CHAPTER 2

DECOMPRESSION SICKNESS IN INSIDE ATTENDANTS

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WHAT IS DECOMPRESSION SICKNESS?

Decompression Sickness (DCS) Defined: DCS is an illness that occurs when environmental pressure is reduced sufficiently to cause gases that are dissolved in body tissues to evolve as bubbles. Primarily consisting of nitrogen, the bubbles evolve from solution when the inside attendant surfaces too fast for the body to compensate. Patients do not have the problem because the oxygen they breathe during hyperbaric oxygen treatment eliminates the nitrogen from their bodies.

Signs and Symptoms of DCS: Bubbles that cause DCS can form in all parts of the body and the anatomic location accounts for the variety of signs and symptoms. (1) DCS can manifest itself from minor to life-threatening symptoms. Minor skin itching or tingling usually passes within 20 to 30 minutes, and no treatment is necessary, all other forms of DCS are treated in the hyperbaric chamber with immediate compression and hyperbaric oxygen. "Bends pain" seen in about 90% of cases, may appear anywhere in the body, but is more frequent in legs or arms that were exercised during the exposure. Neurologic symptoms involving the brain or spinal cord occur in about 25% of cases, and are manifested by a wide variety of symptoms but mainly by headache, numbness, paralysis of an arm or leg, loss of sensation, vertigo, visual distortions or blindness, and extreme fatigue. Chokes is a rare but life-threatening respiratory disorder caused by gas emboli in the lungs, and manifested by wheezing, chest pain, or troublesome cough. Also rare is the circulatory impairment (shock) that is a consequence of chokes, severe bends, or severe neurological impairment.

Predisposing Environment: DCS rarely occurs among inside attendants unless one of the following environmental conditions exist: (1)

- The attendant dives or completes chamber pressurization greater than 10 m (33 ft) of seawater and returns to atmospheric pressure after an inadequate decompression schedule
- The attendant is exposed to an altitude greater than 5,490 m (18,000 ft) following loss of aircraft pressurization
- The attendant is exposed to altitude shortly after a hyperbaric chamber exposure or scuba diving (i.e., flying after diving)
- The attendant has predisposing risk factors for DCS (e.g., increasing age, heaving work at pressure, dehydration)

POTENTIAL FOR DECOMPRESSION SICKNESS: WHY DECOMPRESSION IS REQUIRED

To understand why a decompression schedule is required, one must review the physiological basis of the decompression tables. An excellent review of decompression theory by Hempleman can be found in the Physician's Guide To Diving Medicine. (2)

Nitrogen Uptake and Elimination: When the inside attendant is pressurized in the chamber, the partial pressures of all inhaled gases are increased as the total pressure is increased. This increases the amount of nitrogen that is taken into the body. The body continues to store nitrogen as long as the attendant is inside the chamber. The quantity of nitrogen that can dissolve in tissue is directly proportional to the nitrogen partial pressure. The amount of nitrogen distributed to the various body tissues depends on perfusion (blood supply) and amount of lipids (fat) in the tissue. Thus, nitrogen is not distributed evenly throughout the body tissues.

As the attendant decompresses, some of the nitrogen diffuses into the blood, travels to the lungs, and is exhaled from the body. Nitrogen that remains in the body can form bubbles if the barometric pressure is lowered faster than the body can compensate. A condition called supersaturation occurs on ascent when the tissue nitrogen pressure (PN_2) is greater than the ambient pressure (PB). There is apparently a level of supersaturation that the body can tolerate without causing bubbles. However, once critical supersaturation is reached, bubbles form. Bubbles have been observed in veins, arteries, lymphatic vessels and tissue spaces. Further reduction in barometric pressure causes the bubbles to enlarge and coalesce, leading to DCS.

DECOMPRESSION PROCEDURES

For safe decompression to surface, inside attendants use a number of decompression tables. Since the tables were originally developed for divers, they are often called “dive decompression tables.” So far as decompression is concerned, there is little basic difference between an actual dive and exposure to air in a hyperbaric chamber.

Decompression Tables: In the early 1900s, J. S. Haldane was commissioned by the Royal Navy to make a thorough study of the physiology of diving and to develop a rationale for safe decompression. Haldane and his associates (3) developed the stage decompression method which involves ascending at a fixed rate from bottom to a decompression stop at some shallower depth and then spending a given period of time prior to ascent to the next shallower depth.

In calculating his tables, Haldane and his associates considered that the rate of nitrogen uptake or elimination depended on the nitrogen gradient between tissue and the lung, and would vary by body area due to differences in fat content and blood flow. They developed a decompression schedule on the assumption that the body was a series of mathematical compartments with half times of 5, 10, 20, 40, and 75 minutes. Their concept was that a 5-min tissue compartment would require 30 minutes (6 half-times x 5 min) to become 98.5% desaturated, and a 75-min tissue compartment would require about 7.5 hours (6 half-times x 75 min). The U.S. Navy later added a 120-min half-time rate, which would desaturate in 12 hours (6 half-times x 120 min).

The Haldane concept was that the ambient pressure (PB) that can be attained on ascent depends on the PN_2 in each tissue compartment and the rate that the nitrogen can be eliminated. A critical supersaturation ratio of PN_2/PB was established that could not be exceeded during ascent. Ascent occurred in stages so as not to exceed the critical supersaturation ratio. The Haldane model was used to develop the U.S. Navy Standard Air Decompression Tables, (4) although several refinements have since been made to them. There are more half-time tissues and each has a different critical supersaturation ratio. The decompression tables are designed so that the diver must schedule stops during ascent so as to avoid any tissue from reaching its critical supersaturation ratio. Continued ascent after the critical ratio is reached risks the formation of bubbles and, consequently, DCS.

Many decompression tables are available to the attendant. Some are modifications to the U.S. Navy Standard Air Decompression Tables in an attempt to make them more conservative. Others have been developed independently. Some examples are British Sub-Aqua Club Tables, Canadian Tables, French Navy Tables, Huggins Tables, NAUI Tables, NASDS Tables, PADI Tables, Royal Navy Tables, Swiss Tables, and U.S. Air Force Tables. As of this writing, these are the tables principally used by scuba divers and inside attendants. Each table has a different algorithm, thus they have different degrees of safety and are not interchangeable. One must select a table and stick with it!

Each decompression table provides a method for accounting for the residual nitrogen that remains in the body after completing a dive or pressurization. During the surface interval between repetitive exposures, residual nitrogen continues to leave body tissues. To determine a proper decompression schedule for a second exposure, one must consider the residual nitrogen still remaining in the body from the first exposure. Each table tries to provide a safe method of decompression for the majority of people. Since the anatomy and physiology of each person is slightly different, it stands to reason that not all people can safely decompress on each and every table. Furthermore, even though a person has used a table successfully in the past does not guarantee that DCS will not occur in the future. Even though the tables are properly used, an occasional diver on inside attendant will experience DCS.

Dive Computers: Dive computers are designed to replace the decompression tables. They are excellent dive recording devices because they precisely follow the dive profile. Like the tables, each computer uses a different algorithm, thus having different degrees of safety. Dive computers are especially popular among recreational scuba divers because they are easy to use and usually allow more time in the water with no decompression obligation. As of this writing, recreational scuba divers are using dive computers in increasing numbers, but hyperbaric chamber operators rarely use them.

CARE OF THE ATTENDANT WITH DCS

Consultation: Since DCS is rare, some hyperbaric physicians may be in practice for several years without treating a case. Those with limited experience will find it important to consult with other hyperbaricists who have experience in diagnosing and treating the disorder. An excellent source of consultation is the Divers Alert Network (DAN) located at Duke University.

As of this writing, the 24-hour diving hotline for help in diving emergencies can be reached at +1-919-694-4326 or +1-919-684-8111 and ask for the Diving Medicine Physician on call. Additionally, DAN maintains a worldwide list of hyperbaric referral centers. Other DAN organizations are located in Europe, Japan, South Africa, and Southeast Asia Pacific.

Diagnosis: Early recognition and treatment is paramount in quick recovery from DCS. Early diagnosis of the illness is possible only if hyperbaric attendants are adequately trained in how to recognize DCS symptoms, and are willing to report them to the hyperbaric physician. Assessment will most likely include a review of the patient's diving medical history, screening for DCS risk factors, neuropsychological testing, and investigation for underlying pathology. The presenting signs and symptoms are often subtle and vague, making diagnosis of the side of diagnosing and treating the disorder. Standard medical procedures for maintaining confidentiality and privacy must be provided for the stricken attendant.

Hyperbaric Oxygen Therapy: Once DCS is diagnosed, the patient is treated in the hyperbaric chamber with pressure, oxygen, and fluids. Sometimes multiple treatments are required, particularly if there was a delay in reporting the symptoms. Sometimes emotional support is also required. In most instances, the stricken attendant will be able to resume chamber duties after an adequate recovery period. If predisposing factors for DCS are disclosed, then the risks must be evaluated before the stricken attendant can resume pressure exposures.

Case Report: The two case reports below illustrate the diverse presentation of DCS. Both occurred in nurses with considerable experience as inside medical attendants. In Case 1, it was difficult to identify the specific pressurization profile that resulted in DCS, so the assessment included an extended history leading up to the event. In Case 2, the diagnosis of DCS was easily made immediately following the exposure.

Case 1

Neurological symptoms of DCS. Eleven-day history leading up to DCS diagnosis:

Day 1 1.3 ATA for brief exposure before treatment was aborted due to patient having difficulty clearing ears; 3-hour surface interval; 2.4 ATA for 60 minutes followed by 30-minute oxygen decompression.

Day 2 25 hours surface interval; 2.8 ATA for 60 minutes followed by 30-minute oxygen decompression.

Day 3 Slept

Day 4 36-hour surface interval from last dive; 2.8 ATA for 60 minutes followed by 30-minute oxygen decompression that included a decompression stop at 1.3 ATA.

Day 5 "The next day I woke up with the flu. I went to work and felt terrible. Most of the week was hazy. I was sick, I had the flu. I told myself a hundred times. As the week went by, I slowly improved. In retrospect, I was pathetic. It took me six hours to compose a two-page letter."

Day 6 "On the weekend I took myself off call. Now the flu and sleeping on my arm had made my arm sore. I felt better by Monday, just tired. They needed me to dive again."

Day 8 2.8 ATA for 60 minutes followed by 30-minute oxygen decompression (hard working treatment with critically ill patient). "Got home later that night and was knackered, nothing else, just tired. The next morning (Day 9) I woke up feeling sick, sick, sick! Struggled through work and went to bet early. The next morning (Day 10) my bed did not allow me to get out of it. I was chained to the mattress. I had pain in my shoulder and elbow. I find myself crying. I never cry! This is weird. I went to work the following day (Day 11) and want to speak to the charge nurse, she is in the chamber! Finally, I speak to her and my suspicions are confirmed. Into the chamber I go. I couldn't control the tears. I was on an emotional roller coaster for days. I had to keep showing the nurses what to do. I was supposed to be the patient!"

"After eleven days, eleven treatments, admission to the hospital, and a lignicaine (Lidocaine) infusion my brain functions! When can I go back into the chamber? I loved that job. Now I can't fly. There goes my holiday to the Greek Isles and I missed the bar-b-que on the weekend (elevation too high). Sometimes I still think it was that special flu that responds to hyperbaric. I am thankful to the dedicated staff of the hyperbaric unit that helped me and persevered with treatment even when it looked like there was no improvement."

CASE 2
Bends pain of DCS.

> Arm pain became evident upon decompression from a 2.8 ATA treatment for 60 minutes with a 30 minute decompression breathing oxygen. the nurse was immediately diagnosed and treated by compression on a U.S. Navy Treatment Table 6. The nurse developed pulmonary oxygen toxicity but with medication was able to complete the treatment. After a night's hospitalization and a 2.8 ATA follow up treatment, the nurse had no more arm pain.
>
> "I felt embarrassed to have to report it. All of a sudden I just wanted to curl up and be left alone. It was difficult to take on the patient role. I really needed to be cared for. I was tired and miserable and didn't want to be here (in the chamber). I was so emotionally labile. After I was "unsymptomatic," no arm pain, and my treatment was complete, I felt exhausted, irritable, lacked concentration, and was emotionally labile. I was frustrated with feeling this way."

Recurring Theme in Attendant DCS: Although these are experiences of just two nurses, the author (C. J. Pirone) has witnessed similar stories from other nurse attendants over the years.

There are several recurring themes in attendant DCS. Firstly, there is a reluctance to admit to self or others that the attendant has DCS. This is not unique to hyperbaric attendants but they generally are well trained to recognize this phenomenon. The subtle symptoms of DCS, are often mistaken for other injuries or illnesses. Attendants also are quick to blame self, therefore guilt may accompany their reluctance to report the illness.

Secondly, emotional liability is frequent and can last beyond the physical aches and pains. In addition to the focus on signs and symptoms, there is a pressing need for the attendant's emotional needs to be cared for. It is often difficult for the attendant be a patient in the chamber where he or she has served as an attendant. Having experienced DCs, one attendant noted that the literature was silent about the experience of the patient after experiencing DCS, even though it is not uncommon for these patients to have residual symptoms.

Thirdly, there is an impact on the other staff members, each reacting differently to the situation. While the staff recognizes and treats the illness, they may also deny the authenticity of the diagnosis due to the "safe" decompression tables upon which the event occurred. There is the question of how it occurred. Where all the protocols followed? There is the feeling of concern for a fellow staff member and self-examination of "could this have been prevented?" There is also the relief that "it didn't happen to me" coupled with the realization that "it could have happened to me." The staff's reaction to the illness affects the dynamics of the hyperbaric team.

THE PREVALENCE OF ATTENDANT DCS

Attendant Exposures During Patient Treatment Profiles: The patient treatment profiles vary by institution. Following are some profiles to which the inside attendant is commonly exposed in clinical hyperbaric facilities:

1. For Decompression Illness: USN TT5, USN TT6, USN TT6A, RN62 (see Table 2 for times of exposures).
2. For CO poisoning: descend in 5 min to 3 ATA, remain for 51 min, ascend to 2 ATA in 5 min, remain for 55 min, and ascend to surface in 10 min. This table can also be extended so that the attendant might remain at 2 ATA for up to 175 min.
3. For gas gangrene: descend in 5 min to 3 ATA, remain for 107 min, ascent to 1.9 ATA. Breathe 100% O_2 for 37 min at 1.9 ATA plus the 2 min ascent to surface.
4. For would healing: descend in 5 min to either 2.0 or 2.4 ATA and remain for 110 min, then ascend to surface in 10 to 15 min, depending on condition of the patients.

Literature Reports of Attendant DCS Incidence: There has been very little research on the topic of hyperbaric attendant DCS. Before the 1900s few reports were published and news of attendant DCS was shared mostly through hearsay. In this decade, reporting has improved.

Anderson, Whalen, and Saltzman (5) were the first to report health effects resulting from hyperbaric attendant exposure. The effect of 1,516 compressions on 62 attendants were three cases of transient partial blindness (homonymous hemianopsia) and classic decompression illness symptoms "...occurred only rarely, and were so mile or so fleeting as to require no treatment."

Desautels (6) reported that, in 1990, an American nurse, who was inside attendant for a routine hyperbaric treatment in the morning, was called back as inside attendant for a diver later that day. The nurse and patient were compressed to 6 ATA for a Treatment Table 6A. A gas delivery error occurred and she received air instead of nitrox. The nurse complained of chest pain on ascent to 2 ATA so was brought to the surface and sent home. She died from cardiopulmonary decompression illness a few hours later. This is the only reported death of an inside attendant, not related to fire, in a clinical hyperbaric facility.

Dunford and Hampson (7) reviewed 14 years of clinical hyperbaric treatments with 8,424 pressure exposures of inside attendants. The rate of decompression illness was 0.31% with the incidence related to the level of pressure exposure.

Dietz and Myers (8) examined 23 years of exposures in hyperbaric personnel. A total of 439 attendants had 25,164 exposures, with 19 cases of DCS occurring in 13 attendants. The overall incidence rate was 0.076%. The study did not show a correlation of DCS and gender of the attendant. There was a linear correlation with increasing pressure and incidence of DCS.

Kindwall, (9) stated that standard hyperbaric treatments to 2 ATA are tolerated well in hyperbaric attendants, even when two exposures to this pressure are made in the same day. He found that a problematic exposure for attendants was attributed to a common treatment profile of 45 FSW (2.4 ATA) for a 100-min exposure, reporting several DCS cases for that profile. Although it is equivalent to the No Decompression Limits of the U.S. Navy (USN) No-Decompression Air Dive Table 50/100, Kindwall warned that it is not adequate for civilian hyperbaric attendant use and suggested that oxygen breathing during ascent to be added for attendant safety. Kindwall stressed the importance of calibrating pressure gauges and periodically checking for gauge line leaks in order to prevent false gauge readings that could contribute to attendant DCS.

Geiger, Crouch, and Mezistrano-Boer (10) described their experience of utilizing the USN Standard Air Decompression Table 50/140 for a 90-min oxygen treatment table (with air breaks making a 117 to 127-min attendant exposure). After 8 cases of DCS during a sequential introduction of reducing total bottom time, reviewing the physical status of staff attendants pre-dive, and introducing oxygen breathing for 10 minutes prior to decompression, they reported four more incidents, but none over the past year. The largest single change that coincided with decreasing DCS was the reduction of attendant working hours from 50-60 to 40-45 hours per week. They highlighted the significance of attendant fitness to dive, reducing total bottom time and oxygen breathing as factors in reducing DCS. Specifically, variables such as rest, adequate hydration, afebrile state, and fatigue of attendants were considered important in DCS prevention.

Klossner et. al. (11) could find little in the literature to guide them in establishing a policy for safe decompression of inside nurse attendants. They considered decompression tables developed for Finnish amateur scuba divers with the inclusion of breathing 100% oxygen for the entire decompression to be safe for chamber attendants. Their incidence of DCS using this profile was 1.3%. They considerably lengthened their decompression protocol and reduced the treatment pressure from 2.8 ATA to 2.5 ATA. Their nurses also breathed 100% oxygen at 2.5 ATA for the first 10 minutes of the treatment. Their incidence of DCS after these changes was 0.14%. They reported no adverse effects from the added oxygen breathing.

In a retrospective review, Huggins and Catalano (12) found a 0.26% incidence of DCs in 3,068 people exposed to 6 ATA during training and orientation in a hyperbaric chamber.

Brattebe et. al., (13) presented their DCS incidence rate in nurse attendants over a 30-month period for up to 150-minute exposures at 14 msw (2.4 ATA). Eighteen nurses were attendants for 1,534 compressions with a DCS incidence rate of 0.76% (three cases in 395 compressions). After altering the decompression procedure by having the nurses breathe oxygen for 5-10 minutes at 14 msw (2.4 ATA) and during the 7-minute decompression, they had no more cases of DCS during the subsequent 1,000 attendant exposures.

Kulikovsky and associates (14) described the first documented account of lymphedemia resulting from DCS in a hyperbaric attendant. The nurse was an attendant on a 2.5 ATA treatment of 104-minute duration. Oxygen was breathed for 30 minutes (15 minutes proceeding and throughout the 15 minute ascent). Following the exposure, DCS symptoms were tingling and rash. She responded well to recompression, but later developed lymphedema involving her face and arm, which resolved four days later with lymphatic drainage and compression. Her most recent hyperbaric exposure two weeks previously had required significant physical exertion and was followed by extreme fatigue but no other DCS symptoms.

Baker (15) surveyed North American multiplace hyperbaric facilities for DCS incident rates to determine whether there was a significant DCS incidence among inside attendants during routine wound healing protocols. Thirty-three units responded and the results are shown in Table 1. DCS incidence was low (0.01-0.6%) with U.S. Air Force Decompression Tables producing the lowest DCS rate. The total attendant exposures for the 33 units averaged 29,000 exposures per year, an annual average of 870 per unit. There were only 76 attendant DCS cases reported for the entire period of operation through 1996. (Average period of operation of the reporting facilities was 13 years, with a range of 1 to 41 years.) Breathing oxygen and rotating inside attendants, to remain within no-decompression limits, were better than using standard air decompression methods. Shortening the treatment from 90 to 60minutes had little effect on attendant DCS rates. Reducing the frequency of exposure, rotating inside attendants, reducing pressure from 2.4 to 2.0 ATA, and breathing oxygen were associated with lower attendant DCS incident rates. Although the sample size was small, the most significant factor in reducing DCS in attendants as detected in this survey was oxygen breathing by the attendant.

Cost of Attendant DCS Claim: These reports show a low incidence of DCS in civilian hyperbaric chamber attendants. Even so, the impact on the attendant and staff are significant. worker Rehabilitation and Compensation claims in Australia average $8,500.00 in actual cost. The author (Pirone) estimates that the "hidden" costs caused by the unemployment might exceed $50,000 per attendant DCS claim.

PREDICTING PROBABILITY OF ATTENDANT DCS

Probability of DCS on U.S. Navy Air Decompression Tables: Weathersby and associates, (16) reported the first model for predicting DCS incidence in hyperbaric air exposures and made a major contribution to attendant safety. In 1986, Weathersby et. al.., (17) published risk assessments for standard air dives with hundreds of predictions that ranged from <0.1% DCS to >20% DCS, but there were no treatment table profiles in that report. A substantially improved mathematical model was later developed by Parker et al (18) and used by Survanshi et. al.., (18) to compute complete sets of decompression tables.

TABLE 1
Inside Attendant DCS Incidence in North American Facilities Through 1996

	No. Units	Incidence
Units Reporting	33	
Average Annual Exposures (total of 33 units)	28,769	
DCS Cases	76	
On Wound Healing Protocols	27	
On Other Protocols	49	
Tables Used		
USAF Tables	13	0.02% (3/24, 444)
USN Tables	12	0.25% (13/5, 150)
Local Tables	4	0.03% (6/19, 605)
DCIEM Tables	4	0.67% (1/150)
NASDS Tables	1	- - - - - - - -
Frequency of Exposure (No. of Units)		
> 1 per day	2	
1 per day	20	
1 per week	5	
1 per month	4	
< per month	2	
Wound Healing Treatment Pressure		
2.0 ATA	4	
2.4 ATA	25	
3.0 ATA	1	
Wound Healing Protocol Duration		
60-90 min	3	0.04% (2/5, 150)
91-125 min	24	0.05% (21/44, 199)
> 125 min	2	- - - - - - - -
Methods Used to Protect Inside Attendants		
Breathe Oxygen	2	0.018% (2/11, 330)
Rotate Attendants	5	0.027% (4/14, 964)
Use Standard Air Decompression Tables	5	0.074% (17/23, 005)
Unreported	21	

Probability of DCS Following Exposure on U.S. Navy Treatment Tables: In 1996, Thalmann, (20) reported that predicted probability of DCS in attendants who are exposed to the U.S. Navy treatment tables (TT) that are published in the U.S. Navy Diving Manual. (21) The predictions were based on a model that was calibrated against several thousand air dives of known outcomes. Exposures typical of inside chamber attendant exposures are not included in the calibration data so the probabilities must be interpreted cautiously. Thalmann cautioned that the numbers should be used to look at relative risk between tables rather than as an absolute risk. Table 2 shows the DCS risk (pDCS) in attendants who breathe air throughout the exposure on TT1A, 2A, 3A, 4, 5, 6, and 7. TT5 and TT7 produce little DCS risk, but TT4 and TT6 (extended) have a considerably increased DCS risk (11.1-19.7%). Table 3 shows the DCS risk when the attendant breathes pure oxygen during portions of the decompression. An air-breathing attendant on TT6 halves the risk of DCS by breathing oxygen during the 30-minute ascent to surface. If the attendant also breathed 100% oxygen for the last oxygen period at 30 FSW (1.8 ATA) as well as during ascent to the surface, the risk of DCS would diminish to near zero, even if the treatment table were extended maximally. This analysis was used to increase the attendant oxygen breathing requirements in the 1993 and subsequent revisions to the U.S. Navy Manual. (21)

TABLE 2
Probability of DCS for USN Air or Oxygen Treatment Tables
(Attendant Breathes Air Throughout)

Treatment Table	Max Pressure	Total Exposure (Hrs:Min)	pDCS
TT1A: 30 min at 4 ATA	4 ATA (100 FSW)	6:20	3.3%
TT2A: 30 min at 6 ATA	6 ATA (165 FSW)	10:59	4.6%
TT3A: 30 min at 6 ATA	6 ATA (165 FSW)	18:59	10.6%
TT4: 30 min at 6 ATA		36:41	18.5%
60 min at 6 ATA		37:11	18.5%
90 min at 6 ATA		37:41	1.93%
120 min at 6 ATA	6 ATA (165 FSW)	38:11	18.5%
TT5: 45 min at 2.8 ATA	2.8 ATA (60 FSW)	2:15	1.6%
TT6: 75 min at 2.8 ATA		4.45	6.2%
100 min at 2.8 ATA	2.8 ATA (60 FSW)	6:25	11.1%
TT7: 12+ hrs at 2.8 ATA	2.9 ATA (60 FSW)	48:00+	0.2%

TABLE 3
Probability of DCS for USN Air or Oxygen Treatment Tables
(Attendant Breathes 100% Oxygen)

Treatment Table	Max Pressure	O_2 Period	pDCS
TT4:	6 ATA (165 FSW)	60 min at 10 FSW 60 min at 20 FSW	9.5%
TT4:	6 ATA (165 FSW)	+ 60 min at 10 FSW	0.9%
TT6: 75 min at 2.8 ATA 100 min at 2.8 ATA	2.8 ATA (60 FSW)	30 min during ascent from 30 FSW	3.3% 6.2%
TT6: 75 min at 2.8 ATA 100 min at 2.8 ATA	2.8 ATA (60 FSW)	Last 30 min at 60 FSW and 30 min during ascent from 30 FSW	0%

The Royal Adelaide Hospital Hyperbaric Medicine Unit (RAH-HMU) in Adelaide, South Australia used USN treatment tables for treating DCS patients and used customized tables for all other patient treatments. Generally, wound care treatment tables were at 2.4 ATA and gas gangrene or carbon monoxide tables were at 2.8 ATA. Table 4 shows the actual incidence, the binominal probability 95% confidence limits, and the probability of DCS [p(DCS)] calculated by Doolette for inside attendants using selected RAH-HMU treatment tables during the period 1987 to 1998. Calculations are according to the Naval Medical Research Institute LE1 (base) decompression model and parameters, (22) assuming a 10 minute descent time and oxygen breathing during the final 30 minute decompression (D. J. Doolette, unpublished date).

MONITORING INSIDE ATTENDANT DCS

Baromedical Nurses Association (BNA): An attempt to monitor attendant DCS was undertaken by the BNA in 1992. The BNA Hyperbaric Employee Incident Trending Form was patterned after the Divers Alert Network (DAN) Accident and Decompression Illness Incident Form 23. Intended for use in reporting any injuries that occur to hyperbaric medical staff, the main focus was on inside attendant DCS. In the first six years since its introduction, no data have been reported. Once reason for the lack of reporting could be that the form requires identifying information, which could be a medico-legal risk. Individuals may be reluctant to identify

TABLE 4
Attendant DCS Incidence During Eleven Years (1987-1998) of Hyperbaric Treatments at Royal Adelaide Hospital Hyperbaric Medicine

Treatment Table*	No. of Treatments	No. Attendant DCS	Attendant DCS Incidence (95% C.I. pDCS)	pDCS model
10:90:30*	2266	1	0.0441% (0.015-013%)	0%
14:60:30	180	0	0% (0-2%)	0.01%
14:90:30	1018	0	0% (0-0.37%)	0.04%
14:90:30	2644	0	0% (0-0.228%)	0.08%
USN 5, 6; and 1A converted to heliox	288	1	0.347% (0.01-1.6%)	2.45%
Others (training and research)	178	0	0% (0.2%)	
Total	***6574***	***2***	***0.0304% (0.018-0.18%)***	

*Pressure in meters of seawater; bottom time in minutes; decompression time in minutes.

themselves as having DCS if they think this information might be used against them in future employment prospects.

Hyperbaric Incident Monitoring Study (HIMS): HIMS is an anonymous, voluntary reporting system based at the royal Adelaide Hospital Hyperbaric Medicine Unit in Adelaide, Australia. Implemented in 1992, it is used for reporting all hyperbaric incidents that can or do cause harm to patients, staff, visitors or equipment. There were seven DCS cases in attendants reported in HIMS data over a five-year period (1992-94, and 1996-970. Due to the nature of this reporting system (numerator research), an incidence rate can not be extracted. As often occurs in incident reporting it is likely that the incidents reported are much lower than the actual occurrence. Of the seven attendant-DCS cases reported, three of the attendants highlighted that the extremity involved was held in a stationary position for the decompression period. One of the attendants developed pulmonary oxygen toxicity during recompression therapy. Factors the reporters identified with DCS risk were: pervious injury to affected limb, fatigue, strenuous work, use of contraceptive pill, an extended exposure, and stationary positioning of extremities during decompression. (24, 25)

METHODS USED TO MINIMIZE RISK OF DCS

Decompression Schedule: To minimize DCS risk, inside attendants use several methods. Most attendants follow the tables conservatively, i.e., start the ascent before the maximum allowable bottom time is reached. For those who must make decompression stops, oxygen breathing during decompression is a major benefit. Heavy exercise is avoided during the exposure and for about 4 hours following the exposure. Liquids are periodically consumed and dehydrating drinks such as coffee and cola are avoided. If the hyperbaric chamber is located at elevations above about 2,000 feet, special "Diving at Altitude Tables" are used to avoid the greater risk of DCS that occurs when surfacing at altitude. When flying after a hyperbaric exposure, the attendant waits for a minimum of 12 hrs. surface interval, and, if possible, for up to 24 hours. If decompression stops were required, the wait is a minimum of 24 hours. In order to attain a 24 hour surface interval, some hyperbaric facilities require inside attendants to avoid chamber exposures on the day before flight. Oxygen is sometimes breathed during decompression and at the surface to reduce the risk of DCS during subsequent flight.

The decompression schedule must allow sufficient time for the body to eliminate the excess nitrogen from the body. sometimes the treatment table itself will specify the inside attendant decompression schedule, for example, the U.S. Navy Treatment Tables 5, 6, and 6A. (26) Other treatment tables, such as the wound healing enhancement treatment table, does not specify the attendant decompression schedule, necessitating use of one of the standard air decompression tables.

Oxygen Versus Air Decompression: The process of breathing pure oxygen (denitrogenation) is very effective in eliminating nitrogen from the body. When 100% oxygen is breathed using a hood or tightly fitted mask, an alveolar nitrogen pressure of nearly zero is established in the lung and a marked pressure differential exists between the alveoli and the body tissues. This enables nitrogen to rapidly diffuse from the tissues into the blood, where it is transported to the lung to be exhaled. The amount of nitrogen eliminated in time-dependent. Breathing oxygen of 30 minutes eliminates about 25% of the total body's stored nitrogen, but it is eliminated from the various tissues at different rates. These rates depend on the solubility of nitrogen in specific tissues, but also, on the blood flow through the tissues.

The DCS probability data (pDCS) at Tables 2 and 3 reveal the importance of oxygen breathing during decompression. For example, if two attendants remained with the patient for the duration of U.S. Navy TT6, the attendant who breathed air throughout would have twice the risk of DCS as compared to the one who breathed oxygen during the 30 minute ascent to surface. If one of the attendants breathed 100% oxygen for 60 minutes (the last oxygen period at 30 FSW (1.8 ATA) as well as 30 minutes during ascent to the surface), the risk of DCS would be nil.

Pure oxygen can be breathed by mask or hood at any of the decompression stops. This procedure will speed desaturation of body tissues, but, unless a specific oxygen decompression table is being used, it should not be used to shorted the time spent at the decompression stop and should not be used to select a lower residual nitrogen designation for subsequent exposures. The attendant should receive pure oxygen without interruption throughout the stops and between them.

Attendants are not immune from an oxygen toxicity reaction. Pure oxygen should never be breathed at pressures greater than 66 FSW (3 ATA) because of the risk of seizure. When an attendant breathes oxygen, a second attendant should be present, if possible. As an alternative, oxygen delivery should be such that the oxygen mask will fall away from the face if the attendant has a seizure. The attendant should remain at rest during the decompression because physical activity accelerates the onset of oxygen convulsions.

Rotation Of Attendants to Limit Exposure: Some facilities schedule inside attendants to remain inside the chamber for the duration of the patient treatment, which usually results in a decompression obligation. Others rotate, or replace, the attendant before there is a decompression obligation. For example, if one attendant remained inside the chamber for the entire 120-min duration of a 2.4 ATA treatment, there would be a decompression obligation of about 10 min. However, if two attendants divided the exposure, neither would have a decompression obligation.

During the 20 years of operation at the Jefferson C. Davis Wound Care and Hyperbaric Medicine Center in San Antonio, Texas, two air-breathing inside attendants have divided the 120-min time during each of the 40,000 elective wound-healing treatment profiles at 2.4 ATA (80,000 attendant exposures). Five attendants presented with questionable symptoms after exposure to 2.4 ATA and were subsequently treated for DCS, an incidence of 0.006% (5 cases in 80,000 exposures). DCS episodes also occurred in two inside attendants on a single 6 ATA air embolism treatment. Both attendants performed hard labor at 6 ATA as a previously comatose patient improved and went through a combative period. Despite oxygen decompression, both attendants required HBO_2 for limb pain within 6 hours after the exposure. (27) There have been no cases of DCS among patients in over 150,000 exposures.

Assessment of Attendant's Fitness to Dive: The attendant must have an initial medical examination before exposure to the hyperbaric environment. the medical exam varies by institution, but should include a chest x-ray and a detailed medical history and physical.

The physician's initial assessment of the attendant's fitness to dive includes:

1. Result of a chest x-ray within the past year showing no evidence of blebs, bullae, cysts or other air trapping lesions
2. No history of:
   A. Seizure disorder
   B. Asthma after age 6
   C. Severe allergic rhinitis
   D. Psychiatric disorder
   E. Otosclerosis surgery
   F. Meniere's disease
   G. Spontaneous pneumothorax
   H. Polycythemia or other blood dyscrasia
   I. Pulmonary over-pressure accident
   J. Residua of decompression sickness
   K. Inability to equalize middle ear pressure
   L. Significant cardiovascular disease
3. Applicant is not pregnant (pregnant is a contraindication to pressurization in a hyperbaric chamber)

A regular review of the attendant's fitness is a part of the facility's ongoing occupational health and safety program. Usually, the attendant is considered unfit for hyperbaric exposure if he or she is under the influence of alcohol or drugs, has air-trapping lesions to the lung, has an illness that prevents equalization of pressure in the ears or sinuses, is dehydrated or unduly fatigued, or is pregnant.

Number of Attendant Exposures: The treatment profiles, decompression tables, and number of attendant exposures vary by facility. To protect attendants from oxerexposure, unit policies should specify the type of pressurization and the maximum number of exposures per day and per week. Most facilities insist that the attendant have at least a 24-hour surface interval after any exposure that requires a decompression stop.

Education of Attendants: It is important that the attendant's training in hyperbaric chamber operations include the mechanism, risk factors, and symptoms of DCS. Armed with this knowledge, the attendant can then become involved in and assume responsibility for, his or her own occupational health and safety.

CONCLUSION

Over 30 years ago, Anderson and associates, (5) suggested the practice of attendant oxygen breathing to reduce attendant DCS. A review of the literature reveals that attendant oxygen breathing, more conservative decompression profiles, and attention to variables that affect attendant fitness were effective actions taken to reduce DCS incidence. although the attendant DCS incidence is small, it warrants the careful attention of the international hyperbaric medicine community. Decompression procedures that minimize the risk to inside attendants should be incorporated into international hyperbaric safety guidelines.

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