We had previously presumed that this air supply problem at depth was a rare one, contributing to only the occasional death. However it may be more widespread, and perhaps even the norm at these depths, with the scuba equipment currently in use. None of the findings should be used to denigrate any specific piece of equipment, which may be lifesaving in certain circumstances. The lesson is to understand and instruct others about the limitations of this equipment.

Conclusions

Once a LOA situation has been reached at depth, the reliable duration of the air supply for both BC inflation and breathing is very limited, and measured in seconds rather than minutes.

While engaged in tasks requiring moderate to heavy breathing (respiratory minute volumes of 35-90 litres/min) with a low tank pressure, it may take a considerable time (if it is possible at all) to inflate a BC with 10 litres of air at 40 m. This was only achieved by half of the inflator systems, when the diver was breathing from the second stage regulator. In the other half, the 10 litre volume was not achieved, at that depth, before the tank effectively ran out of air.

Problems of an inadequate air supply may exist no matter what low pressure outlet is used, a second stage regulator, buoyancy compensator inflator or octopus regulator second stage.

Recreational divers should avoid, as far as possible, exposure to depths in excess of 30 m, unless more effective equipment is available and training has been undertaken in buoyancy control and in the appreciation of equipment limitations.

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EVALUATION OF DECOMPRESSION SICKNESS INCIDENCE IN MULTI-DAY REPETITIVE DIVING FOR 77,680 SPORT DIVES

Bret Gilliam

Introduction

I conducted the logkeeping data contained here as a private project in association with my contract positions as Director of Diving Operations for Ocean Quest International (a dive/cruise company now defunct). The majority of the data is from personal review of dive boat logs, passenger records, diver interviews, recompression chamber histories and interviews with members of the professional dive staff of the ship.

I was responsible for the overall diving co-ordination of the ship including orientation of the sport dives each week, development of the computer diving program and certification course, supervision and operation of the recom-

pression chamber facility, development of the treatment protocols, and captaining one of the ten 32 foot dive boats deployed from the ship. Additionally, as a USCG Merchant Marine Master, I served as a senior officer aboard the 457 foot cruise ship.

Background

In June of 1988, I was contacted through my consulting firm, Ocean Tech, by representatives of Ocean Quest International who wished me to undertake a variety of technical projects on their behalf. This corporation wished to enter the sport diving market with a cruise ship converted to carry 160 sport divers on diving vacations in the western Caribbean. It was anticipated that these customers would be offered as many as 17 dives in a four day period during these one week cruises.

Initially, I was asked to design a high speed, high volume air filling system, design and build the custom dive boats and consult with the ship's engineering firm on a gantry crane to launch and recover them, hire the diving and medical staff, write the operations manual, develop the training programs and refit a 60 inch multi-place, multi-lock recompression chamber for installation aboard the vessel.

One of my first concerns about the operation was the large number of dives to be offered in such as short period. This program called for four dives per day for four straight days with a night dive added in the same period. This meant that I would be facing as many as 2,720 dives by sport divers each week if the company was successful in realizing its market. To this figure would have to be added the diving schedules of the 28 professional staff members, approximately 500 additional dives. Looking at the possibility of handling over 3000 dives per week posed obvious operational cautions. To put it in perspective, many top dive resorts do not conduct that much diving in a whole year!

Addressing the issue of expected incidences of decompression sickness (DCS) left many unanswered questions. No one has ever seemed to be in agreement on the statistical incidence of DCS in sport divers. Several "experts" were polled on this issue and a wide spectrum of "qualified" responses were received. One respondent predicted 12.5 cases of DCS per week. This type of feedback was daunting to say the least.

After going forward with the design projects etc., I was asked to join the company under a consulting contract as an Executive Staff member with specific responsibilities as Director of Diving Operations.

This paper addresses the data compiled after one year of operation of the vessel. Statistics presented were recorded from March 4th 1989 to March 4th 1990. 77, 680 dives were logged during this period.

The multi-level question

Traditional sport diving resort operations typically deal with far smaller numbers of divers and rarely conduct dive operation schedules that permit up to four dives per day. Virtually all resort diving in the summer period of 1988 was conducted by "divemaster log sheets" handwritten at the dive site. Most diving was calculated using conventional tables, with the Haldane model U.S Navy tables seeing the widest use.

Given the extraordinary number of dives that this company was committed to, I wanted to provide every possible safety edge and discipline of logging dives. The basic weakness of most sport diver profile logs has been twofold:

1 Sport divers are notoriously poor record keepers with regard to times, depths and surface intervals.

2 Several surveys and volunteer test studies have proved evidence beyond doubt that the majority of sport divers cannot calculate repetitive dive planning correctly.

One issue that came up almost immediately was whether any meaningful dive profiles could be allowed if the divers exclusively used square profile computational methods. In most circumstances, it proved unworkable for a four dive schedule in the time allowed by the ship's strict sailing routine. Therefore, the viability of "multi-level" profiling became interesting.

We felt that this method was best accomplished through the use of diving computers and eventually our program had almost 57% of sport divers utilizing these devices. (A more detailed treatment of this subject is available in my paper "One year database of sport diving exposures: comparisons of computer vs table usage" contained in the 1991 Proceedings of the International Conference on Underwater Education (IQ'91) available from NAUI).

By the fall of 1989, we made minor changes to the ship's itinerary and had modified the diving schedule to average 13 dives per week for the sport customers. However, the numbers of divers had increased dramatically during certain periods and we frequently handled in excess of 200 divers per week. We had actually got to the point where we considered 100 divers a week to be a slow period. One day in December of 1989, we did over 1000 dives!

Dives and DCS

Through the one year period March 4, 1989 to March 4, 1990, we conducted a total of 77,680 dives including customers and professional staff. Water temperature ranged

from 77° F to 85° F and cannot be considered a factor in any DCS hit. Approximately 57% of our dives were done on computers, a total of 44,277. Divers' ages ranged from 9 to 72 years old. The great majority of diving was conducted with exposures of 100 feet or less. Divers were instructed to limit their diving to a maximum of 130 fsw with a 30 feet a minute ascent rate above 60 fsw; or to conform with their computer's ascent rate, whichever was more conservative. Divers averaged three dives per day although a significant number (over 20%) of customers made over 5 dives in one day if weather circumstances permitted. Reverse profiles were conducted by many divers with no adverse effects reported. Computer divers frequently admitted to reverse profiles in their personal dive scheduling. Although not sanctioned, we had knowledge of sport divers doing dives in excess of 130 fsw routinely while conducting their own dive plans. Over 40% of the computer owners questioned admitted to frequently diving below 130 fsw, several to depths in excess of 200 fsw. No hits were recorded in this group.

In conjunction with some other on-going research projects, members of the professional staff made over 600 dives to depths of 250 fsw. All were calculated by the computer (Bühlmann model) and repetitive dives were taken the same day. There were no cases of DCS on these dives.

I made over 625 dives in the one year period including 103 below 300 feet with one penetration to 452 fsw, a new air depth record. All decompression schedules for dives up to 300 feet were derived from the Dacor Mircobrain Pro Plus computer (Bühlmann model). Below that depth, I used custom propriety tables. No DCS hits were recorded.

No hits were recorded for the professional staff. Most members averaged 500 to 725 dives during the one year period. Age span was 21 to 43 years old with approximately a third of the staff being female. Dive staff members averaged between 11 and 15 dives per week.

During the year we treated seven cases of DCS for customer sport divers and none for staff. There were 12 other divers with symptom suggestive of DCS in who complete relief of symptoms was achieved by breathing 100% oxygen , by demand system, before they got to the ship. These were not recompressed. All seven patients who were treated for DCS had limited dive experience; usually less than 40 dives. Of the seven hits, 4 were women and 3 were men. All DCS hits fell in the 26 to 45 year old range. In four of the seven cases, ascent rates in excess of 60 ft/min were reported. In five of the seven cases no safety stops at 15 fsw 94.5 m) were taken. All of the DCS cases were divers using tables. DCS did not occur in any divers using dive computers correctly. The one computer user who required treatment had a decompression obligation which he ignored. This kind of stupidity obviously cannot be blamed on the device (be it tables or computer). This diver was not a graduate of our on-board multi-level computer training program. He had brought his own computer with him and declined to attend our seminar. In fact he had not even completed reading the computer manual. Of the 7 clearly symptomatic of DCS, all were successfully treated in the ship's recompression chamber with full resolution. Five of the seven divers with DCS hits were diving within the limits of their tables and can be categorized as "undeserved hits". No hits were recorded during the first two days of diving.

Incidence of DCS

With 77,680 dives in the total database and seven DCS cases, the incidence was 0.00901% or approximately one in 10,000 dives. If those with suggestive symptoms are included there were 19 cases in 77,680 dives, an incidence of 0.024459% or just over 2 in 10,000 dives.

If just the group using tables is considered, the incidence rate is 0.02%, 2 in 10,000 dives. If those with suggestive symptoms are included there were 19 cases in 33,403 dives, an incidence of 0.05688% or nearly 6 cases per 10,000 dives.

The group which used computer calculations properly had a zero (0%) incidence rate.

Discussion

Originally, the project was to keep records for a six month period. This was expanded as the diver population aboard ship increased. Of particular interest to me was the lack of DCS incidence in computer users and in the more "aggressive" experienced diver population. Precisely the diver group that we suspected was most at risk to DCS proved to be the safest. Why?

Several factors may provide partial answers. We observed the computer diver and experienced, aggressive diver groups to be far more disciplined in their regard for ascent rates, "safety" and decompression stops. They generally had better watermanship skills. Most were also more attuned to proper hydration and generally refrained from alcohol consumption during the evening periods. The decompression algorithm employed by their computers were generally more conservative than the typical Haldane U.S Navy models.

Overall, the low incidence of DCS surprised all involved in the record keeping project. Taking the whole group into perspective, and with the benefit of hindsight, I made to several observations which may account for the excellent DCS safety record.

This ship's schedule had sport diving customers board the vessel on a Sunday and depart that afternoon. Monday was an orientation day with a safety lecture required for all divers. To ensure their attendance, it was made

clear that dive boat assignments would be conducted immediately following the conclusion of the one hour orientation. Fear of being left off the boat list or not being assigned to a favourite boat crew provided virtually 100% co-operation in attendance. Also, since the ship was at sea and no other diversions offered, it was relatively easy to lure divers there.

We tried to get sport divers to regard their role in our operation as a mutually co-operative one with the professional staff. We avoided any domineering or "lecture" attitudes and endeavoured to communicate safety and environmental protection information with a "we need your help to best serve you" approach that was generally well received and not resented. Many divers reported our orientation to be more instructive and less intimidating than typical resort "tirades", no matter how well intended.

Orientation served to acquaint the divers with our ship's diving operations but also had detailed general safety recommendations that we feel should be emphasized within all sport diving groups in resort settings. Of particular importance in our opinion was reinforcing disciplines of ascent rates and "safety stops" at the 15 fsw (4.5m) level for at least five minutes. By my observation, most sport divers initially have little concept of safe ascent rates even if given instruction during their entry level scuba training. Most seem to understand that slow ascents are important but fail dismally to execute proper ascents in the field.

If anything, we overstressed adherence to a 30 ft (9 m)/min ascent rate at least in the last 60 feet (18 m). The "safety stop" was further emphasized and we felt that, even if ascent rates were too rapid, instilling the "safety stop" ethic would at least slow the divers down approaching the surface. Many other resort operations stress returning to the dive boat with from 700 psi to 500 psi remaining in the diver's scuba tank. We departed from this conventional instruction and urged divers to arrive at the safety stop level with sufficient reserve for a 5 minute "hang" and then to use the remaining air for additional stop time, saving only a small reserve for the easy return to the surface. Each boat was equipped with a weighted 20 foot (6 m) PVC pipe bar hung from the dives boat's side at 15 fsw (4.5 m). This afforded an easy and comfortable platform for "safety stop" observance and the large size of the "Deco-bars" enabled as many as a dozen divers to be accommodated at once.

From observation, we found a significant number of divers did not realize that their ascent rates were excessively rapid. Typically, we would time divers in ascents ranging from 100 to 125 ft (30-37.5 m)/min and upon questioning, the diver would express surprise and voice the opinion that they thought they were conforming to 60 (18 m) or even 30 ft (9 m)/min rates. Most divers simply find these recommended rates to be ridiculously slow (from their perspective) and only through continued education and patient explanation will the disciplines of proper ascents be applied. Most important however, is to establish a non-confrontational relationship with sport divers so that a willingness to learn will evolve. Our staff was trained to emphasize all safety recommendations daily on the dive boats and to observe divers in the water. Tactful suggestions and critique were to be offered in areas where divers could improve technique. We had great success with these methods and felt reasonably confident that 90% of our customers were complying.

Due to the temptation of being aboard a cruise ship where the availability of alcohol was ever-present we felt obliged to remind divers that alcohol consumption the night before a heavy diving day was ill-advised. Surprisingly, we met with few problems from our diver population in this regard. Most got their "partying" out of their systems on the Sunday night departure from the U.S. port and refrained from or adopted modest alcohol attitudes until the four days of diving were completed. Staff example went a long way to promoting compliance. Our professional divers generally observed a voluntary curfew on evenings before diving of 11:00 p.m. Since most diving would begin as early as 8:30 a.m., we encouraged a good night's rest in customers and staff. For staff, it was a necessity due to their heavy work and diving schedule.

Another strong emphasis was placed on proper hydration of divers. We recommended consumption of non-carbonated beverages; but suggested staying away from orange, tomato and grapefruit juices due to their tendency to precipitate seasickness in many divers. Each boat was supplied with large containers of cold fresh water and unsweetened apple juice (the latter affectionately known as "Emmerman" due to this individual's advocacy in his many articles on hydration). Each boat crew pushed consumption of these fluids between dives during the course of the diving day.

We also included a detailed segment on recognition of DCS symptoms. Since we had a fully staffed and functional recompression chamber aboard we made our guests aware of its location and that we used it not only for training programs but we expected to use it for treatments as they presented.

Denial of symptoms and subsequent delay of treatment has always been major problems in sport divers. We tried to make it clear that DCS has a certain statistical inevitability and that no stigma or "blame" would be placed on an individual who reported problems. We let our divers know that each boat captain was trained in diver first aid and each boat was equipped with O_2 units equipped with demand regulators to insure delivery of 100% O_2 if needed. There was no charge for the O_2 or for evaluation by the author and diver medical technician. In fact, we did not charge for tests of pressure or treatments.

As a result of the orientation sessions, we overcame the traditional reluctance to report symptoms and in many

cases found ourselves burdened with evaluations of numerous muscle strains etc. not related to DCS. But at least, our divers were enthusiastically coming forward to report even slight perceived symptoms. We would always prefer to err on the side of caution and the few cases of obvious non-DCS injury were welcome in preference to the denial attitudes so frequently prevalent in the past.

Chamber facility

We were lucky to acquire a 60" PVHO classed recompression chamber which we completely refitted for use on the ship. We purchased the chamber and essentially discarded everything but the pressure vessel. Two staff members then replaced all fittings, installed a new radio communications system including two sound-powered phone handsets, 6 new BIBS (built in breathing system) masks with overboard dumps for O_2 delivery, two new O_2 analyzers, a fire suppression system, 50/50 Nitrox therapy gas, new gauges and timing devices. All ports were removed and replaced along with all hatch o-rings. The entire unit was cleaned and repainted white with all gas lines colour coded.

When completed, the chamber was state-of-the-art and Dick Rutkowski of Hyperbarics International was brought in to examine and certify its readiness. Rutkowski was also used on three occasions to conduct specialized training for chamber operators and technicians with his well known courses.

I and two other staff members had extensive prior chamber operation experience from military and commercial backgrounds and we had one DMT graduate from Oceaneering. Training runs and protocol discussions were conducted weekly with the majority of the dive staff participating in various roles in the chamber's operation. This provided a continuing education process and ensured operational readiness of all systems and staff. Periodic test cases were presented by passenger volunteers coached to appear with DCS symptoms to present staff with actual "real life" scenarios to react to.

Additionally, we developed the first sport diver certification program in Accident Management /Introduction to Recompression Chambers. I wrote the course with the intent of involving sport divers in an intensive hands-on learning situation that included field evaluation of diver patients, O_2 administration, patient handling and transport, record keeping and actual dives in the chamber including breathing from the BIBS with dives to 60 feet.

This program was approved by both PADI and NAUI and hundreds of divers participated in it during 1989 and 1990. This program was scheduled for a travel day at sea after conclusion of the diving program on Friday afternoon. Most divers expressed the opinion that this course made them far more aware of pre-disposing factors and health conditions to DCS and AGE, and appreciated the in-depth accident management modules especially with O_2.

Our protocols called for very aggressive diver treatment. Divers reporting symptoms were placed on 100% O_2 by demand mask and immediately transported to the ship for evaluation by the author or DMT. Significantly, we had approximately 12 cases of symptomatic DCS that relieved completely during the 100% O_2 breathing period during transit from dive site to ship. As is standard practice in the commercial diving industry, we have not counted these cases as confirmed DCS incidents since they were not confirmed through a recompression test of pressure. However, in my opinion, the importance of 100% O_2 by demand mask cannot be over-emphasized.

With regard to treatment tables, it is my firm opinion that use of U.S Navy table 5 is not appropriate in sport diver DCS presentations. Virtually all sport diving DCS cases I have treated in my career will show Type II symptoms upon close examination. In many cases, Type I symptoms present and the patient may complain vigorously of muscular/skeletal "pain only" symptoms only to discover further evidence of Type II numbness etc. once the "pain only" symptoms have abated. The masking of Type II DCS has led to improper and insufficient treatment on table 5 when a table 6 with extensions may have been called for.

We aggressively treated all presentations with table 6 and used table 5's for clean-ups when initial treatment did not produce full resolution. Under these protocols we had complete resolutions in all patients.

It should be noted that the data base presented here only considers the ship's sport diver population. Other patients presented for treatment from time to time from resorts, commercial divers engaged in fishing using scuba etc. Case 4 is included because it is of interest due to its extreme repetitive exposure.

Selected case reports

Case 1

The patient presented with numbness and tingling on his right side localized to the foot, ankle, wrist and forearm. Skin mottling was also noted. Numbness etc. had become progressively worse since making 2 dives in Cozumel with profiles of 60 fsw (18 m)for 32 minutes with an approximate 1 hour surface interval followed by second dive to 48 fsw (14.5 m) for 25 minutes. He was in fourth day of a repetitive diving vacation, with over 24 hours since the previous day's diving. The dives were unremarkable with normal ascents and no work. Water was 79° F with excellent visibility although a moderate current was prevalent in both dives, as is typical for Cozumel diving conditions. Symptoms developed within one hour of surfacing from the second dive but they were not reported until approximately eight hours later

as they progressively worsened. He did not believe he could be bent.

A test of pressure was performed and after a 20 minute breathing period on O_2 by BIBS mask at 60 fsw in chamber the patient reported complete relief. A standard treatment table 6 was followed with complete resolution.

He was calculating his dives using standard USN tables. He was a 43 year old male with no obvious physical detriments; diving experience included frequent sport diving in the four years since he was certificated.

Case 2

The patient presented with shoulder pain after making two dives in Cozumel with profiles: 76 fsw (23 m) for 25 minutes; approximately 1 hour ten minutes surface interval with second dive to 58 fsw (17.6 m) for 32 minutes. The diving conditions were ideal, with the typical Cozumel current. Symptoms developed approximately 2 hours after surfacing from the second dive but were not reported until nine hours later when pain had progressively worsened.

A test of pressure was performed and after a 12 minute period breathing O_2 by BIBS mask at 60 fsw (18 m) in the chamber she reported complete relief. A standard table 6 was followed with complete resolution.

She was a 44 year old female, overweight by approximately 35 pounds (16 kg) and in generally poor physical condition. She reported a previous injury to the shoulder where the initial symptoms developed.

She had infrequent diving experience although certificated for five years. She was calculating dives using PADI RDP tables.Her dive buddy reported poor ascent technique and poor buoyancy control throughout both dives.

Case 3

This patient presented initially with mild tingling in both hands. He was held two hours for observation and upon re-examination was found to have marked progression of tingling and numbness and fatigue. Also his disposition had altered and he was becoming lethargic and unstable while walking and had difficulty maintaining normal balance.

He had made a total of nine dives all within USN table limits in the three previous days. He had a 20 hour interval before resuming diving on the fourth day. He dived to 51 fsw (15.5 m) for 58 minutes, 67 fsw (20.3 m) for 43 minutes and 95 fsw (28.8 m) for 46 minutes. Neither he nor his buddy could provide accurate surface interval information. They were using profiles supposedly obtained from USN tables. He had declined to dive under the supervision of a ship's divemaster. Symptoms developed within one hour of surfacing and he immediately reported to the ship's diving officer upon returning from the Mexican Cozumel diving boat. This was approximately two hours after the last dive.

He was given a test of pressure and reported complete relief after 10 minutes of O_2 by BIBS mask at 60 fsw in chamber. A standard table 6 was followed with complete resolution.

Case 4

This man presented with severe symptoms including inability to walk, bilateral paraesthesia, incoherent speech. He collapsed during examination. He was immediately recompressed to 60 fsw (18 m) in the chamber and put on O_2 by BIBS mask with no relief. Compression was continued to 100 fsw (30 m) on air where relief was reported of most symptoms. He was decompressed to 60 fsw (18 m) and a standard table 6 was followed with complete relief.

A history was obtained of his previous day's diving. The patient was a male Mosquito Coast Indian professionally employed as a lobster diver, using scuba gear, in the Bay Islands of Honduras. He made between 10 and 12 dives in a nine hour period to average depths of 125 fsw (37.5 m) or greater. The procedure was to dive until his tank was exhausted and then make a free ascent. Repetitive dives were performed non-stop in this manner until the diver began to feel numbness and tingling in his right arm and shoulder. Another dive was made and these symptoms were relieved underwater and he continued diving until he ran out of air and ascended rapidly. Almost immediately upon surfacing he noticed pain in his legs and then progressive numbness and tingling. His boat was over 12 hours from Guanaja (Bay Islands) and on the trip in, he consumed a large quantity of a native alcoholic drink and ultimately passed out.

His diving buddies brought him to the Ocean Quest when they heard that there were divers on board who "knew how to fix divers when they get twisted". The patient was paddled out to the ship in a dug-out canoe by his companions who related his profiles.

Although he was completely relieved following a table 6, he was advised to remain on board the ship for transfer to Roatan's chamber facility for observation for recurrent symptoms. At this point the patient became highly agitated and insisted on leaving the ship. When attempts were made to restrain him in order to have his companion better explain (as interpreters) the seriousness of his condition, he attempted to jump over the side into the water and swim to shore. I explained that he could leave at any time and urged him not to return to diving for at least a week and to obtain a medical examination. He chose to depart immediately by canoe with his companions. Apparently his immigration status was questionable and had prompted his anxiety about transfer to Roatan.

I learnt later that he resumed diving two days later and I understand that he still continues to dive, with no apparent further problems.

Conclusions

This data would suggest that the incidence of DCS in sport divers is far lower than that was originally expected.

In this diver population certain factors may have contributed to their safety record. These include aggressive counselling, through the orientation sessions, about proper hydration, rest and low alcohol usage. Of primary importance was the constant stressing of slow ascent rates and "safety stops". Additionally, professional diver staff members were trained to observe and tactfully correct bad diving habits and to assist with the review of dive planning and repetitive table use.

Also, the importance of dive computer use in contributing to more accurate dive profiling and use of more conservative decompression algorithms clearly played an important role in limiting DCS incidence rates. The fact that the group using dive computers properly made 44,277 dives with zero incidence of DCS must be considered significant.

Interestingly, the most aggressive group of divers making the deeper and largest number of repetitive dives had the best overall safety record against all conventional wisdom. This would seem to be due to the experienced divers' greater discipline with regard to ascent rates, observance of "safety stops" for long hangs, proper hydration practices, better knowledge of table and/or computer use, and overall better diving and watermanship skills.

Further, aggressive use in the dive boats of O_2 administration by demand mask may well have relieved other unconfirmed DCS hits. On-site chamber treatments that offered tests of pressure and evaluations usually within two hours on symptom onset certainly contributed to the 100% resolution rate for patients. Finally, the encouragement of prompt symptom reporting with no associated peer or professional "blame" or stigma attached is refreshing in a sport diver community that has historically been infamous for symptom denial.

In the case of the professional dive staff some validity to the hypothesis of "adaptation" must be given serious consideration. These individuals dived aggressively for four straight days, then received three days off before resuming that schedule. Most made between 500 and 725 dives in the one year period. Many routinely performed diving in the 250 fsw range or greater with subsequent repetitive dives and yet no DCS hits were recorded in any staff. The "multi-day skip" suggestion may well be validated later.

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