Adam Shoelson
DAN Internship Final Report
May 19-August 15, 2008

Part 1

Introduction

Two years have passed in a somewhat uneventful fashion for me at the University of Richmond. Don't get me wrong, I've loved every minute of my time there and I couldn't have hoped to attend a better university, but when I look back on my first two years there I realize that I've basically just gone through the motions. I've completed most of the required classes, joined a fraternity, attended concerts on campus, and have participated in most other everyday university activities. But as spring break rolled around during the second semester of the 2007-2008 school year it began to seem as if every student at Richmond had visited the Career Development Center, joined mentor groups led by already established professionals, or began striving to achieve summer internships. I had done none of these, and for the first time during my tenure at Richmond, I felt out of the loop. So I spent my spring break trying to get back into it.

Since high school, science classes, specifically those related to biology, have been my academic passions. My passion for science has carried over into college, where I've begun preparing for medical school by taking biology and chemistry classes with a declared major in biology. So, with medical school hopefully on the horizon, I knew internships related to the sciences, medicine, or research would be most appropriate. Though I do want to attend medical school, my love of the ocean and scuba diving have opened up other career options besides traditional medicine. Dive medicine and marine veterinary medicine are two other potential options. So when I stumbled upon an Our World-Underwater Scholarship Society internship at the Diver's Alert Network (DAN) headquarters involving research on decompression sickness (DCS), I knew it would perfectly combine my love of science and scuba diving. Furthermore it would serve as a strong introduction to the general practice of scuba diving medicine and physiology and hyperbaric research.

I thought my chances of receiving the internship were low, not because I wasn't qualified but because I was applying as a sophomore undergraduate student. Students with more scholastic experience and in greater need of a résumé-boosting internship had undoubtedly applied for the same position, so after three and a half weeks had passed, I had basically dismissed any chance of receiving the DAN internship. In fact, I had even accepted, informally, a summer research position at my school involving sponge genetics. But shortly after my acceptance into the summer research program at Richmond, I received an email stating I was a finalist for the DAN internship. A week later, the position was mine. I had finally joined the ranks of those University of Richmond students seeking to gain a certain advantage by exploring career options early on.

Training Week

Training week for all of the DAN interns (there were five of us) began just one week after I finished up with finals at the University of Richmond. I drove from Richmond to Durham, North Carolina to get set up for an intense week of physiology lectures, Project Dive Exploration (PDE) training, and some diving off the coast of Wilmington, North Carolina. I knew upon my immediate arrival in Durham that I'd enjoy spending my summer there immensely. The house I'd be renting a room out of was located in a small neighborhood 15 minutes from the DAN headquarters. My roommate for the summer was another one of the interns remaining at the headquarters to help with research. The three other interns collected PDE data at various locations around the world (Scapa Flow, Scotland, Grand Cayman, and Santa Cruz). Though at times I was envious of the other interns' travels, the physiology lectures on scuba diving and DCS that we received from DAN researchers throughout the week eventually made me glad to be staying. I knew at the headquarters I'd learn far more about DCS, physiology, and research methodology than I would out in the field.

Training week was extremely hectic. Early morning alarm clocks led directly to rushed drives to the headquarters where lectures would begin almost immediately. In fact, the lectures had begun a week prior to our arrival in Durham when we were asked to complete an online course that would familiarize us with Institutional Review Board (IRB) rules and regulations, and another online lecture entitled "What is DAN?" Lectures touched on nearly every aspect of the DAN organization. We heard from researchers Richard Vann, Neal Pollock, and Petar Denoble about the various research projects that DAN was pursuing or had completed (these lectures generally concerned DCS). The medical services staff gave lectures on diving fatalities and ways to cope with DCS cases. Dan Orr, the president of the organization discussed with us the history and importance of DAN. The training department certified all of us to administer First Aid Oxygen and to conduct brief on-site neurological assessments of injured divers.

Despite the crammed agenda, the training week at the headquarters was entertaining and quite enjoyable as well. The chemistry between the DAN staff members, their senses of humor, and the way they reached out to us as interns certainly played a role in making training week fun. The trip to the hyperbaric facilities (see photo above) at Duke was also a very rewarding experience. Though the chambers there are extremely old, the setup, functionality, and organization of the hyperbaric program at Duke is

absolutely amazing. Prior to my visit to the Duke chamber, I thought recompression was used only for the treatment and study of DCS. While at the chamber though, we were able to witness the recompression treatment of patients with a variety of other ailments ranging from diabetic wounds to burns. It was truly fascinating to learn about all of the ways the hyperbaric chambers at Duke were being used.

My favorite aspect of the training week was undoubtedly the diving and PDE data collection we performed while diving with Aquatic Safaris off the coast of Wilmington, North Carolina (photograph on previous page is of myself (2^{nd} row, center) and the other DAN interns aboard the Aquatic Safaris dive boat). I hadn't ever scuba dived in North Carolina, so this was a completely new experience for me. The water was murkier and colder than I'm generally used to and we didn't spot any of the resident Sand Tiger sharks, but diving the wreck called the Liberty Ship and seeing some new marine life was definitely enjoyable. Our task for the trip, to collect PDE data, also encouraged us to interact with other divers aboard the charter boat. Each of the interns had several small, faceless computers that record PDE dive profile data. As interns, it was our job to request permission to attach these computers to the divers' BCDs so information on their dive profiles could be collected, submitted to DAN, and analyzed. At the end of the training week, post-diving, all of the interns departed for their various host facilities and our summer work began.

My Position

During the intern training week I learned that I'd be working under Petar Denoble on a study examining the impact of first aid oxygen (FAO_2) administration on the treatment of DCS. FAO_2 has long been thought of as a successful immediate treatment for DCS-related dive injuries by contributing to the resolution of harmful intravascular nitrogen bubbles that may be present in tissues. A previous study conducted by Denoble and several other DAN researchers supported the practice of providing FAO_2 to those experiencing symptoms of DCS or arterial gas embolism (AGE). According to this study, administration of FAO_2 limited the number of recompression treatments before complete symptom resolution (Longphre et al, 2007).

When I first read the paper discussing Denoble's research, I had some immediate questions regarding some problems and limitations with the research. First of all, FAO_2 can be administered at different times following symptom onset, in different ways, and for different periods of time so I wondered how these variables could be controlled. The mode, duration, and time of oxygen administration could undoubtedly have an impact on its efficacy, but this wasn't explored in the initial experiment, primarily because information regarding the specific characteristics of the FAO_2 treatment was so often missing. Because this was a huge problem with the research, Denoble had me compiling cases from the Medical Services Call Center (MSCC) that were not missing any information. For a case to be included in the ongoing study on the effects of FAO_2 on the treatment of DCS, FAO_2 had to be administered within 6 hours of symptom onset, and for a duration of at least 20 minutes. Mode of FAO_2 delivery also had to be specified. For a case profile to be considered complete, information regarding the nature of the DCS-related symptoms both before and after FAO_2 and recompression treatments was required as well. Upon the commencement of my internship, my immediate job was to locate

complete DCS/ FAO_2 profiles, and to make follow-up phone calls to the DCS patients with incomplete case profiles so that enough data could be compiled to complete a meaningful study.

Data Collection

To begin the data collection we scoured the MSCC database for DCS cases. The located DCS cases were placed in a Microsoft Access file to allow us to easily gather and track full case profiles. We originally located 320 DCS cases where FAO_2 was administered. I reviewed each of these cases individually. Cases that indicated that FAO_2 was given within 6 hours of symptom onset and for a period of at least 20 minutes were marked for inclusion in the study. If any of the FAO_2 information was missing, the case was marked for follow up. Cases were also marked for follow up to determine the nature and severity of symptoms, mode of FAO_2 administration, dive profile information, and recompression treatment information. After reviewing the 320 DCS cases I determined that approximately 150 of these cases needed follow up to be included in the study. I also made the decision to conduct follow up phone calls to cases I had originally deemed complete to verify their accuracy.

To successfully complete my follow up phone calls, I modified my working hours to when I thought I'd have the greatest chance of reaching the subjects at their homes. A typical day started at 12:00 pm for me and went until about 7:00 pm, depending on what kind of luck I was having. Even with the modified hours, the follow up process was long and tedious. Over the first 3 weeks I had only made approximately 40 successful calls. However, despite my somewhat futile efforts, I was still enjoying my time at DAN throughout this process. My office was located in the heart of the medical portion of the DAN headquarters. My location allowed me to listen in on the calls received by the medics. I learned a lot this way about what kinds of maladies provide limitations on diving, and what kind of treatments can be used for the more common diving related injuries (marine life stings, ear infections etc). The conversations I had with the people I did reach were also extremely interesting. The divers I talked with were generally very open and willing to share their experiences with DCS with me. Through these conversations I was better able to grasp the nature of DCS and how FAO_2 may impact the illness. Interestingly, the majority of the follow up calls I made were to divers that were bent while diving within recreational limits. Finding this just verified for me the importance of having functional FAO_2 kits onboard dive boats.

After 3 weeks I decided to try and expedite the follow up process by designing a questionnaire I could send to divers via email. The questionnaire contained the same questions I would ask via telephone, but would allow divers to answer my questions on their own time. I had some initial success with these emails but their efficacy was limited as well. During the data collection process I had the opportunity to sit in on a meeting between Dr. Denoble, two other DAN researchers and a statistician at Duke. The purpose of the meeting was to determine how the FAO_2 study could be statistically analyzed to produce meaningful data. Several ideas, including survival analysis and basic logistic regression were tossed around, and some good progress was made, but at this meeting I began to understand just how complex the analysis for this study was going to be. The

reasons for the complexity were the number of variables involved and the limited number of complete cases to be reviewed.

By the end of my internship I had successfully completed more than 80 follow up interviews with divers who had experienced cases of DCS. I'll share the content of one of the more interesting of these cases. A man had been diving the previous five days of a scuba diving vacation in Micronesia. His last dive prior to the onset of DCS was his deepest of the trip, a 148 foot dive with a total bottom time of 38 minutes. The dive was within the limits of US Navy dive tables, the diver reported no complications with this dive and stated that he had performed similar profiles many times before. After surfacing, the diver described numbness and motor weakness in both legs. He was helped onto the liveaboard diving vessel where he began breathing an unknown nitrox mix since first aid oxygen was not readily available. After breathing the nitrox, the diver felt well enough to walk to his cabin under his own power. He rested while the crew transported him to a hyperbaric chamber on the island of Chuuk. He received a TT6 chamber ride at the facility there without a change in the remaining symptoms. The following day, new symptoms and complications appeared. The diver experienced complete paralysis of lower body, bowel/bladder problems, and severe nerve pain throughout the trunk of his body. Diver underwent three more chamber rides on Chuuk and two chamber rides on Guam. The diver reported no symptom resolution throughout these treatments. Additionally, treatment was complicated by the onset of a kidney infection contracted on Chuuk. When asked about residual symptoms appearing at the time of the interview, the diver answered that he was now a paraplegic, still experienced bladder/bowel problems, and had severe phantom nerve pain. Diver was undergoing physical therapy in an attempt to regain movement of lower body. This case was the most serious described to me, and it really gave me a new appreciation of just how severe and detrimental DCS can be. It also confirmed that DCS does happen, quite commonly, when divers are obeying the US Navy dive tables. Despite the terrible outcome of this case, the diver was very enthusiastic about trying to help with the research DAN was conducting. He agreed to talk to us again about his experience and even asked if we knew of other divers experiencing serious residual DCS symptoms that he could talk to and perhaps help. Conversations like the one described above were very rewarding and enlightening for me.

After completing my data collection, I composed a scientific paper using Dr. Denoble's previous first aid oxygen paper as a model. Due to time constraints, I used only 50 treatment and 50 control cases for my study, but I believe the paper provides a general idea of how DAN plans to examine the relationship between first aid oxygen and DCS once a sufficient number of cases are gathered.

Thanks

Thank you to the Our World-Underwater Scholarship Society and George Wozencraft for providing me with the unique opportunity to work with renowned researchers on projects relating to scuba diving medicine. Being able to interact and work with these researchers allowed me to experience first hand what goes into clinical research. From the DAN researchers I learned important details of scientific methodology and a great deal about human physiology. I would specifically like to thank Dr. Petar Denoble, who guided me through the first aid oxygen study, and Donna Uguccioni, my

internship coordinator at DAN. Both of these people made life much easier for me on day to day basis.

Part 2: Scientific Paper

Introduction

It is currently recommended that all cases of decompression sickness (DCS) and arterial gas embolism (AGE) be treated immediately with first aid surface oxygen (FAO_2). Providing FAO_2 to a diver experiencing symptoms of DCS may contribute to the successful resolution of symptoms mediated by harmful intravascular nitrogen bubbles. As first reported in the late 1800s, physiologists such as Bert and Zuntz have had success using oxygen as a treatment for DCS (1,2). Since then specific guidelines for the treatment of DCS have included the use of FAO_2 as an immediate treatment for DCS (3). Despite its widespread use, few studies have carefully documented clinical outcomes. One recent study suggests that divers who receive FAO_2 after onset of DCS symptoms require less time in recompression than divers that do not receive FAO_2, though the results of this study were inconclusive and limited (4).

Our current study reexamines this question through the collection of diving injury data through the Divers Alert Network (DAN) Medical Services Call Center (MSCC), and further analyzes the efficacy of FAO_2 as an immediate treatment for DCS. FAO_2 can be administered to divers through a variety of modes (demand valve, simple face mask, non-rebreather mask etc), at different times following symptom onset, and for different periods of time depending on the oxygen supply present. Successful analysis of the data collected may allow DAN to construct specific guidelines according to outcomes and to recommend desired modes and times of FAO_2 administration.

Methods

The MSCC is a computer program used by DAN to store information on all medical calls received, the dives performed, treatment provided, and information on the diver's symptoms. 50 treatment and 50 control cases were located using MSCC search procedures. Selection was random. Requirements for the treatment cases were that the divers' received FAO_2 within six hours of symptom onset and for a period of at least 20 consecutive minutes. The MSCC case file also had to be complete with information including dive profiles, dive complications, reports of symptom onset and resolution using the Scuba Epidemiological Reporting Form (SERF), and information on both FAO_2 and hyperbaric oxygen treatments. Cases lacking complete documentation were contacted via telephone for a follow up interview. The control cases did not receive FAO_2. After selecting the records, data analysis using ANOVA was performed to draw statistically meaningful conclusions.

Note: I only used 50 treatment cases and 50 control cases due to time constraints. The actual study may require far more cases for the sake of statistical accuracy. A power calculation is necessary to determine the number of cases necessary.

Results

Effect of FAO_2 on number of recompression treatments

Divers experiencing DCS symptoms who received FAO_2 within six hours of symptom onset for a period of at least 20 minutes required significantly less recompression treatments than those divers who were not administered FAO_2 ($p<0.05$). An average of 1.14 recompression treatments were required by divers receiving FAO_2 compared to 2.12 required by those not receiving FAO_2 (Figure 1).

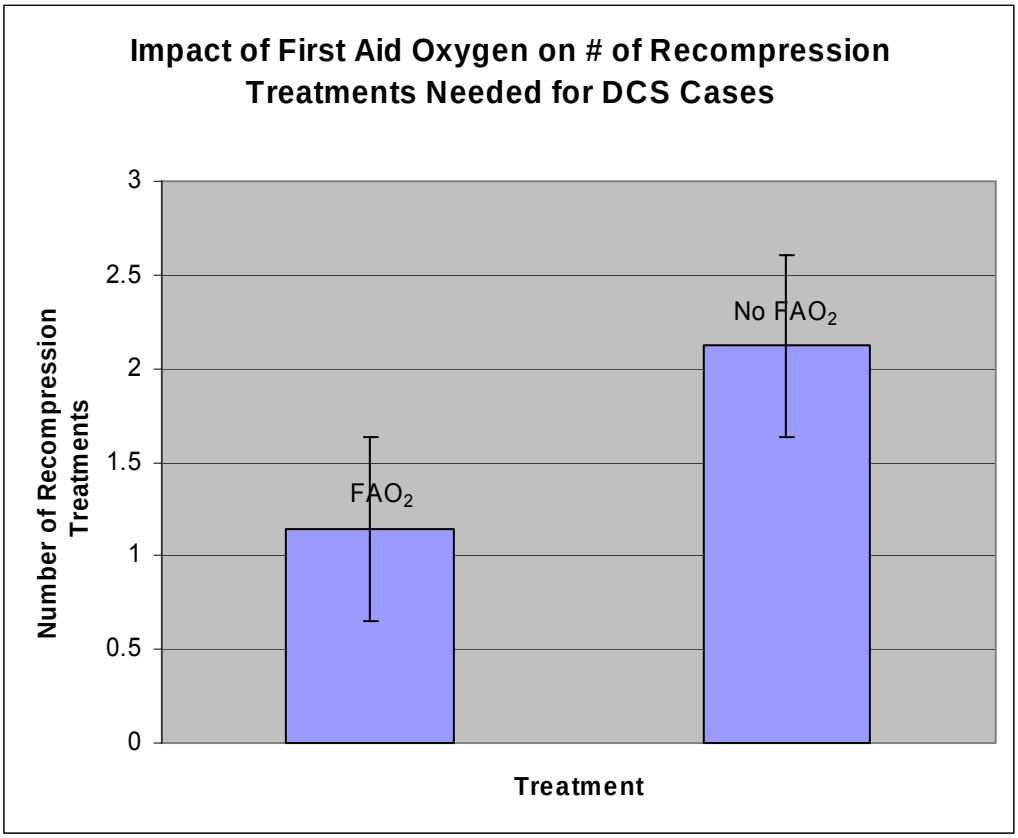

Figure 1: 50 treatment DCS cases (FAO_2 administered) and 50 control DCS cases (no FAO_2 administered) were gathered and compared to examine how many recompression treatments were required.

Effect of FAO_2 on symptom relief

The majority of the patients (70%) receiving FAO_2 experienced an improvement of symptoms. Smaller percentages experienced complete symptom resolution (18%) or no change in symptoms (12%), while none of these subjects worsened (Table 1).

Table 1	
Symptom Relief	Percent
Complete	18%
Better	70%
No Change	12%
Worse	0%

Table 1: Effect of FAO_2 on symptom relief was examined for the treatment group.

Time of FAO_2 delivery in relation to number of recompression treatments.

An ANOVA was used to compare the number of recompression treatments delivered to affected divers who received FAO_2 within two hours after surfacing, those who received FAO_2 greater than two hours after surfacing, and those who received no FAO_2. The analysis was significant (p=0.005), with the fewest recompression treatments . received by those in the less than two hour group (1.11), slightly more by those receiving FAO2 ≥2 h after symptom onset (1.2), and the most recompression treatments for those in the control group (2.12 treatments, Table 2).

Table 2		Recompression Treatments
Time of FAO_2 post surfacing		
< 2 h	35%	1.11
≥ 2 h	15%	1.2
No FAO_2	50%	2.12

Table 2: Timing of FAO_2 treatment in relation to number of recompression treatments required.

Mode of delivery in relation to number of recompression treatments

An ANOVA was performed to show that there was not a significant difference in the number of recompression treatments required based on the mode of FAO_2 administration (p=0.740, Table 3).

Table 3 Mode	Frequency	Percent	Recompression Treatments
demand valve	29	58	1.07
non-rebreather	6	12	1.17
simple face mask	9	18	1.44
unknown	4	8	1.25
Other	2	4	0.5
Total	50	100	

Table 3: Mode of FAO_2 administration in relation to number of recompression treatments required.

Discussion

It is clearly beneficial to receive FAO_2 in the event of DCS. Those who were administered FAO_2 within six hours of symptom onset for a period of at least 20 minutes reduced the number of recompression treatments by nearly half. Furthermore, 88% of the DCS cases that received FAO_2 either experienced improvement or complete symptom resolution. These findings support those previously reported (4). In an attempt to expand upon these previous findings, we also plan to ask whether the rapidity with which FAO2 is delivered and modes of delivery have distinguishable roles in symptom resolution. The best way to utilize FAO_2 remains inconclusive. There was no significant difference between the number of recompression treatments required by DCS patients in relation to the mode of FAO_2 delivery. Similarly, there was not a significant difference in recompression treatments between those who received FAO_2 within two hours after surfacing and those who received it greater than two hours after surfacing. The cause for this is likely that more serious cases had symptom onset earlier, resulting in earlier treatment, while less serious cases had later symptom onset and later administration. Though treatment came later with these cases, the reduced severity of the case likely kept recompression treatments deceivingly low.

Despite the lack of conclusive evidence supporting specific timing guidelines for FAO_2 administration, there is reason to believe that future studies may address this question. Studies in which DCS cases are stratified based on severity (neurological cases, cardiopulmonary cases, cases involving just pain etc.) may better suit projects involving FAO_2 timing. Production of this study would require the analysis of significantly more DCS cases than were performed in the discussed study. Continued collection and follow up of DCS cases in the MSCC database will eventually permit such a study. The real difficulty with undertaking the described project is establishing suitable control groups (DCS cases, stratified by seriousness, that did not receive any FAO_2).

Though no significant evidence was produced for which mode of FAO_2 delivery is best for DCS cases, in none of the examined cases was a nasal cannula used as the FAO_2 administration device. The nasal cannula has a low flow rate (2-6 L/min) in relation to some of the other mechanisms, and may not be as successful in the treatment of DCS. Finding no evidence of nasal cannula use in the study is encouraging because EMTs and the staff members of diving operations are properly treating their DCS cases.

Overall, it is useful to know that DCS cases are often at least partially resolved by FAO_2. But if improvement of DCS treatment is to be achieved, the continued documentation of DCS cases is required. Once sufficient case information is gathered, future, more detailed studies on timing and mode of FAO_2 delivery may be achieved. These studies could potentially lead to revised guidelines for FAO_2 treatment.

References

1. Bert, P. Barometric Pressure (La pression barométrique). Bethesda, MD: Undersea Medical Society. Originally published in 1878. Translated by Hitchcock MA and Hitchcock FA; 1978.
2. Zuntz, N. Pathogenese und Therapie der durch rasche Luftdruckänderungen erzugten Krankheiten. *Fortschr Med.* 1897; 15:632-9.
3. Moon, R, Sheffield, P. Guidelines for the treatment of decompression illness. *Aviat Space Environ Med.* 1997;68(3):234-43.
4. Longphre J, Denoble, P, Moon, R, Vann, R, Freiberger, R. First aid normobaric oxygen for the treatment of recreational diving injuries. *UHM.* 2004; 34 (1): 43-9.