder pain maybe, and it gets better, and it goes away ,and now they're there. If I don't treat that person, nothing's going to happen. Yeah. There's essentially no rest, but if I don't treat the other person

Nick Bird:
Is this better?

Tom Newman:
Yes, and Did you just have that, or-

Nick Bird:
I did. I no … I just had it. Thank you. Everyone was so in my head that I didn't even write it down, so I appreciate it very much.

Mike Bennett:
Yeah, Mike Bennett here from Sydney. What Tom's worried about, I guess I wasn't worried because my interpretation of that first statement is that that person couldn't possibly be described as mild. I guess it all depends on how we define mild and if we're sticking to the 2004 definition: someone who's been unconscious would not be mild.

Tom Newman:
But they're not unconscious now?

Mike Bennett:
Yeah. I think that's the whole of it, Tom, and we make that pretty clear.

Tom Newman:
That's fine. I really don't mean to get anybodies panties in a wade. I just want to make sure that that's not something that people think, oh, you had symptoms. It's DCI. They've gone away. He's completely in the normal. I don't need to treat that person, and I just want to make sure that that's not the case because I certainly wouldn't consider somebody who loses consciousness as mild symptoms. It's also not, and who wakes up. It's also certainly not decompression sickness.

Petar Denoble:
Yes. Well wait, when we asked in the survey if it was moderate DCS and now symptom-free for 24 hours whether you would treat or not, and most people would not treat. The neurological DCS most would treat, but not everybody. Most of the people would use the table six. So you are right.

Tom Newman:
The point I'm trying to make is this is not the DCS.

Nick Bird:
Right.

Tom Newman:
That's the point I'm trying to make.

Nick Bird:
My apologies as this wording is a little awkward. I just was getting cranked out during the break so it's a quick as I can type, but that's rarely going to have the eloquence of-

Jim Chimiak:
And so you put severe DCS in that same category particularly cause you don't know. It's paradoxical in nature. So you possibly throw that in any category. A showering, cerebral vasculature with VGE. Would you not …

Tom Newman:
The black ones, the black ones, the safest.

Simon Mitchell:
I don't want to derail that line of conversation. Simon Mitchell here. I just wanted to say maybe a lot of efforts gone into defining mild decompression illness, decompression sickness. So actually it's mild decompression almost typically. So you probably should make reference to, you know, mild decompression illness is defined by either … well probably the latest iteration of the guidelines which is the 2018 paper. I mean you just want to reference it that's all cause you don't wanna have to go through, all that nausea here. That wasn't the point of this was it. So … That work's already been done so you might as well cite it.

Petar Denoble:
Yes, I agree with Simon, and the purpose was not to question any of the statements in the consensus of previous meetings. It was just to establish how that was accepted in the community. We have seen that there are still some differences there. So yes, we will refer to previous workshops.

Mike Torrs:
So I think this is important that we do this because I don't know if anybody knows about the recent Minnesota State Supreme Court ruling where a physician did not have to establish the patient relationship to get sued, and it was a mid-level provider who found a physician who told the mid-level provider, and I think some patient had an adverse outcome. They sued the physician who gave that recommendation.

So the more we can do to help that physician who has to do this over the phone because there is no nobody local on site. I mean that was a trained mid-level provider, who did all the standard exams and so forth that is now, and don't even someone take phone call. But that is now this is very important to give them. That was the impetus of the 2004 one that we can give the physician who receives the call actually does something to go to work. But this is very important now, and now the courts and you never know what they do. And in Minnesota, they ruled against the physician now actually what you say over the phone. You don't even have to establish a patient relationship. So at least in that state. So it would be interesting to see if other states follow suit.

Simon Mitchell:
I completely agree. The only point I'd make is that that's exactly what we did two years ago at this thing, so it's being published. It's out there in the literature. You can look it up, the paper is there and the whole idea is to provide an umbrella under which the sorts of decisions we're talking about here can be made with reference to an expert body based practice guideline, so that you're right. You're absolutely right. There's no need of reiteration here. We're not here to re-litigate the prehospital management guidelines. It's done. I think the whole idea of this decision was more about the management as that occurs in the hospital. That's what I thought we'd come to do.

Petar Denoble:
Well, we have just described what we discussed here. That was the purpose of this. I wish we could have a practical algorithm as the one you guys presented for a medical center. We have to understand that physicians in Australia, they have a patient who has to fly back home on the long-range trip. That affects their advice on how long to wait to fly after treatment. The practices around the world vary, and we have to live with that. At least there is convergence toward the table six as a standard initial treatment. For any comparative analysis of different practices, we need more data that we could acquire through broad collaboration.

You know that Michael Bennet and then Simon Mitchell suggested that for better data would be necessary to establish a kind of registry. Now we have at DAN new director of injury surveillance, the preventions that he is a trained epidemiologist with experience in registries in other diseases. So we hope that he will help us to establish a multicentric collaborative study with the intention to get the minimum core data about the DCI that would be used for analysis in the future. There are many obstacles to that, starting with a definition of DCS, DCI

DAN made tremendous improvements in data quality thanks to two new forces there, doctors Matias Nochetto and Jim Chimiak and their team. They now have excellent follow-up and data quality control, but because it is just secondary data, it is not sufficient for comparative efficacy studies. So that is why we believe the more national registers of DCI cases is necessary.

REPRINTED WITH PERMISSION FROM THE UHMS $HBO_2$ INDICATIONS MANUAL
14TH EDITION: CHAPTER 7

# HYPERBARIC TREATMENT FOR DECOMPRESSION SICKNESS: CURRENT RECOMMENDATIONS

Richard E. Moon MD, Simon J. Mitchell MD, MBChB, PhD

## RATIONALE

Decompression sickness (DCS, "bends") is caused by formation of bubbles in tissues and/or blood when the sum of dissolved gas pressures exceeds ambient pressure (supersaturation).[1] This may occur when ambient pressure is reduced during any of the following: ascent from a dive; depressurization of a hyperbaric chamber; rapid ascent to altitude in an unpressurised aircraft or hypobaric chamber; loss of cabin pressure in an aircraft; [2] and during space walks. In diving, compressed gas breathing is usually necessary, although rarely DCS has occurred after either repetitive or very deep breath-hold dives.[3-4] Although arterial gas embolism due to pulmonary barotrauma can occur after a dive as shallow as 1 meter, the threshold depth for DCS in compressed gas diving is around 20 feet of sea water (fsw).[5] DCS after a dive can be provoked by mild altitude exposure, such as a commercial aircraft flight,[6-7] but without a preceding dive the threshold altitude for DCS occurrence in unpressurized flight is 18,000-20,000 ft.[8-9]

Several mechanisms have been hypothesized by which bubbles may exert their deleterious effects. These include direct mechanical disruption of tissue,[10] occlusion of blood flow, platelet deposition and activation of the coagulation cascade,[11] endothelial dysfunction,[12-13] capillary leakage,[14-18] endothelial cell death, complement activation,[19-20] inflammation[21] and leukocyte-endothelial interaction.[22] Recent evidence suggests that circulating microparticles may play a pro-inflammatory role in DCS pathophysiology.[23-24]

The diagnosis of DCS is made on the basis of careful evaluation of the circumstances of the dive (or altitude exposure), the presence of known risk factors, and the post-dive latency and nature of the manifestations.[25-28] DCS manifestations most commonly include paresthesias, hypesthesia, musculoskeletal pain, skin rash and malaise.[25-28] Less common but more serious signs and symptoms include motor weakness, ataxia, vertigo, hearing loss, dyspnea, pulmonary edema,[29] bladder and anal sphincter dysfunction, shock and death.[25-28] Severe DCS may be accompanied by hemoconcentration, hypotension and coagulopathy.[17,30] Severe symptoms usually occur within one to three hours of decompression; the vast majority of all symptoms manifest within 24 hours, unless there is an additional decompression (e.g. altitude exposure).[27] Altitude DCS has similar manifestations, although cerebral manifestations seem to occur more frequently.[27]

Investigations have limited value in diagnosis of DCS. Chest radiography prior to hyperbaric oxygen ($HBO_2$) treatment in selected cases may be useful to exclude pneumothorax (which may require tube thoracostomy placement before recompression). If the clinical presentation is not typical of DCS or notably inconsistent with the circumstances of the dive, neural imaging is occasionally useful to exclude causes unrelated to diving for which treatment other than $HBO_2$ would be appropriate (e.g. herniated disc or spinal hemorrhage). However, imaging studies are rarely helpful for the evaluation or management of DCS.[31-32] Magnetic resonance imaging is not sufficiently sensitive to consistently detect early anatomic correlates of neurological DCI.[33-34] Bubbles causing limb pain cannot be detected radiographically. Neither imaging nor neurophysiological studies should be relied upon to confirm the diagnosis of DCS or be used in deciding whether a patient with suspected DCS needs $HBO_2$.

Improvement of decompression sickness symptoms as a result of recompression was first noted in the nineteenth century.[35] Recompression with air was first implemented as a specific treatment for that purpose in 1896.[36] Oxygen breathing was observed by Bert in 1878 to improve the signs of decompression sickness in animals.[37] The use of oxygen with pressure to accelerate gas diffusion and bubble resolution in humans was first suggested in 1897[38] and eventually tested in the 1930s for human DCS and recommended for the treatment of divers.[39] The rationale for treatment with $HBO_2$ includes immediate reduction in bubble volume, increasing the diffusion gradient for inert gas from the bubble into the surrounding tissue, oxygenation of ischemic tissue and reduction of CNS edema. It is also likely that $HBO_2$ has other beneficial pharmacological effects, such as a reduction in neutrophil adhesion to the capillary endothelium.[40-41] The efficacy of $HBO_2$ is now widely accepted, and $HBO_2$ is the mainstay of treatment for this disease.[27,42-47]

## PATIENT SELECTION CRITERIA

Treatment is recommended for patients with a history of a decompression and whose manifestations are consistent with DCS. $HBO_2$ treatment is recommended for all patients with symptoms of DCS whenever feasible, although normobaric oxygen administration may be sufficient for the treatment of altitude DCS when neurological manifestations are absent, and for mild DCS (as defined below) following diving. For definitive treatment of altitude-induced cases that do not respond to ground level oxygen, and for more serious cases of DCS after diving, $HBO_2$ remains the standard of care.[44-45,48-49]

At a consensus workshop on remote treatment of mild DCS (limb pain, constitutional symptoms, subjective sensory symptoms or rash, with non-progressive symptoms, clinical stability for 24 hours or more and a normal neurological exam), it was concluded that some patients with mild symptoms and signs after diving can be treated adequately without recompression.[50] Thus, although $HBO_2$ remains the preferred intervention in all cases of DCS, not least because DCS may recover more slowly without recompression,[50] it is acceptable to treat cases fitting the mild classification with first aid measures (see below) alone if access to $HBO_2$ is logistically difficult or hazardous. Such decisions should only be made on a case by case basis and must always involve a diving medicine physician.[51]

## CLINICAL MANAGEMENT

**First Aid.** In addition to general supportive measures, including fluid resuscitation, airway protection and blood pressure maintenance, administration of 100% oxygen at ground level (1 atmosphere absolute [ATA]) is recommended as first aid for all cases of DCS. Normobaric oxygen can be definitive treatment for altitude-induced DCS.[51, 52]

The following consensus guidelines for pre-hospital care have been developed by a group of international physicians organized by the Divers Alert Network.[51]

- Normobaric oxygen (surface oxygen administered as close to 100% as possible) is beneficial in the treatment of DCI. Normobaric oxygen should be administered as soon as possible after onset of symptoms.
- Training of divers in oxygen administration is highly recommended.
- A system capable of administering a high percentage of inspired oxygen (close to 100%) and an oxygen supply sufficient to cover the duration of the most plausible evacuation scenario is highly recommended for all diving activities. In situations where oxygen supplies are limited and where patient oxygenation may be compromised (such as when drowning and DCI coexist), consideration should be given to planning use of available oxygen to ensure that some oxygen supplementation can be maintained until further supplies can be obtained.

- A horizontal position is generally encouraged in early presenting DCI and should be maintained during evacuation if practicable. The recovery position is recommended in unconscious patients. The useful duration of attention to positioning in DCI is unknown. The head-down (Trendelenburg) position is no longer recommended in management of DCI.
- Oral hydration is recommended but should be avoided if the patient is not fully conscious. Fluids should be noncarbonated, noncaffeinated, nonalcoholic and ideally an electrolyte-containing oral resuscitation fluid such as WHO oral rehydration solution or Pedialyte™ (but drinking water is acceptable).
- If suitably qualified and skilled responders are present, particularly in severe cases, intravascular rehydration (intravenous or intraosseous access) with non-glucose containing isotonic crystalloid is preferred. Intravenous glucose-containing solutions should not be given.
- Treatment with a nonsteroidal anti-inflammatory drug (NSAID) is appropriate if there are no contraindications.
- Other agents such as corticosteroids, pentoxifylline, aspirin, lidocaine and nitroglycerine have been utilized by suitably qualified responders in early management of DCI, but there is insufficient evidence to support or refute their application.
- Divers should be kept thermally comfortable (warm but not hyperthermic). Hyperthermia should be avoided especially in cases with severe neurological signs and symptoms. For example, avoid exposure to the sun, unnecessary activity or excess clothing.

**Hyperbaric Oxygen.** Recommended treatment of DCS is administration of oxygen at suitable pressures greater than sea level (hyperbaric oxygen). The choice of treatment table and the number of treatments required will depend upon the following: (a) the clinical severity of the illness; (b) the clinical response to treatment; and (c) residual symptoms after the initial recompression. A wide variety of initial hyperbaric regimens have been described, differing in treatment pressure and time, partial pressure of oxygen and diluent gas. Although there are no human outcome data obtained in prospective, randomized studies for the treatment of diving related decompression sickness, broad principles that are generally agreed upon include the following: (a) complete resolution is more likely to result from early hyperbaric treatment;[27,44] (b) the U.S. Navy oxygen treatment tables[49] (and the similar RN and Comex tables), with initial recompression to 60 fsw (18 msw, 2.82 ATA) have been the most widely used recompression procedures for DCS treatment beginning at the surface, and have achieved a high degree of success in resolving symptoms.[27,43,46-47,52-53] Treatment at shallower depths (e.g. 33 fsw, 10 msw, 2 ATA) can also be effective, although published case series suggest that the success rate may be lower at treatment depths less than 60 fsw.[46,54]

**Treatment Depth Exceeding 60 fsw (18 msw).** For the vast majority of cases of DCS, superiority of treatments at pressure exceeding 2.82 ATA or using helium as the diluent gas has not been demonstrated.[55] The speculative use of treatment schedules that deviate from the U.S. Navy oxygen treatment tables or published monoplace tables are best reserved for facilities and personnel with the experience, expertise and hardware necessary to deal with untoward responses.

**Number of Treatments.** Most cases of DCS respond satisfactorily to a single hyperbaric treatment, although repetitive treatments (typically once daily) may be required depending on the patient's initial response. For patients with residual deficits following the initial recompression, repetitive treatments are recommended until clinical stability has been achieved. $HBO_2$ should be administered repetitively as long as stepwise improvement occurs, based upon clearly documented symptoms and physical findings. The need for such follow-up "tailing" treatments should be supported by documentation of the clinical evaluation before and after each treatment. Complete resolution of symptoms or lack of improvement on two consecutive treatments establishes the endpoint of treatment; typically no more than one to two treatments.[27] The optimal choice of recompression table for repetitive treatments has not been established. It is generally agreed that for tailing treatments, repetitive long treatment tables (such as the U.S. Navy Table 6)[49] are not justified, and it is typical to utilize shorter treatments (such as the U.S. Navy Table 5)[49] or even wound treatment tables conducted at 2-2.4 ATA for this purpose. Although a small minority of divers with severe neurological injury may not reach a clinical plateau until 15-20 repetitive treatments have been administered, formal statistical analysis of approximately 3,000 DCI cases supports the efficacy of no more than 5-10 repetitive treatments for most individuals.[56]

**Time from Symptom Onset to Hyperbaric Treatment.** Available data do not convincingly demonstrate superior outcomes in "rapid" vs. delayed treatment.[53,57] For example, in two published series, time to treatment greater than 24[47] or 48[46] hours was as effective as earlier treatment. However,

most series in recreational diving lack cases with extremely short symptom-to-recompression latency as comparators. In contrast, there are data from military experimental diving, which suggest immediate recompression is extremely effective in controlling symptoms.[43,58-59] As a general principle, timely treatment is preferred. Currently available data have not established a maximum time (hours or days) after which recompression is ineffective.[59-65]

**Monoplace Chamber Treatment.** Monoplace chambers were originally designed for the continuous administration of 100% oxygen and were not equipped to administer air for "air breaks," which are incorporated in U.S. Navy treatment tables for DCS. For monoplace chambers of this type, tables are available for treatment of decompression sickness that are shorter than standard USN treatment tables.[66-68] Retrospective evidence, using telephone follow-up, suggests that such tables may be as effective as standard USN tables for the treatment of mildly or moderately affected patients.[42,69-70] However, many monoplace chambers are now fitted with the means to deliver air to the patient, and thus can be used to administer standard 2.82 ATA USN treatment tables.[71]

**Saturation Treatment.** For severe DCS in which gradual but incomplete improvement occurs during hyperbaric treatment at 60 fsw, saturation treatment may be considered if the hyperbaric facility has the capability. There is, however, no convincing evidence that such interventions are associated with a better outcome than other approaches.

**In-Water Recompression.** In-water recompression (IWR) of injured divers has been proposed as an emergency treatment modality if evacuation of a symptomatic diver to a hyperbaric facility cannot be performed in a timely manner. The advantage of IWR is that it can be initiated within a very short time after symptom onset. IWR breathing air has been used by indigenous divers with a high reported success rate, although clinical details are scant.[72] There is anecdotal evidence that IWR using oxygen is more effective.[73] However, a major risk is an oxygen convulsion resulting in fatal drowning. IWR using oxygen has been discussed in the literature[51,73-74] and is described in the *U.S. Navy Diving Manual.*[49] Typical IWR oxygen-breathing protocols recommend depths no greater than 30 fsw (USN) or shallower.[73] Recommendations include a requirement that the diver not use a regular scuba mouthpiece but rather a full face mask, surface-supplied helmet breathing apparatus or regulator retention strap ("gag strap").[75] Other requirements include the need for a tender in the water and the symptomatic diver to be tethered.[73] IWR is not recommended or may cause harm in the setting of isolated hearing loss, vertigo, respiratory distress, airway compromise, altered consciousness, extreme anxiety, hypothermia and hemodynamic instability.

In the absence of a sufficiently detailed case series from which risks and benefits can be assessed, IWR is not presently endorsed by the UHMS but was cautiously endorsed in a recent expert consensus for use by properly trained and equipped divers.[51] It should not be attempted without the necessary equipment, training and a full understanding of the necessary procedures.

**Altitude DCS.** The following algorithm has been used effectively by the U.S. Air Force.[44,76]

- Mild symptoms that clear on descent to ground level with normal neurological exam: 100% oxygen by tightly fitted mask for a two-hour minimum; aggressive oral hydration; observe 24 hours.
- Symptoms that persist after return to ground level or occur at ground level: 100% oxygen; aggressive hydration; hyperbaric treatment using U.S. Navy (USN) Treatment Tables 5 or 6, as appropriate. For individuals with symptoms consisting only of limb pain, which resolves during oxygen breathing while preparing for hyperbaric treatment, a 24-hour period of observation should be initiated; hyperbaric therapy may not be required.
- Severe manifestations of DCS (neurological, "chokes", hypotension or manifestations that progress in intensity despite oxygen therapy): continue 100% oxygen; administer intravenous hydration; initiate immediate hyperbaric therapy using USN Treatment Table 6. Recompression to 2 ATA (USAF Table 8) has also been used effectively for altitude DCS.[77]

**Adjunctive Therapy.** Adjunctive treatments such as first-aid oxygen administration, fluid resuscitation and for patients with leg immobility, venous thromboembolism prophylaxis, are indicated. These are discussed in detail in a separate monograph,[78] which is available on the Undersea and Hyperbaric Society website (www.uhms.org/images/Publications/ADJUNCTIVE_THERAPY_FOR_DCI.pdf).

Table 1. Evidence-based Review of Adjunctive Therapies for DCS
(from Moon:[78] www.uhms.org/images/Publications/ADJUNCTIVE_THERAPY_FOR_DCI.pdf)

| | Condition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | AGE (no significant inert gas load) | | DCS: pain only/mild | | DCS: neurological | | DCS: chokes (cardiorespiratory) | |
| | Class | Level | Class | Level | Class | Level | Class | Level |
| Surface $O_2$ (1 ATA) | I | C | I | C | I | C | I | C |
| Intravenous Fluid Therapy | D5W[†] III<br>LR/crystalloid[‡] IIb<br>Colloid[!!] IIb | C | D5W[†] III<br>LR/crystalloid[‡] I<br>Colloid[!!] I | C | D5W[†] III<br>LR/crystalloid[‡] I<br>Colloid[!!] I | C | D5W[†] III<br>LR/crystalloid[‡] IIb<br>Colloid[!!] IIb | C |
| Aspirin | IIb | C | IIb | C | IIb | C | IIb | C |
| NSAIDs | IIb | C | IIb | B | IIb | B | IIb | C |
| Anti-coagulants* | IIb | C | III | C | IIb[§] | C | IIb | C |
| Cortico-steroids | III | C | III | C | III | C | III | C |
| Lidocaine | IIa | B | III | C | IIb | C | III | C |

[§]For decompression illness with leg immobility, low molecular weight heparin is recommended as soon as possible after injury (enoxaparin 30 mg or equivalent, subcutaneously every 12 hours).
[†]5% dextrose in water.
[‡]Lactated Ringer's solution, normal saline or other isotonic intravenous fluid not containing glucose.
[!!]Starch, gelatin or protein fraction with isotonic electrolyte concentration.
*Full dose heparin, warfarin, thrombin inhibitors, thrombolytics, IIB/IIIA antiplatelet agents.

## EVIDENCE-BASED REVIEW

The use of $HBO_2$ for decompression sickness is an AHA level I recommendation (level of evidence C). A number of adjunctive therapies have been used for the treatment of DCS (see Table 1) and discussed in the Report of the Decompression Illness Adjunctive Therapy Committee of the Undersea and Hyperbaric Medical Society.[78] These guidelines can be accessed via the internet at www.uhms.org/images/Publications/ADJUNCTIVE_THERAPY_FOR_DCI.pdf.

## UTILIZATION REVIEW

Utilization review should occur after 10 treatments.

## COST IMPACT

Only those people exposed to increased ambient pressure (divers or compressed air workers) or who suffer decompression sickness at altitude are affected. Because there are relatively few individuals who develop this condition, the application of $HBO_2$ will be limited. $HBO_2$ is a treatment that usually provides resolution or significant improvement of this disorder that can otherwise result in permanent spinal cord, brain or peripheral nerve damage or death, and is therefore an exceptionally cost-effective treatment.

## NOTE:

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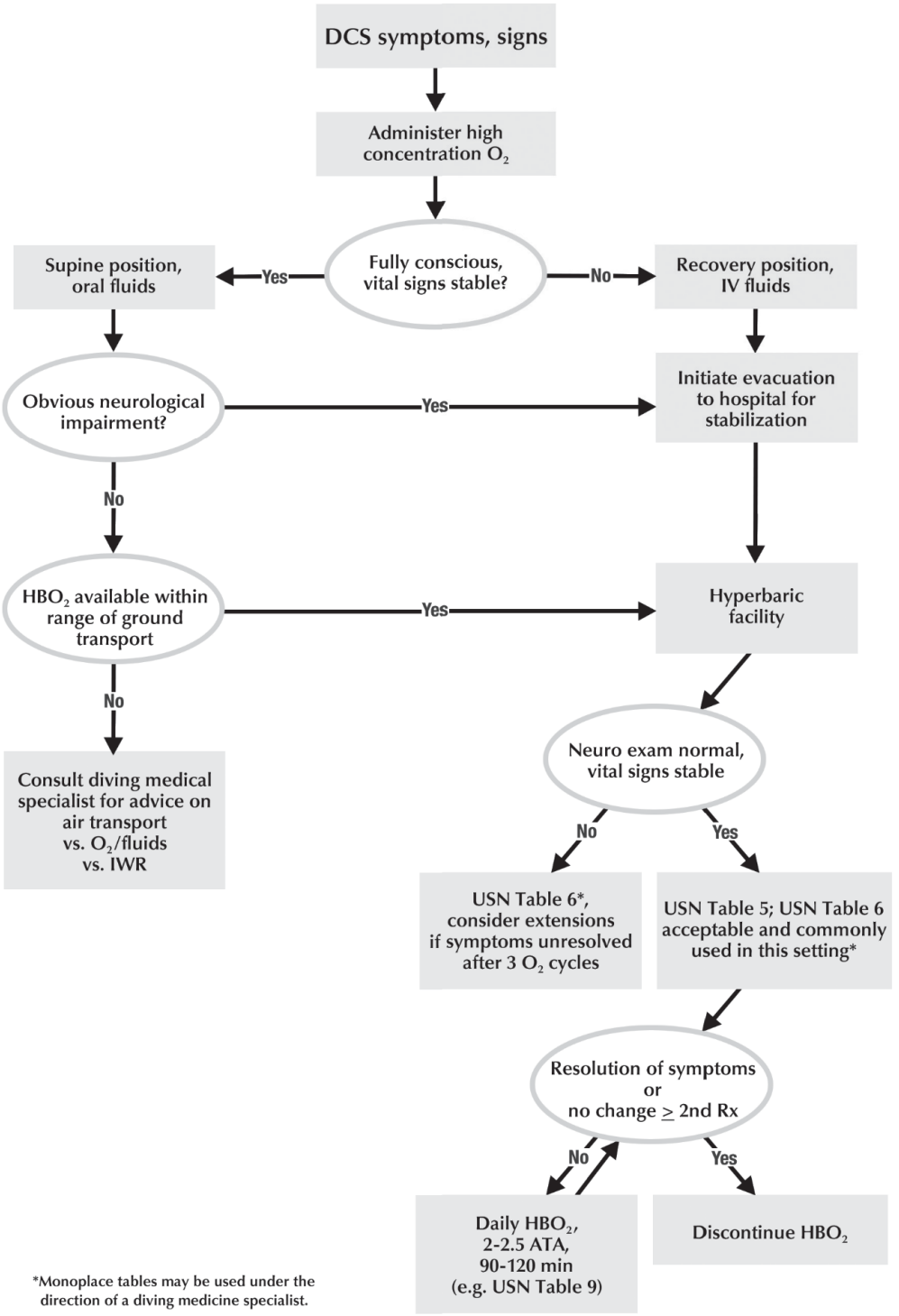
Figure 1. Flowchart for DCS Symptoms
Details of management are described in the text.




*Monoplace tables may be used under the direction of a diving medicine specialist.

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