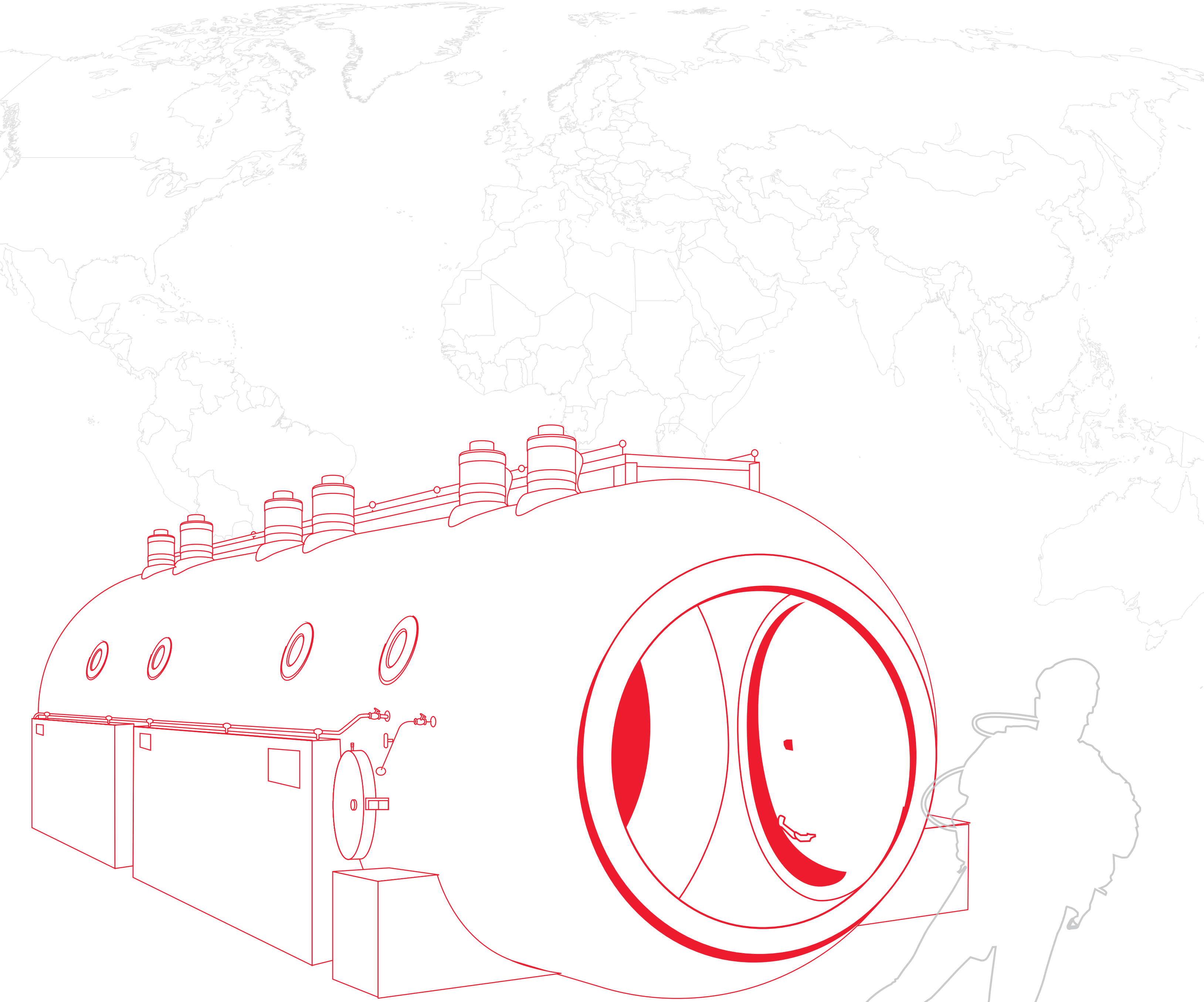

ANNUAL DIVING REPORT

2011 Edition

A Report on 2009 Diving Incidents, Injuries and Fatalities

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International DAN Offices

International DAN (IDAN) is comprised of independent DAN organizations based around the world that provide expert emergency medical and referral services to regional diving communities. These local networks have pledged to uphold DAN's mission and to operate under protocol standards set by the IDAN Headquarters. Each IDAN organization is a nonprofit, independently administered organization. Each DAN depends on the support of local divers to provide its safety and educational services, such as emergency hotlines. In addition, each country has its own rules and regulations regarding insurance. Each regional DAN is cognizant of the insurance regulations of its territory.

DAN

DAN America serves as the headquarters for IDAN. Regions of coverage include the United States and Canada.
Diving Emergencies: +1-919-684-9111 (accepts collect calls)

DAN Brasil

Region of coverage is Brazil.
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DAN World

Regions of coverage include the Caribbean, Polynesia, Micronesia and Melanesia, Puerto Rico, Guam, Bahamas, British and U.S. Virgin Islands, Central and South America, and any other area not designated below.
Diving Emergencies: +1-919-684-9111 (accepts collect calls)

DAN Europe

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Diving Emergencies: +39-06-4211-8685

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DAN Asia-Pacific

Diving Emergencies: 1800-088-200 (toll free within Australia - English only)
+61-8-8212 9242 (from outside Australia - English only)

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Regions of coverage include South Africa, Swaziland, Lesotho, Namibia, Botswana, Zimbabwe, Mozambique, Angola, Zambia, Zaire, Malawi, Tanzania, Kenya, Madagascar, Comoros, Seychelles and Mauritius.
Diving Emergencies: 0800-020-111 (within South Africa)
+27-10-209-8112 (outside South Africa - accepts collect calls)

1. INTRODUCTION

Neal W. Pollock

1.1 The Diver's Responsibility

Diving can provide a flexible foundation for a lifetime of enjoyment or professional satisfaction. The choice of environment, equipment and purpose create a wide range of opportunities to explore. It is the responsibility of the diver to be prepared for whatever diving is to be undertaken. This requires medical, physical and psychological fitness, appropriate knowledge, and physical competence. Since many of these elements can change over time, either acutely or chronically, it is important to re-evaluate readiness before every dive. An ongoing relationship with medical monitors, regular physical exercise, and sound nutritional habits can preserve or improve physical preparedness. Appropriate training, both initial and continuing, can help address knowledge and physical competence issues.

Maturity and sound judgment are critical for safe diving. The ability to resist peer pressure is particularly important. Each person should understand his or her strengths and limitations and choose accordingly when and how to act. The conditions and factors in play at the time of any dive need to be critically appraised and correctly addressed to help ensure problem-free events.

The diving enthusiast will commit a great deal of time mastering the physics, physiology, equipment and environment to be fully prepared. The material found in this diving report can help in diver preparation. We learn a great deal through our mistakes, but we can avoid unnecessary stress if we also learn from the mistakes of others. Most situations that end badly are the result of a chain of events, one that can often easily be broken by judicious action taken when appropriate. Being aware of practices and patterns that escalate risk can help ensure that unmanageable conditions do not develop. The range of incidents and victims described in this report should remind readers that accidents can occur anytime, anywhere, and to anyone.

A good foundation of training and experience facilitates rapid recognition of issues and the flexibility to address them effectively. Practicing skills until responses are automatic is a good start, but recognizing that each situation can have some idiosyncratic twist is also important. Case summaries can be a powerful teaching tool, safely placing the reader into a wide array of scenarios to stimulate the important 'What if?' thoughts that help divers critically evaluate and improve their readiness. Physical fitness and buoyancy should be thought about in this process. Problems with either or both can easily contribute to an unmanageable chain of events, but they can be overlooked since they are very difficult to fully assess after the fact.

1.2 Physical Fitness

Physical fitness is important for divers to operate safely under normal and emergent conditions and to be able to assist others in case of difficulty. Good physical fitness can often fit hand-in-hand with good medical fitness. Similarly, deficiencies in physical fitness increase the strain of any activity. Having less physical reserve can make an otherwise fairly benign set of circumstances much more serious, even life-threatening.

Defining a required level of physical fitness is difficult because of the broad range of conditions a diver may encounter. Arbitrary definitions are less important, though, if divers make physical fitness a core priority. While water is a supportive medium, it is important to remember that it is also an unforgiving one. Immersion alone puts a significant strain on the cardiovascular system, which is a particular concern for unfit or medically compromised persons. If the additional demands of diving leave little fitness reserve, divers should improve their physical fitness or limit diving to less stressful conditions. Increasing age will eventually compromise the safety of even the most fitness-conscious individuals. Since diving is a lifelong activity for many, a realistic appreciation of capabilities is important to know when diving practices should be modified or, ultimately, suspended.

Surprisingly little is known of the physical fitness of the typical recreational diver (Pollock 2007). It is a common misconception that a swim test will evaluate physical fitness; it is simply too skill-dependent to do so. A skilled swimmer may perform well even if unfit while a non-swimmer will perform poorly even if supremely fit. Swim tests are important to evaluate watermanship, but not physical fitness. Reasonable watermanship will be sufficient for comfort and good outcomes in many situations, but events can arise that demand substantial physical fitness to manage effectively.

The first test of physical fitness for diving should be an evaluation of the ability to handle typical tasks associated with diving. This includes wearing and carrying the required gear on the surface before and after diving as well as through water entry, the dive itself, and exit. Physical fitness reserves should be sufficient to handle emergent demands that can substantially exceed the normal burden. A good target would be to maintain a fitness level adequate to meet twice the normal demand of the most strenuous dive conducted. If this standard cannot be met it is still possible that a diver can dive with full service ('concierge') support. It is important to remember, though, that at this point, the diver may well not be able to offer meaningful support to a buddy. Concierge support is best provided by highly skilled and capable individuals, usually professional divers, who accept that the care they provide will not be reciprocated.

The retrospective assessment of physical fitness in the case of fatal incidents is extremely difficult. We report on body mass index (BMI) when height and weight data are available. BMI is not a measure of body composition, but it does provide modest insight into an individual's physical state. While BMI can be high due to well developed muscle mass, population trends indicate that higher values are more likely associated with increased fatness. While not a measure of physical capacity, BMI values are often inversely related to overall physical, and sometimes medical, fitness.

BMI is a reasonable benchmark to monitor; encouraging individuals to maintain exercise and nutritional practices to minimize or eliminate the typical upward creep that occurs with age. BMI is a measure of body weight:height proportionality used to predict body composition. It is computed by dividing body weight in kilograms by the squared height in meters. Weight in pounds is converted to kilograms by dividing by 2.2. Height in inches is converted to meters by multiplying by 2.54 and then dividing by 100.

BMI is often used as a convenient surrogate for actual body composition measures. Categorization by BMI (in $kg \cdot m^{-2}$): <18.5 = underweight; 18.5 to <25.0 = normal; 25.0 to <30.0 = overweight; 30.0 to <35.0 = grade 1 obesity; 35.0 to <40.0 = grade 2 obesity; and ≥40.0 = morbid obesity. Calculating waist-to-hip ratio (WHR) is a good follow on to computing BMI. WHR is computed by dividing the circumference of the waist at the narrowest point by the circumference of the hips at the widest point. Optimal target scores are ≤0.8 for men and ≤0.7 for women. Efforts to reduce higher scores are well-advised, particularly if BMI values are also higher than the normal category.

Aerobic capacity is a standard measure of overall physical fitness. Minimum aerobic capacity thresholds have been recommended for divers, but little direct testing has been conducted (Pollock 2007). Practically, the ability to run three miles nonstop in no more than 30 min reflects an aerobic capacity adequate to provide a reserve ample for most diving conditions. Unfortunately, there are no similar easy guidelines for cycling, swimming or most pieces of gym equipment since these are again skill-, equipment- or equipment-setting-dependent.

Strength can be evaluated through functional tests of lifting tanks or climbing ladders and/or steps while wearing tanks and weight belts. Samples of physical fitness standards and recommendations for scientific and professional divers are available in a recent review (Ma and Pollock 2007; Mitchell and Bennett 2008).

Smart divers limit their physical exercise during diving to reduce air consumption, minimize inert gas uptake and maintain most of their capacity in reserve. While moving tanks and other gear can help with core strength, maintaining physical fitness requires effort outside of diving. It is best when efforts are incorporated into daily life. Maintaining a high level of physical fitness provides important protection for all types of diving (and life) activities.

1.3 Buoyancy Control

Poor buoyancy control is a plague in diving that often begins with initial training. Instructors learn that if they put extra lead on students they will have less difficulty with them in early training. The same mentality afflicts divemasters who are anticipating the responsibility of leading a group of divers with unknown skill level through recreational dives. This practice, however, is a major disservice that can often become a chronic problem. The diver who grows accustomed to the feeling of wearing extra lead will be slow, or may never, appreciate the benefits of optimized buoyancy. Overweighting requires more air in a BCD, which demands more active management during descent and ascent, which uses more gas and becomes an additional task burden. Keeping more air in a BCD also contributes to poor trim while swimming, increasing the frontal surface and resistance to movement. The overweighted becomes both a distractor and an additional physical load. The former can impede the timely response to other issues, like middle ear equalization, and the latter reduces the physical reserve capability left for other demands.

Instructors sometimes remind divers to reassess their ballast weight but divers are more likely to remember what they do than what they are told. The comfort zone that is established often leads to inaction, and then complacency. Diver performance and safety would be improved by focusing on optimizing weighting and buoyancy control from day one. Since it will be difficult to get this push from those looking for an expedient situation, it is up to the individual diver to take responsibility for the optimization. Changes should be incremental but relentless, until the diver is so exquisitely aware that a 0.5 lb (0.2 kg) change in ballast weight is noticeable and the benefit in trim and reduced effort of minimal weighting truly appreciated. Shedding the weight will improve air consumption, reduce active buoyancy management, reduce the workload, and even reduce decompression stress (by reducing inert gas uptake and the surface effort of moving the load).

The final piece to weighting efforts is the placement of weights. The decision to move weight from a single weight belt to negatively buoyant cylinders and a range of other positions can improve comfort and trim. However, such distribution schemes can create additional hazards. There are circumstances, such as catastrophic BCD failure, when the ability to immediately ditch most if not all ballast weight could make the difference between an inconvenient event and a fatal problem. Minimizing the weight worn will reduce any discomfort of wearing weight on a belt, but in any case ditchability is a benefit that should not be underappreciated. Thoughtful use is critical, and what has gone wrong in many of the cases described in this report may remind readers that the hazards are not just theoretical, and the outcomes not always good.

1.4 The Annual Diving Report

The Divers Alert Network (DAN) Annual Diving Report presents information on diving activity and incidents collected by DAN. This report, the 2011 edition, is based on events occurring in 2009. Key sections include reviews of 2009 case data on dive injuries, dive fatalities, and breath-hold dive incidents.

Case reports are a popular tool for reviewing operational practices. Brief summaries are available for data gathered by DAN America for compressed gas diving fatalities (Appendix A), and breath-hold diving incidents (Appendix B). Brief summaries are available for fatal dive case data gathered by DAN Asia-Pacific (AP) for Australian waters (Appendix C) and other Asia-Pacific waters (Appendix D). The DAN AP data include both compressed gas and breath-hold cases. This is the first report in which complete summaries of data from another DAN unit have been included.

A list of publications and materials authored or co-authored by DAN America Research personnel and affiliated investigators from 2009 through 2014 is found in Appendix E. These include peer-reviewed research reports (primary literature), review articles (secondary literature), textbooks and book chapters (tertiary literature), editorials (opinion pieces requested by journals), papers published as part of scientific meeting records (proceedings), published research summaries presented at scientific meetings (abstracts), general audience articles (lay literature), and web-based training materials. Addressing as many levels as possible is an important strategy to communicate messages regarding diving safety. The productivity of the mission team is demonstrated by a high annual production rate.

Web-based training continues to be a useful tool for continuing education and to prepare individuals before they begin hands-on training programs. Further information on the DAN web-based programs can be found at http://www.diversalert-network.org/training/seminars/index.asp.

A list of presentations delivered by DAN America Research personnel and affiliated staff from 2012 through 2014 is found in Appendix F. Presentations were delivered at a range of venues, including private events, public events, special topic workshops, academic courses (university credit and continuing medical education), and scientific meetings. Again, the productivity of the mission team is evident by the high annual delivery rate.

A glossary of terms used in this and recent reports is located in Appendix G. It continues to grow with each issue.

Electronic portable document format (PDF) copies of all DAN America (DAN) reports continue to be available for download free of charge to anyone. It is our hope that wide dissemination of the material will improve hazard awareness and promote diving safety. This is in keeping with DAN's vision statement, "Striving to make every dive accident- and injury-free."

1.5 Data Collection by DAN America

The data discussed in this report represent a cross-section of events occurring in the recreational diving community, not an exhaustive one. The majority of the report (the first four sections and first three appendices) includes only data made available to DAN America and only cases that could be followed up with a manageable effort. The majority of sections are limited to cases involving residents or citizens of the United States or Canada. The exception to this is the breath-hold material (Section 4 and Appendix C), which includes cases without national or geographical restriction.

Figure 1.5-1 depicts the annual record of inquiries to DAN America Medical Services since DAN was formed in 1981. The total count for 2009 was 12,078.

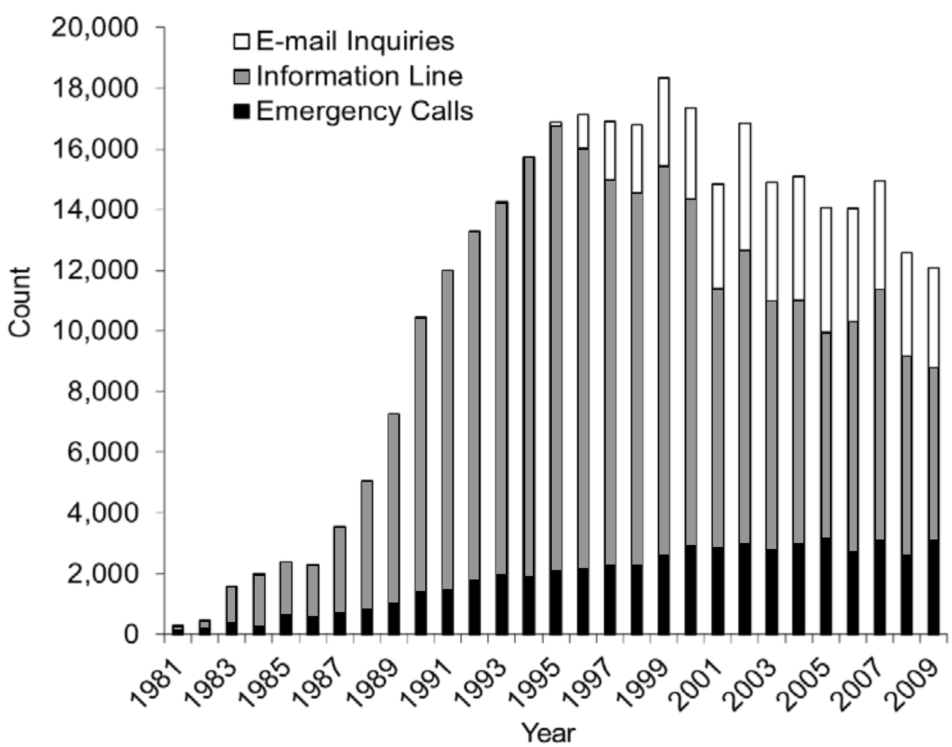

Figure 1.5-1 Emergency calls, information calls and e-mail requests for information

Information on dive injuries is captured by DAN America through the Medical Services Call Center (MSCC). A total of 9,133 calls or e-mails were logged into the MSCC system by DAN medics during the 2009 calendar year. The most common working diagnoses of the reported injuries were decompression sickness (DCS), non-diving-related, barotrauma, hazardous marine life-related, and trauma, respectively. Details are found in Section 2.

A major effort to track US diving fatalities was started in 1970 by Mr. John McAniff at the University of Rhode Island. This effort transitioned to DAN in 1989, expanding to include Canadian fatalities. A summary of the annual record of combined US and Canadian diving fatalities appears in Figure 1.5-2. The annual case intake (mean±standard deviation) for the 19-year period from 1970 through 1988 was 107±24, with a range of 66-147 cases. The annual case intake for the 21-year period from 1989 through 2009 was 89±12, with a range of 67-114 cases. The 2009 intake was 80 cases, just below the 2008 intake of 83 cases. The rate of case capture has been fairly stable for more than 30 years, with some expected fluctuation on an annual basis. It is important to appreciate that while we do have counts for events, we cannot compute incidence rates since we do not have meaningful estimates of the number of divers or the number of dives conducted in the covered area during this period. Information on the medical history, physical fitness, and capabilities of victims is rarely complete. The same shortcomings can be said for the details on the events associated with most accident. The available data is summarized in Section 3 and Appendix A.

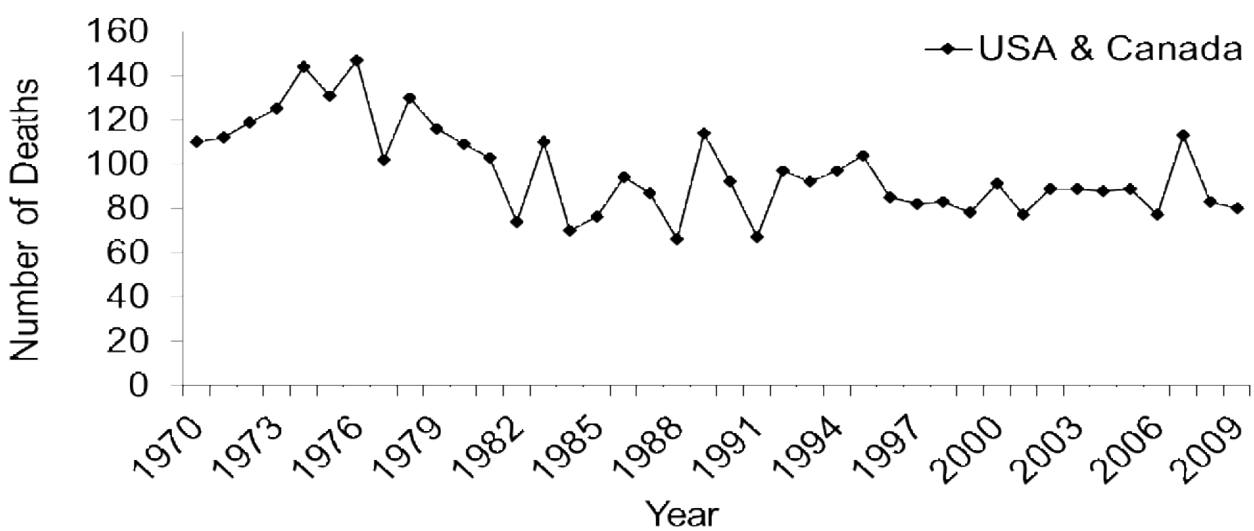

Figure 1.5-2 Annual record of US and Canadian diving fatalities

DAN America has collected unsolicited reports of breath-hold incidents since 1993. A dedicated effort to capture breath-hold case data was initiated in 2005, including cases from 2004 forward. Breath-hold sections were added to the annual report in 2005. Figure 1.5-3 summarizes the breath-hold cases recorded at DAN since 1993. The low numbers in the early years undoubtedly reflect the fact that these data were not actively sought. The sharp rise seen in 1997 likely reflects improved accessibility to reports available through the Internet. The jump in 2004 coincides with the dedicated collection effort. While there may have been an increase in the absolute number of incidents recently, it is also possible that reporting has increased through enhanced community awareness and better case capture.

The annual number of breath-hold cases captured in the six-year period from 2004 through 2009 was 58±20 (mean±standard deviation), with a range of 30-80 cases. A total of 79 breath-hold incidents were collected in 2009, 56 fatal (71%) and 23 non-fatal (29%). The ranked order of commonly identified disabling agents includes hypoxic blackout, health issues, animal-involved, boat strikes, environmental conditions, and entanglement, from most to least frequent. Details are found in Section 4 and Appendix B.

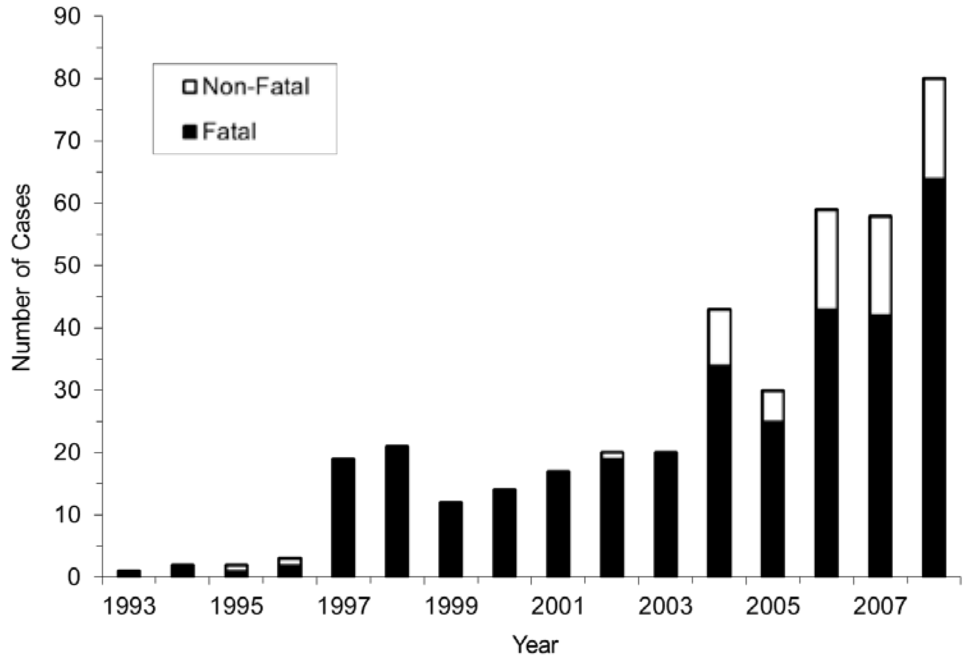

Figure 1.5-3 Annual record of captured breath-hold diving incidents

1.6 References

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2. DIVE INJURIES

Petar J. Denoble

2.1 Introduction

The Medical Services Call Center (MSCC), introduced in 2006, captures all phone calls and e-mails reaching the DAN Medical Services Department. These include information requests and requests for emergency assistance from divers, dive operators, first responders, and requests for consults from physicians. There are separate phone lines for emergency and non-emergency calls, but callers do not always distinguish between emergencies and information requests. In addition, DAN members have had an option to call Travel Assist services for non-diving-related injuries. Regardless of the line used, an actual injury is classified as a case.

The assistance for emergency cases that DAN provides does not replace a visit to a physician. Instead, DAN provides information to divers, patients and physicians as the course of action is developed. Assistance in locating and evacuating to treatment facilities is also provided. When the patient is in the care of medical professionals, DAN can offer expert advice based on queries by the treating physician. Ultimately, the treating physician will decide the necessary treatment.

Call records are a valuable resource to study the most common concerns that prompt divers to call DAN and the difficulty of problem recognition. In the past, our injury surveys were based on chamber reports that included only cases treated for suspected decompression sickness (DCS) or arterial gas embolism (AGE). Through the MSCC, we can look at all concerns regarding the possible injury that prompted calls to DAN, regardless of the final diagnosis. We also see a different mix of cases from those reported by hyperbaric chambers, which are usually limited to cases most likely needing recompression treatment.

2.2 Data Sources

A total of 9,133 calls or e-mails were logged into the MSCC system by DAN medics between January 01 and December 31, 2009. The frequency distribution of call origin is shown in Table 2.2-1. There were 6,350 information requests and 2,783 calls regarding actual cases. A "case" is defined as a call for assistance from somebody (or on behalf of somebody) who has an actual health problem (or concern) that needs medical evaluation and possibly care. Seven percent of information requests came through the emergency line, which is significantly less in comparison to previous year but is still higher than desirable. Ideally, the emergency line should not be used for information requests because it may interfere with calls of divers in real emergency. On the other hand, there was an increase of information requests coming through email (47% of all requests) which is a favorable trend. A total of 2,783 calls pertained to cases. Twenty-five percent came through the information line (+1-919-684-2948), five percent through email and eight percent were transferred from Travel Assist. Only 62% of cases came through DAN emergency line (+1-919-684-9111) which is staffed around the clock and best equipped to provide assistance. Email should not be considered a primary line of communication in case of emergencies. However, it is an excellent auxiliary line that enables the sharing of documents, dive profiles, images and other material, which may help in defining the problem and providing proper assistance.

Table 2.2-1 Origin of DAN calls entered into the MSCC in 2009

Source	Information requests Frequency	%	Cases Frequency	%	Combined Frequency	%
Information Line	2,827	45	684	25	3,511	38
Emergency Line	444	7	1,738	62	2,182	24
E-mail	2,999	47	126	5	3,125	34
Referred from Travel Assist	77	1	214	8	291	3
N/A	3	<1	21	<1	24	<1
Total	**6,350**	**100**	**2,783**	**100**	**9,133**	**100**

2.3 Working Diagnosis - Call Concerns

Each call logged by the MSCC is categorized by the main concern that required immediate attention. These categories are also a starting working diagnosis in the process of case management. A breakdown of the main concerns is shown in Table 2.3-1.

Table 2.3-1 Classification of main complaint by case manager

Main Concern	Cases		Information requests	
	Frequency	Percent	Frequency	Percent
DCS	608	22	35	1
Non-diving related	596	21	61	1
Barotrauma	372	13	38	1
Trauma	121	4	16	<1
Hazardous marine life injuries	101	4	20	<1
Other	812	29	110	2
Subtotal	2,610	94	280	4
Not assigned	173	6	6,070	96
Total	**2,783**	**100**	**6,350**	**100**

Cases are consistently classified in accordance with internal standards of procedure, while the information calls get classified only if there is a need for additional assistance beyond providing requested information. Fifty percent of cases involved non-diving medical issues (“non-diving related” and “other” in Table 2.3-1). In most dive related cases the main complaint was a suspicion of DCS (22%), followed by barotrauma (13%) and hazardous marine life injuries (4%).
The distribution of cases by main complaint was similar to previous years. The DCS-related complaints remain the most frequent acute health concern divers call DAN for assistance. This probably reflects both reporting and classification bias. Namely, divers are more likely to call DAN to report suspected DCS than for other concerns like ear problems. In addition, the DAN operator who is unable to examine the diver will apply higher sensitivity criteria and classify a case as DCS to be on a safe side.

2.4 Decompression Illness (DCI)

The DCI designation includes both DCS and arterial gas embolism (AGE). Because both conditions may present similar symptoms, many treating physicians do not make any distinction between them and diagnose both as a DCI. Distinguishing between the two conditions is not necessary to provide proper treatment for patient. However, for research and educational purposes it is worthwhile to try to distinguish them.

2.5 Arterial Gas Embolism (AGE)

AGE occurs when alveolar gas enters into arterial circulation and is carried to the brain. Bubbles in the brain circulation can produce sudden neurological symptoms like loss of consciousness or other impaired functionality. The underlying lung injury which opened the path for alveolar gas to enter arterial circulation may be minimal and undetectable. If local manifestations of lung injury are absent, the ability to distinguish AGE from DCS may be difficult or even impossible.

In 2009 MSCC data, there were 31 cases with explicit concerns or suspicion of AGE. Twelve were probable AGE, 10 were unlikely AGE and in nine cases there were insufficient data to make any classification.

Rapid ascent was reported in 11 cases and that was the main reason that AGE was a concern. In seven of those cases the AGE did not seem likely. In two cases the only additional complaint was a headache, two had signs of anxiety, one complained about cramping, another had hemoptysis, and one had unsteady gait that occurred 24 hours after surfacing.

In one case, the diver developed weakness and paresthesia of his entire left side (hemiparesis) five minutes after a dive to 90 ft (27 m) for 45 min using 38% enriched air nitrox (EAN). He self-administered oxygen for 30 min and his symptoms completely resolved. He then returned underwater to a depth of 30 ft (9 m) breathing 36% EAN for 30 min. He returned to the surface and again breathed oxygen for 15 min. He stated he had no symptoms at that time and had no return of symptoms. He also stated that he had an unrelated reverse block in his ear. He is seeking any additional information. The symptoms, the onset time and evolution were consistent with AGE. The surface oxygen breathing was proper first aid. Returning underwater was not wise since the symptoms of AGE can return (a relapse) even during hyperbaric oxygen treatment in a recompression chamber. It would have been more appropriate to continue breathing oxygen as long as the supply lasted while initiating the evacuation to the nearest emergency department.

One diver made a rapid ascent from a depth of 33 ft (10 m). Within 30 min he developed mid-sternal chest discomfort and some dyspnea. Within the next hour he developed paresthesia and weakness in his right arm. Another 30 min later he developed the same symptoms in his right leg. He was brought to a hyperbaric chamber for evaluation. At admission, his strength was 4/5 in his arm and leg. Breath sounds were normal in all fields. He was treated with US Navy Treatment Table 6 (USN TT6) and all symptoms resolved.

Loss of consciousness (LOC) was the main problem in seven cases. Five cases occurred immediately upon surfacing and lasted from a few minutes to one-half hour. All received first aid surface level oxygen. In two cases, divers lost consciousness at depth and were brought to the surface, this raising concerns that they may also have suffered from AGE in addition to the main cause of their LOC.

Loss of consciousness may have many causes, some of which may not be established even after extensive work up in hospital. In this case, a 45-year-old woman was brought to the hospital after diving earlier that day to a depth of 150 ft (46 m) for just five minutes. Her dive buddy reports that he felt a tap on his back and when turning around found her unresponsive. He immediately brought her to the surface. During the ascent, her regulator fell from her mouth. At the surface she was unresponsive and received CPR. She apparently briefly regained consciousness, vomited and lost consciousness again. EMS evacuated her to a local emergency department. On exam she had crackles in the left lower lobe of her lungs. The chest X-ray reportedly indicated adult respiratory distress syndrome (ARDS). Neurological examination showed normal status. This case may have been an unconfirmed case of immersion pulmonary edema. In another case, a 50-year-old woman lost consciousness at depth during a 38 ft (12 m) dive. She was brought to surface and CPR was initiated but she never regained consciousness. In this case, an acute cardiac event was suspected. In another case, a 29-year-old divemaster candidate became disoriented during his dive at 40 ft (12 m) and may have been low on air. He reportedly panicked and ascended rapidly. He reached the surface conscious but became unresponsive within minutes. He was quickly brought onboard the boat. His pupils were dilated and fixed. He was put on oxygen and evacuation was started. Twenty minutes later he arrived at a hyperbaric chamber. He regained consciousness shortly upon arrival. He complained of weakness, dizziness, and had some difficulty recognizing people, and visual disturbances associated with movement. A physician conducted a neurological examination and found only a “shaky” Rhomberg and impairment in his “finger counting” ability. He was treated with hyperbaric oxygen in the recompression chamber (USN TT6) with complete recovery.

In most reported cases, the loss of consciousness (LOC) did not last long. However, a history of a rapid ascent and LOC immediately upon surfacing should always be considered AGE unless another more probable cause is identified. Evaluation in an appropriate medical facility is recommended and recompression treatment may be administered regardless of the symptom resolution.

2.6 Decompression Sickness (DCS)

We have reviewed all cases labeled as DCS by case managers. There were a total of 643 cases with complaints of symptoms possibly related to acute DCS.

Pain was the leading complaint, followed by numbness and tingling. Most often, pain affected one shoulder and/or hand. In this case (63560), the caller stated he did a series of four dives over two days. All were multi-level and uneventful. The last dives were to 145 ft (44 m) for 40 min and 62 ft (19 m) for 62 min, respectively. Again, both dives were multi-level with very short bottom times at the maximum stated depths. Approximately 20 min after the last dive the caller began to experience right shoulder discomfort which did not change with position or exertion and, in his words, “throbbed like a toothache.” He was uncertain of any changes in strength and denied any numbness or tingling. The complaints in this case are quite typical of joint pain associated with DCS. The diver was advised that he needed medical evaluation and probably hyperbaric oxygen treatment.

Another case (65756) was reported by a cave diver. The caller said that he and his dive buddy had surfaced 30 min earlier after completing a decompression dive down to 91 fsw (28 msw) for 119 min. After carrying some of the stage bottles, his dive buddy started complaining of shoulder and elbow pain. No other symptoms were reported. A decompression dive of this duration by itself carries a risk of DCS and shoulder symptoms could have been caused by DCS. However, physical work immediately after surfacing, and especially lifting heavy objects like compressed gas cylinders, may cause joint pain by mechanical strain, or it may induce symptoms of DCS. Without evidence to rule out DCS, hyperbaric oxygen recompression is usually advised, as it was in this case.

The joint pain related to DCS may be dull or sharp but is usually not related to joint position. In this case the caller was a 52-year-old male technical diver calling from his home. He stated he had completed a series of four dives during a two-day period ending the previous day. It was trimix dive, first to 180 ffw (55 mfw) for 15 min; and the second dive after 3:30 h:min surface interval time (SIT) to 100 ffw (30 mfw) for 15 min (the times given were probably bottom times). One hour after his last dive, the diver experienced a sudden onset of persistent right shoulder pain. The pain was dull and non-positional. The diver graded the severity of the pain to be seven on a zero to ten intensity scale. The pain was radiating into his upper arm and interfering with his ability to sleep. He denied any other symptoms. No follow up was available.

Shoulder pain is frequently associated with some degree of local swelling, pain radiation to distal limb segment, or tingling.

Skin rash possibly related to DCS was reported in 91 cases and discussed in 30 more inquiries.

Skin manifestations include itching, rash, mottling, swelling and tenderness. Divers readily associate mottling with possible DCS. In the case of itching and swelling, the association was not straightforward. Itching is often attributed to contact with marine life. In the case of swelling, if breasts or abdominal skin were affected, both callers and case managers were likely to suspect DCS.

Numbness and tingling was the most common neurological symptom. When this is the only symptom, diving and non-diving causes are equally likely. When associated with other possible DCS symptoms, the diagnosis of DCS becomes more likely. There were a few cases where numbness and tingling were associated with limb weakness, likely manifestations of spinal cord DCS.

Spinal cord involvement is especially to be feared when the symptoms occur within minutes after surfacing from a dive. DAN received a call about such a case from a major hospital. The caller was an emergency room attending physician, who had in his care a 68-year-old diver who made a series of three dives while abroad. Ten minutes after the last dive, the diver began experiencing paresthesias in all extremities with rapid progression to motor weakness and profound changes in mental status. He was transported to the local hyperbaric chamber and treated with a USN TT6 with two extensions. After the treatment he was still paralyzed and he was evacuated by air ambulance to a mainland US hospital. Further treatment was established based on consults with DAN-associated diving medicine experts. The path to recovery in cases like this is long and slow.

Cerebral manifestations

Twelve calls reported symptoms initially classified as cerebral, but not all could be confirmed as related to DCI. The two typical cases with likely cerebral DCS are described below.

The caller stated that he had participated in two dives, the first to 90 fsw (27 msw) for 45 min using 32% EAN and after a 45 min surface interval, a second dive to the same depth and duration using 30% EAN. Five minutes after surfacing from his last dive, he developed weakness and paresthesia on his entire left side. He self-administered oxygen at the surface for 30 min. Within that time he reported that his symptoms completely resolved. He then returned underwater to a depth of 30 ft (9 m) breathing 36% EAN for 30 min. Upon return to surface he again breathed oxygen for 15 min. He stated that he had no symptoms at that time and had no return of symptoms.

In another case, the caller stated that she and her husband were diving earlier that day. They had been diving for five days and have participated in nine dives. Their deepest dive was 80 fsw (24 msw) and all dives were uneventful. The morning of the call, they dived to 80 fsw (24 msw) for 40 min with no problems reported and a normal ascent. Within 10 min after surfacing her husband complained of right lower quadrant abdominal pain with nausea and vomiting. The symptoms progressed to include right hemiparesis. High flow oxygen was administered on the boat. In the 15 to 20 min boat ride to shore his symptoms improved so that he had a return of movement on the right side but not full strength. He was taken directly to an emergency room for evaluation and treatment. At the time of the call, the husband was receiving a HBO treatment (USN TT6) and was much improved.

2.7 Ear barotrauma

Ear barotrauma was the main concern in 350 calls. Over 90% involved reports of ear pain or fullness associated with equalization problems. Based on reported symptoms, eardrum rupture was suspected in 11 cases, but many more cases were probably diagnosed with otoscopy.

This caller (63886) dived the day before her call. She was having some trouble equalizing at the surface, before descending. While descending, the difficulty persisted until she could not equalize anymore. At 25 fsw (8 msw), she felt a pop and a rush of air coming out of her ear. She had minor vertigo, but it subsided shortly. At the surface, she had slight dizziness. She took some non-steroidal anti-inflammatory medications, but her ear was still itching.

In another case (70903), the caller was a concerned son calling about his father. The father was diving earlier that day and had experienced the sensation of air escaping from his ear canal while trying to equalize. At the time of the call, he complained of mild fullness in the affected ear and denied experiencing any other symptoms. He had an appointment with a local physician the next day.

In both cases, the history was indicative of eardrum rupture. Divers often self-diagnose ear barotrauma. Sometimes they call DAN to obtain a referral to a local doctor. In some cases divers seek advice after pain and discomfort has lasted a number of days. While ear barotrauma is not a life-threatening condition, it does require urgent care. When it is associated with prolonged vertigo or dizziness, it should be considered an emergency. For more about first aid and treatment of ear barotrauma read here (link to dan,org/health/ear and diving).

Three cases of one-sided facial numbness and weakness were reported after experiencing equalization difficulty during a dive.

2.8 Vertigo

Vertigo was a leading symptom in 65 cases.
This caller (65522) described his last dive as a planned decompression dive. He experienced acute vertigo during ascent. The vertigo resolved within 20 ft (6 m) of the surface. He was able to meet all decompression obligations. After surfacing he had a slight headache and explained that he has a history of Meniere's disease and also had cold symptoms prior to diving. He continued to have a sore throat and slight headache. He denied any other symptoms. He was encouraged by the dive shop to contact DAN.

2.9 Chest pain

There were 51 calls where chest pain was the main complaint. This poses a dilemma since the differential diagnosis of the chest pain varies from the relatively benign to a time sensitive emergency that requires rapid evacuation. As with most cases called in from a remote dive location by either the diver or a partner, the diagnosis is hampered by difficulty in obtaining even a basic examination of the diver, and a lack of lab tests or imaging studies. The case manager often depends on the dive scenario associated with presenting symptoms to provide advice about the disposition. In the case of chest pain, the advice is usually to proceed to the closest emergency medical facility. This is consistent with the triage of chest pain that presents in the field for the general population.

Surprisingly, for this subset of chest pain complaints, the etiology may not be from coronary artery disease. Here is the breakdown of the actual cases reported.

Two cases of chest pain below the right breast were reported independently by two female divers in their 40s, one week and one month respectively, after the last dive. There were no singular factors to make an association with the diving exposure.

One case of saltwater aspiration with chest pain and associated "sweating" that started the day following the dive.

Forty-seven cases involved shallow diving (less than 35 fsw [11 msw]) or new divers. The majority of cases (49 out of the 51) reported symptoms consistent with pulmonary over-inflation syndrome (POIS). Two of the 51 were more experienced divers who conducted rapid ascents, one specifically in response to equipment problems.

Three cases involved children. Females appeared to be overrepresented, possibly more susceptible to injury, more comfortable with reporting symptoms or "dragooned" to participate unprepared. All cases seemed to have resolved.

2.10 Immersion pulmonary edema (IPE)

Immersion pulmonary edema is characterized by dyspnea, hemoptysis, and respiratory distress while immersed. After first being described as a rare condition in cold water scuba divers, the number of reported cases involving myriad conditions has increased.

There were 17 calls regarding patients with possible IPE in 2009. Since its complex and typically self-limiting nature can make it difficult to diagnose, it is impossible to distinguish which cases were truly IPE. Six cases were confirmed diagnosis of pulmonary edema by a treating physician or considered very likely based on symptom presentation. Two cases reported the patient having symptoms not typical of IPE. Limited information in nine cases made the determination impossible.

Of the six confirmed cases of IPE, two calls were from the patient's medical care team for consultation. Four calls came from divers reporting their incident retrospectively. Two of the six callers reported having had similar symptoms on separate occasions while diving. All six cases reported the patient having had a past history of cardiovascular disease or evidence of cardiac dysfunction at the time of the IPE event.

One self-reported case was from a 66-year-old male who experienced shortness of breath on a dive to a maximum depth of 65 fsw (20 msw) for a total run time of 45 min. He had a history of hypercholesterolemia, hypertension, and benign prostatic hyperplasia. Onset of mild dyspnea was noted on ascent and worsened progressively throughout the remainder of the dive. Upon surfacing, the diver was towed to shore, placed on oxygen, and taken to the local emergency department. Wheezing and crackling were audible on auscultation. Chest X-ray confirmed pulmonary edema. Complete symptom resolution occurred a few hours after onset. Follow-up with the patient's regular physician reported a "clean bill of health."

In another case in which IPE was considered, a divemaster called to report an incident with a 24-year-old male participating in a 'discover scuba' class with his wife. The diver was in the military and a heavy smoker but was otherwise in good health. The divemaster reported the diver as appearing anxious and coughing while at the surface of the water prior to descent. The group dived to 7 fsw (2 msw) for 13 min and then to 14 fsw (4 msw) for a few moments before the male diver surfaced. The divemaster and his wife followed him and found that he was unresponsive to commands and in respiratory distress, coughing up white, frothy sputum. The divemaster inflated the diver's BCD, removed his weight belt, and towed him to the boat. He was placed on oxygen and transferred to the local clinic. The diver remained conscious but incoherent and combative. There were no signs of focal neurological deficit or pulmonary barotrauma. Pulmonary edema was diagnosed, and the patient required ventilation. The outcome of this case was not revealed to DAN, and thus the cause of the pulmonary edema cannot be confirmed. While the severity of this case is not typical, there have been several published reports of death in scuba divers and snorkelers as a result of IPE.

3. DIVE FATALITIES

Petar J. Denoble, Jeannette Moore, Brittany M. Trout, James L. Caruso

3.1 Introduction

Injury is the leading cause of death for people under the age of 45 in the US. Each year, more than 187,000 deaths from injuries occur in the US and 32 million are treated for injuries in emergency departments. In 2009, more than 34,000 people in the US died and over 2.5 million people were treated in emergency departments after being in motor vehicle accidents. About 3,500 people died due to unintentional drowning and 350 drowned due to boating-related incidents (www.cdc.gov/Injury). In the same year, there were 117 deaths (80 in US and Canadian citizens) due to recreational scuba diving. Participation in scuba diving was estimated by the Sports and Fitness Industry Association (SFIA) at 2,970,000 or about 1.1% of the US population (Sport and Fitness 2014). Scuba injury causes one out of every 2,600 injury deaths and does not make the national priority list for injury prevention; but for the three million scuba divers, prevention of scuba fatalities is a priority. Injury data collection and analysis is the first step in prevention. Presentation of this data contributes to that purpose.

The Data Collection Process

DAN starts its data collection by first identifying scuba diving deaths worldwide. Each event, upon discovery, is classified whether it is possible to be followed up on or not. Most US and Canadian fatalities are tagged as follow-up cases and fatalities that occur in foreign countries or involving foreign nationals are tagged as no follow-up as it is virtually impossible to get additional details beyond what is found in news reports.

News reports, mostly online, are monitored constantly for keywords involving diving deaths and scuba. Other sources for notification regarding fatalities include notifications from families of DAN members and friends and acquaintances of the deceased who are aware of DAN's data collection efforts. Most importantly, the DAN Medical Services Call Center (MSCC) is a great resource as the DAN Medical Services Department usually helps in the management of any scuba diving event that is called in, whether the person is a DAN member or not.

Investigator and Medical Examiner Reports

Most of the scuba-related deaths in the US are investigated by local law enforcement agencies or the US Coast Guard (USCG) and are subject to autopsies. The investigation reports and autopsies are integral in DAN's research into the cause of scuba-related fatalities. Without access to these reports, it would be virtually impossible to compile enough data for analysis.

Each state in the US has its own set of regulations regarding the release of information in addition to compliance to the federally mandated privacy rule - the Health Insurance Portability and Accountability Act of 1996 (HIPAA). Some states consider investigation and medical examiner's reports to be public information and are released easily while others are governed by more stringent privacy laws. Florida and California are examples of states with straightforward protocols for requesting relevant reports. But even within states, the regulations which govern the ease in procuring reports can vary from county to county.

Local investigating agencies (sheriff and police departments) adhere to the privacy laws of their states as the medical examiners. However, since not all the information contained in their reports contain private medical information, they are able to release reports under the Freedom of Information Act (FOIA).

Reports for cases that are investigated by the USCG can now be requested from one central location in Washington DC. However, it can still take up to two years after the incident before a case is closed and information released. The USCG follows FOIA protocols by removing all personal and identifying information before releasing a redacted copy of the reports.

Reports from Witnesses and Next-of-Kin

DAN uses the Fatality Reporting Form to collect data from witnesses and family. The form may be downloaded from the DAN website (http://www.diversalertnetwork.org/files/FATform.pdf) or may be requested from the research and medical services departments. When necessary, the family of the decedent or his next-of-kin may be contacted to assist in the data collection. They may complete the Fatality Reporting Form and/or provide authorization for release of their family members' autopsy reports.

The online incident reporting form on the DAN website (https://www.diversalertnetwork.org/research/IncidentReport/) can also be used by family and witnesses to report a fatality and provide additional details regarding any scuba diving fatality.

Data Entry and Analysis

DAN research maintains the scuba diving fatality data in a secure server. Once all pertinent information have been gathered and entered into the database, results are analyzed and published in the DAN Annual Diving Report.

3.2 Geographic and Seasonal Distribution of Fatalities

Worldwide, DAN received notification of 117 deaths involving recreational scuba diving in 2009. This is shown in Table 3.2-1. Only the deaths of 80 US and Canadian recreational divers were actively investigated by DAN America. Reports of dive-related deaths from other regions were recorded but, due to geographical limitations, were not investigated.

Table 3.2-1 DAN-received notifications about fatalities by country

Region	Country	US & Canada Residents	Non-US & Canada Residents	All Cases
America	Bahamas	1	1	2
	Bermuda	1	0	1
	Canada	3	0	3
	Cayman Islands	5	0	5
	Netherlands Antilles	1	0	1
	Puerto Rico	0	1	1
	United States	58	2	60
	British Virgin Islands	0	1	1
	America Totals	**69**	**5**	**74**
Central America	Honduras	2	0	2
	Mexico	6	1	7
	Central America Totals	**8**	**1**	**9**
South America	Brasil	1	0	1
	Ecuador	1	1	2
	Trinidad and Tobago	0	1	0
	South America Totals	**2**	**2**	**3**

Table 3.2-1 DAN-received notifications about fatalities by country (continued)

Region	Country	US & Canada Residents	Non-US & Canada Residents	All Cases
Europe	Egypt	0	1	1
	France	0	1	1
	Germany	0	0	0
	Greece	0	2	2
	Scotland	0	3	3
	Spain	0	1	1
	United Kingdom	0	7	7
	Europe Totals	**1**	**15**	**15**
Asia-Pacific	Australia	0	1	1
	Guam	0	1	1
	Indonesia	0	1	1
	Malaysia	0	1	1
	New Zealand	0	4	4
	Philippines	0	4	4
	Singapore	0	1	1
	Thailand	1	0	1
	Vietnam	0	1	1
	Asia-Pacific Totals	**1**	**14**	**15**
	Totals	**80**	**37**	**117**

The 80 cases involved US (n=78) and Canadian (n=2) residents. Most US residents scuba fatalities occurred in the US (58 out of 78, 74%).

Table 3.2-2 shows the geographic distribution of domestic US fatalities by state or province in follow-up cases. Twenty-two US domestic scuba fatalities occurred in Florida,10 in California, and three cases were reported in British Columbia.

Table 3.2-2 Number of fatalities in US and Canada by state or province in 2005-2009 (n=61)

Accident State	2005	2006	2007	2008	2009
Florida	17	17	32	30	22
California	9	11	15	8	10
Hawaii	3	1	5	4	4
New Jersey	0	2	2	1	4
Washington	5	7	5	5	4
British Columbia	5	2	1	2	3
Massachusetts	3	1	3	3	3

Accident State	2005	2006	2007	2008	2009
Pennsylvania	2	0	2	0	3
Wisconsin	0	0	0	2	2
Arizona	0	0	0	0	1
Georgia	0	0	0	1	1
Nevada	0	0	0	1	1
Ohio	0	0	4	0	1
Rhode Island	0	0	1	2	0

Table 3.2-2 Number of fatalities in US and Canada by state or province in 2005-2009 (n=61) continued

Accident State	2005	2006	2007	2008	2009
South Carolina	1	0	0	1	0
Texas	3	0	2	1	0
Utah	0	0	1	0	0
Vermont	1	0	0	0	0
Virginia	0	0	0	1	0
Total	**68**	**59**	**93**	**71**	**61**

Figure 3.2-1 shows the occurrence of fatalities in 2009 by month and how it compared to the average number of fatalities in the same months from 2004-2008. In 2009, the distribution by month was similar to the five-year average.

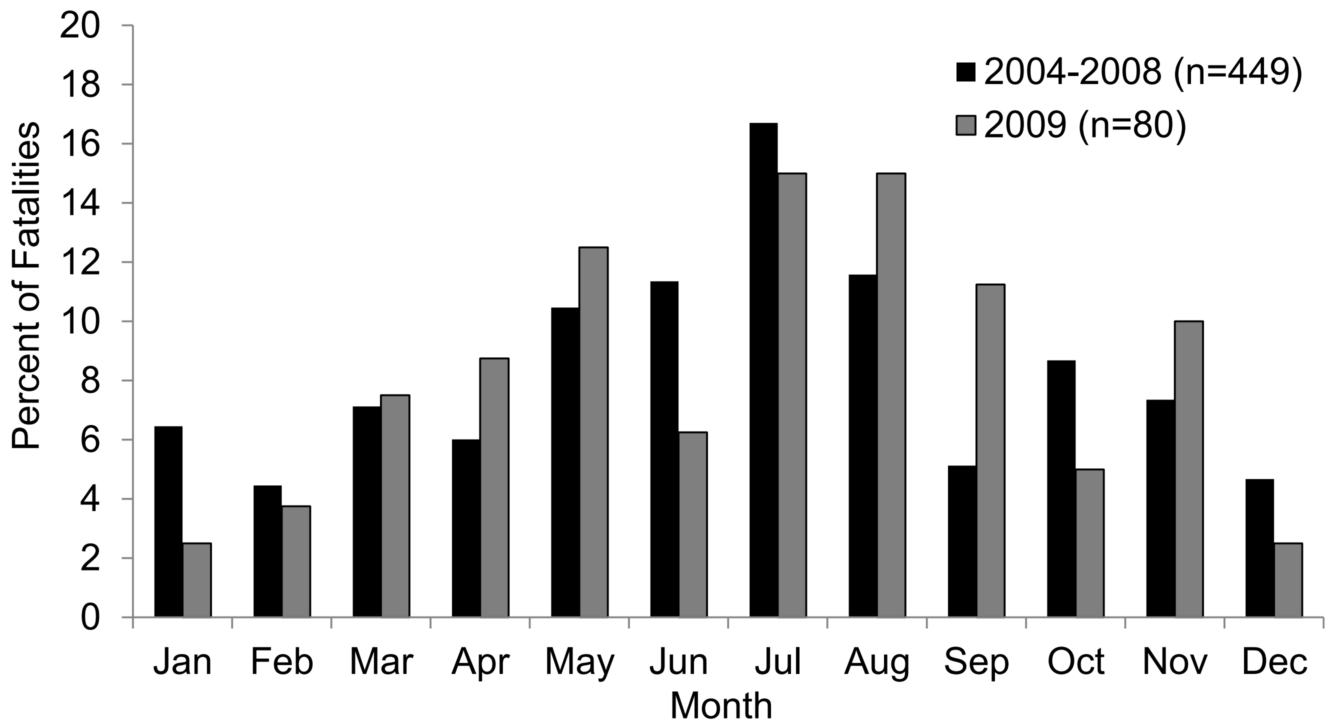

Figure 3.2-1 Monthly distribution of diver deaths

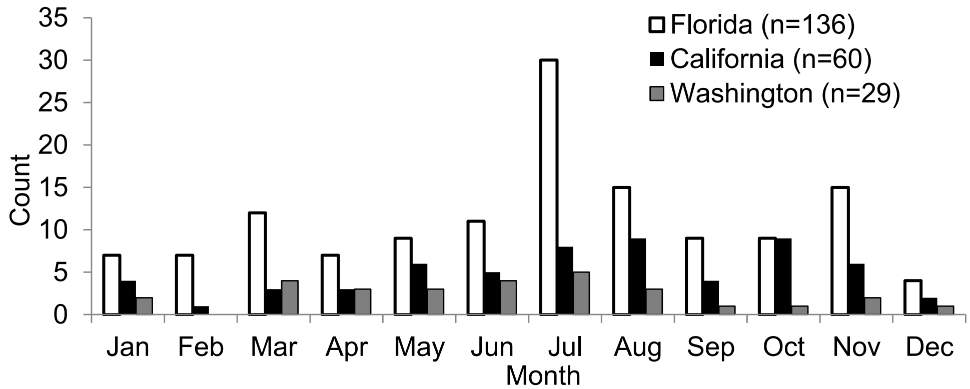

Figure 3.2-2 Month of accident by states with the most diving fatalities in 2004-2009

3.3 Source of information

Out of 80 cases, eyewitness reports were available for 40 cases. Twenty-two cases were not witnessed and for 13 cases, the witnesses may have been present but did not come forward.

Autopsies were conducted in 49 out of 80 US and Canadian cases and medical examiner reports were available for 40 cases as shown in Table 3.3.1. Coroner summaries were available for one case and one case included a death certificate. The body of the decedent was not recovered in three cases. An autopsy was not performed in two cases. It was unknown if an autopsy was performed in 24 cases. Witness reports were obtained in 40 cases (50%), 22 cases (27.5%) occurred without witness and for 13 cases (16%), there were no data.

Table 3.3.1 Medical examination data (n=80)

ME reports available	40
Autopsy conducted, report not available	9
Coroner summaries	1
Death certificate	1
Autopsy not performed	2
Body not recovered	3
Unknown/Missing	24

3.4 Age and Health of Decedents

Figure 3.4-1 shows the age distribution for dive fatalities. In 80% of cases, the victims were males, and in 20%, females. Seventy-five percent males and 65% of females were 40 years or older. Fifty-one percent of male and 41% of female victims were 50 years old or more. The median age of male victims was 52 years and the median age of female victims was 45 years. In the case of two males and one female, age is unknown.

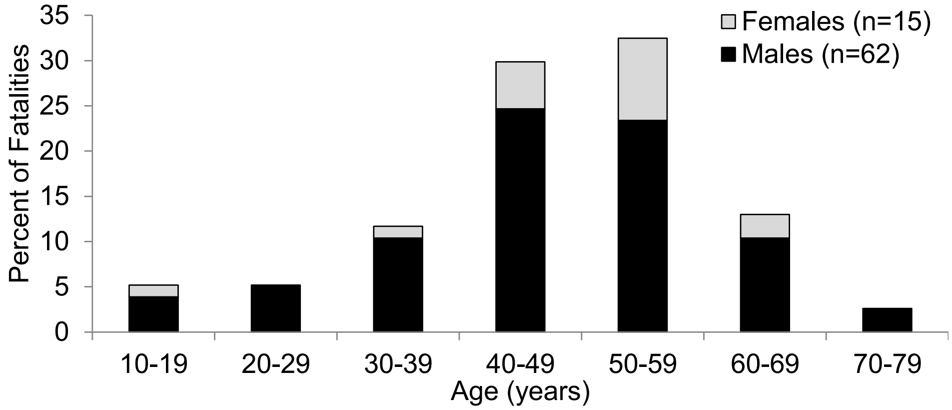

Figure 3.4-1 Distribution of fatalities by age and sex (n=77)

There were four teenagers among the victims.

A 15-year-old male was participating in an open water certification class with an instructor and two others. While descending, the victim began to have problems with his mask at 15 fsw (5 msw). He headed to the surface and the two divers in the dive group and instructor followed him. The instructor found the victim unresponsive at the surface. Further details were not available.

This 16-year-old, inexperienced diver became separated from his buddy. The victim was found near the shore in shallow water. No equipment problems were found by investigators, but the BCD was negatively buoyant, possibly indicating the diver did not inflate the BCD on the surface. The cause of death was determined to be drowning.

This 18-year-old female, unknown certification or experience level, surfaced from the dive and collapsed. The death certificate indicated the cause of death as air embolism. No further information was available.

This 19-year-old male (Case #09-28) was an experienced, certified diver. He made a scuba dive earlier, and the group he was diving with was taking turns using dive equipment. His scuba dive was to 44 fsw (13 msw) for 32 min, followed by a 30 min surface interval before he started freediving. The diver was spearfishing when he was seen to sink to the bottom. He was brought to the surface where resuscitation attempts were made but were unsuccessful. The only known medical issue was a childhood history of asthma. An autopsy was performed and the cause of death was determined to be an air embolism. This was based on the finding of gas in the heart. An air embolus may have been possible if the diver had taken air from another diver's regulator while freediving and then failed to exhale appropriately while ascending.

Medical history was, in most cases, incomplete. In 19 cases (24%), it was explicitly reported that there were no known medical conditions. The most frequently reported medical conditions in decedents were high blood pressure (HBP) (n=8; 10%) and heart disease (n=4; 5%).

Table 3.4-1 Known medical history on decedents

Current Medical Condition	count	%
Hypertension	8	10
Cardiovascular disease	4	5
Allergies	1	1
Asthma	1	1
Ear/Sinus	1	1
Diabetes	1	1
Flu/Cold	1	1
Lung Disease	1	1

The true prevalence of high blood pressure and cardiovascular diseases among victims is not known. The numbers in Table 3.4-1 represent a number of cases with known diseases. The medical history was not known for many cases and some of those who were reportedly healthy may have had undiagnosed hypertension, heart disease or diabetes as is often the case in the general population.

Out of four cases with a history of heart disease, two accidents were caused by mismanagement of the rebreather (cases #09-07, #09-27), and one diver died while cave diving without certification (#09-58). Only in one case (#09-20) did it appear that the diver felt ill at depth and died during an attempted ascent.

A history of asthma was known in one victim (#09-29) but asthma was not explicitly implicated in this fatality.

Body mass index (BMI) was available in 41 victims as shown in Figure 3.4-2. Twenty percent of victims' BMI classified as normal weight (18.5-24.9 $kg \cdot m^{-2}$), 37% as overweight (25.0-29.9 $kg \cdot m^{-2}$) and 41% as obese (30.0-39.9 $kg \cdot m^{-2}$). One teenage girl (2%) classified as underweight (<18.5 $kg \cdot m^{-2}$). Prevalence of obesity among scuba fatalities seems higher than in US population (Ogden et al. 2014). The data for scuba diving population is not available.

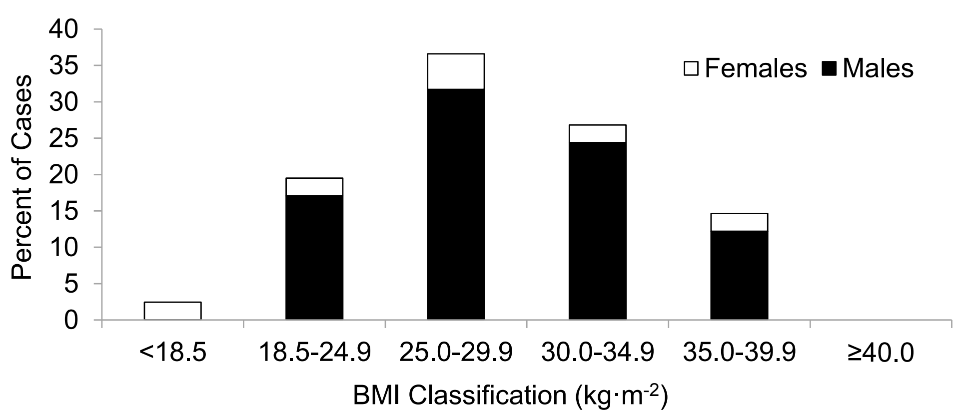

Figure 3.4-2 Classification of fatalities by BMI (n=41)

Trends of obesity prevalence among scuba fatalities are shown in Figure 3.4-3. As in the general population, obesity prevalence among adults remains steady in recent years with apparently random annual variation attributable to small numbers

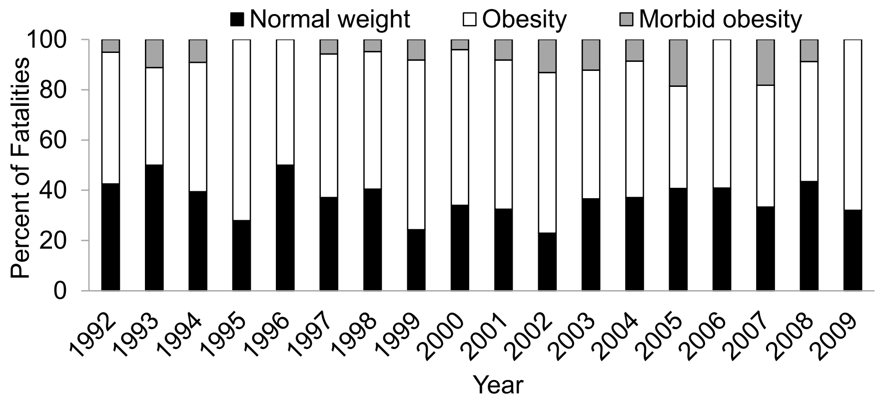

Figure 3.4-3 Obesity prevalence 1992-2009

of observed sample.

3.5 Diving Certification and Experience

Information about certification was available in 35 cases as shown in Table 3.5-1. Four victims were students. The youngest victim was a 15-year old boy in an open water course (discussed earlier). The age of the other students who died were between 41 and 68 years. One cause of death was attributed to a cardiac event. In one case, the victim's body was not recovered, and an autopsy was not performed in the fourth case.

Case #09-12: This 56-year–old male was a student in an initial open water certification class. He was a heavy smoker and took medication for a thyroid problem. The diver was among a group of students who submerged to 10 ft (3 m). He surfaced, called for help, and then went under again. The diver was brought to the surface where resuscitation efforts were unsuccessful. The autopsy showed severe three-vessel coronary artery disease and dilatation of all four chambers of the heart. Death was attributed to a cardiac event. A small remote infarct in the brain was also noted.

Case #09-57: This 68-year-old female was diving with a private divemaster during an open water certification dive. She had a history of “minor strokes” in the past. She was seen descending down a coral reef wall, beginning at 35 fsw (11 msw). The divemaster attempted to stop her but the victim pushed her away and continued her descent. The diver was last seen at approximately 100 fsw (30 msw) and continuing to descend. Her body was not recovered. Possible contributing factor: nitrogen narcosis.

Case #001: This 15-year-old male was participating in an open water class with his parents and an instructor (discussed previously in this report).

Case #09-30: This 41-year–old male was a student in an initial open water certification class. A significant medical issue was that the diver was an amputee and only had one leg, his right. The diver complained of weakness in his right leg prior to entering the water and he was apprehensive according to witnesses. He made a shore entry with an instructor and another student. The diver wore 34 lb (15 kg) of ballast weight. They descended to 15 ft (5 m) and spent about 14 min performing drills. For unknown reasons, the diver panicked and spat his regulator out. The instructor first tried to hand the diver the diver's octopus but without success. The instructor had no more success trying to provide his own octopus to the diver. The instructor held the regulator in the stricken diver's mouth and brought him to the surface where resuscitation efforts were unsuccessful. An autopsy was not performed and the death was most likely a drowning due to panic at depth while scuba diving.

Most victims had basic open water diving certification (9) but there were also two instructors, two master divers or assis-

Table 3.5-1 Diving certifications of fatality cases (n=80)

Certification	Count
None	4
Student	4
Basic/Open water	9
Advanced/Specialty	7
Master/Assistant Instructor	2
Instructor and above	2
Technical	7
Unknown	45

tant instructors and seven divers with technical certifications.

The experience of divers as indicated by the number of years since certification was known in only 31 cases. The details are shown in Figure 3.5-1.

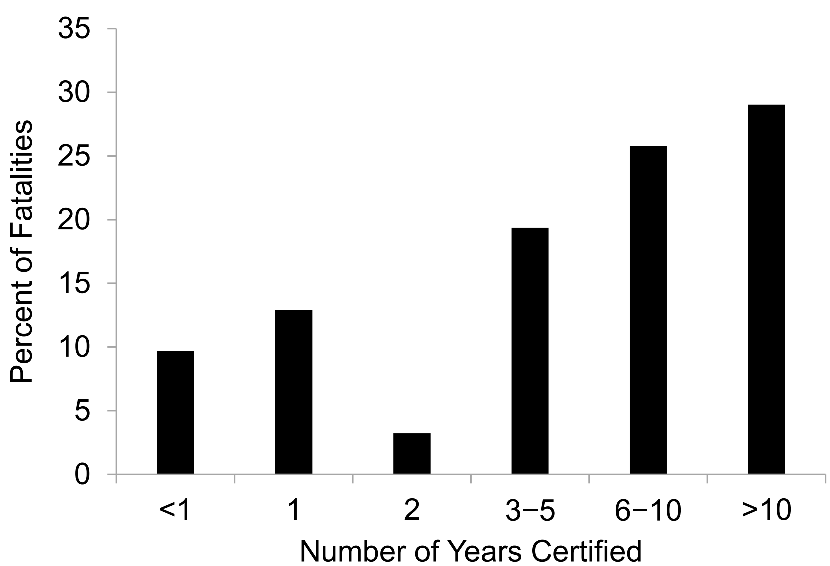

Figure 3.5-1 Number of years since initial certification of divers who died (n=31)

3.6 Characteristics of Dives

Figure 3.6-1 shows the type of diving activity during the accident. Information was available for 80 cases. Fifty-two (65% of known cases) of the fatal dives involved pleasure or sightseeing, 13 cases (16% of known cases) involved spearfishing, hunting or collecting game, 9 (11% of known cases) involved training.

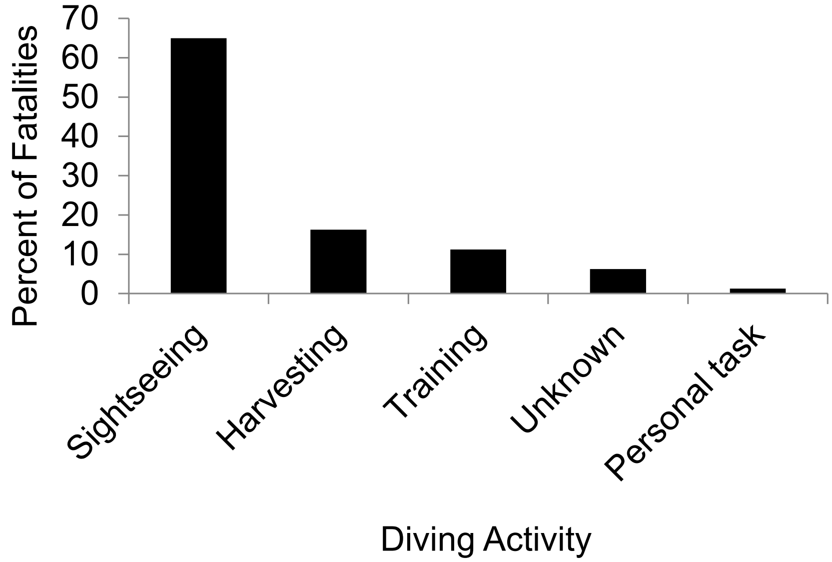

Figure 3.6-1 Diving activity (n=80)

Figure 3.6-2 shows the platform from which the fatal dives began. In most cases, the dive began from a charter boat or private vessel (n=55; 69% of known cases), which is higher than in previous reports. Dives began from beach or pier in 22

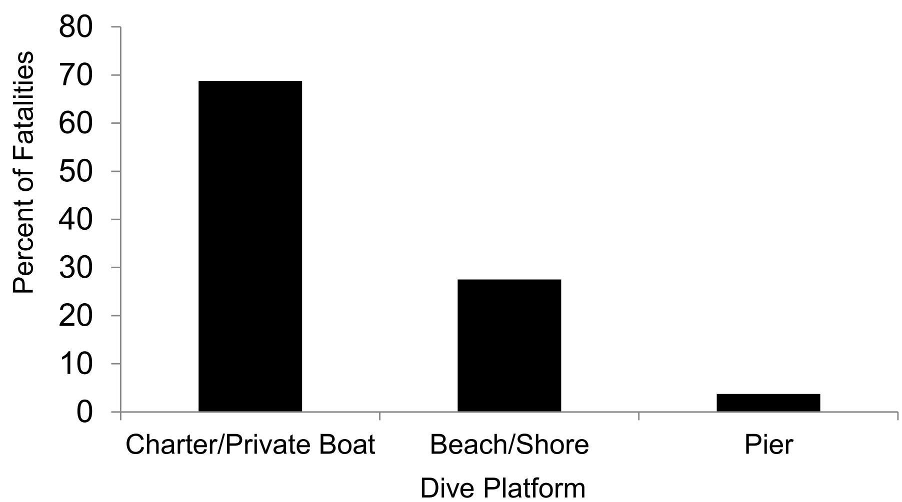

Figure 3.6-2 Dive platform (n=80)

cases (28% of known cases).

Most dives occurred in ocean/sea environment (n=65) with a significant number occurring in stationary freshwater (n=13) and rivers (n=2).

Visibility was reported in 35 cases. It was described as excellent (>50 ft [15 m]) in six, moderate (10-50 ft [3-15 m]) in 21 and poor (<10 ft [<3 m]) in seven cases. Some dive sites have poor visibility most of the time but inexperienced divers may not appreciate the risks involved.

Water condition (sea state) was reported in 33 cases (41% of total). Rough seas were reported in six cases. Currents were described as strong in nine cases.

Information about **protective suits** worn by divers was available in 47 cases (59% of total). Thirty-two of the victims wore wetsuits and seven wore drysuits. Drysuit did not appear to be part of the problem in any of the seven fatalities. Most of the fatalities involving drysuits occurred in cave, wreck and deep diving environments.

Figure 4.6-3 shows the **maximum dive depth** reported for known cases (n=53; 66% of total). Nineteen (24%) occurred in depth up to 30 ft (9 m), 15 (19%) in depth range of 31-90 ft (9-27 m), and 19 (24%) deeper than 90 ft (27 m). Data were not available for 27 cases (33%).

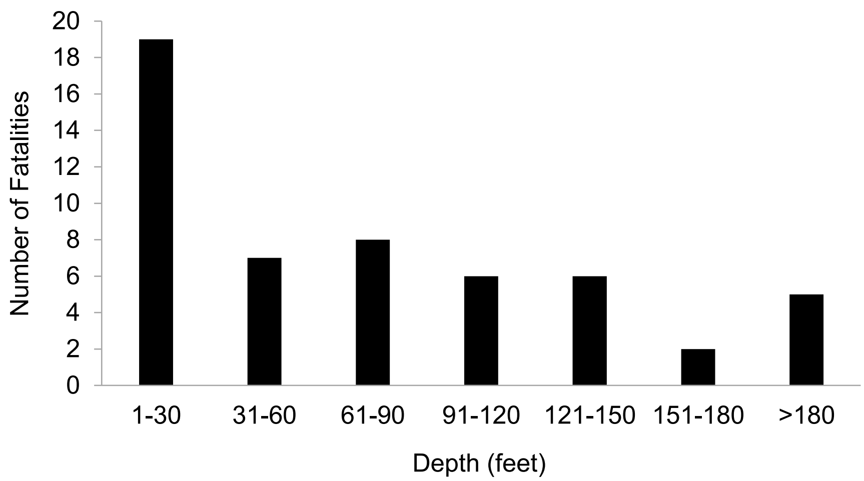

Figure 3.6-3 Maximum depth of accident dive (n=53)

While 12 of the fatal dives were intended as solo dives, most dives started with defined buddy pairs. Adherence to buddy system diving is difficult to establish retrospectively. When survivors notice that their buddy is missing it does not necessarily mean that the buddy intentionally separated; it may rather mean that nobody noticed the diver having problems that eventually contributed to cause of death.

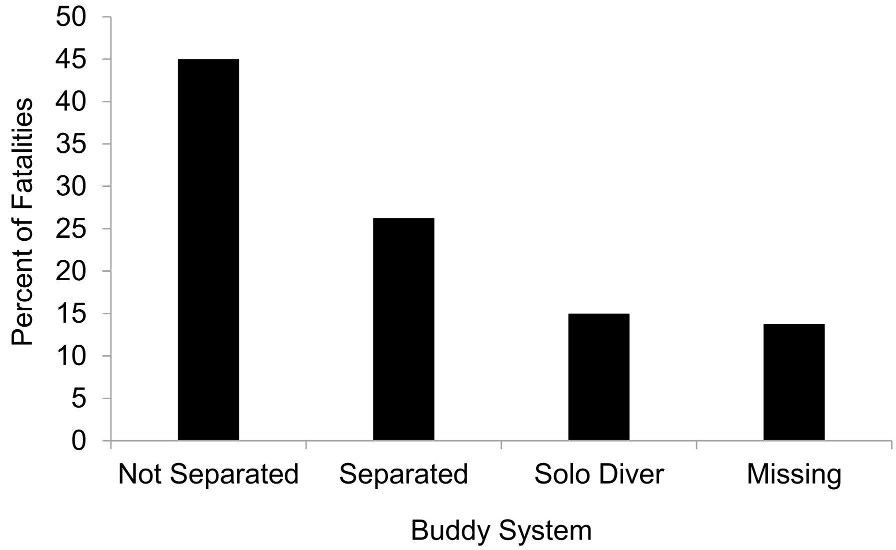

Figure 3.6-4 Buddy system (n=80)

Open-circuit scuba was used in 68 cases (85%), rebreathers in nine (11%) and surface-supply in three cases (4%). Two rebreather fatalities occurred on US territory, but they were not recreational cases. At least 13 more rebreather fatalities occurred worldwide in 2009 (n=24).

Breathing gas was compressed air in 42 cases (53%), enriched air nitrox was used with scuba in five cases (6%), and trimix in one. Rebreathers used unspecified gas mixes. Information was not available in 26 cases (33%).

3.7 Analysis of Situations and Hazards

We explored each case according to the phase of the dive in which the incident occurred, and the chronological chain of events ending in death.

3.7.1 Fatalities by dive phase

Dive phases included: a) on the surface before diving, b) descent/early dive, c) on the bottom, d) ascent, e) on the surface after diving and f) upon exiting the water. Figure 3.7.1-1 shows the distribution of fatalities by dive phase when the problem became apparent.

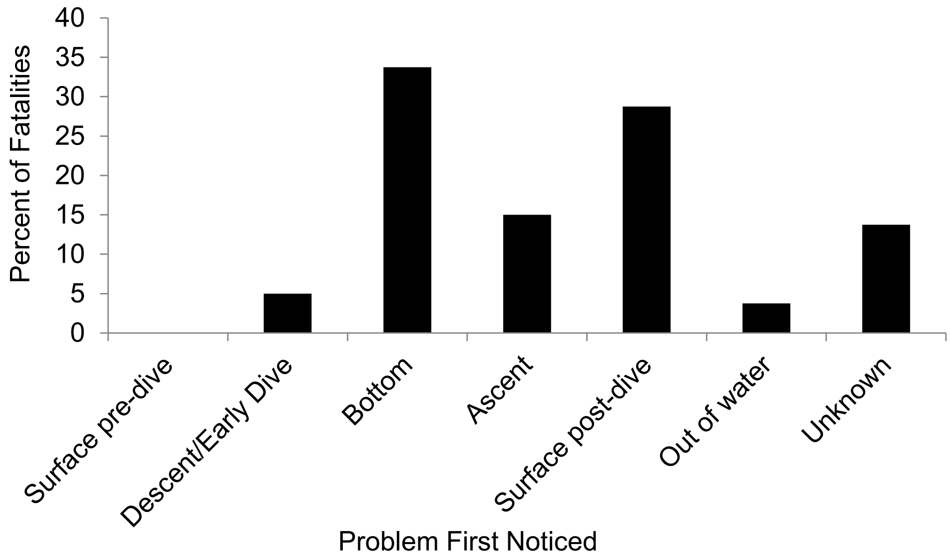

Figure 3.7.1-1 Dive phase when it became obvious that the diver had a problem (n=80)

The accident description was available in 69 cases (86% of total). Problems developed during descent in four cases (5%), on the bottom in 27 cases (34%), during ascent in 12 cases (15%), at the surface post-dive in 23 cases (29%) and after exiting water in three cases (4%).

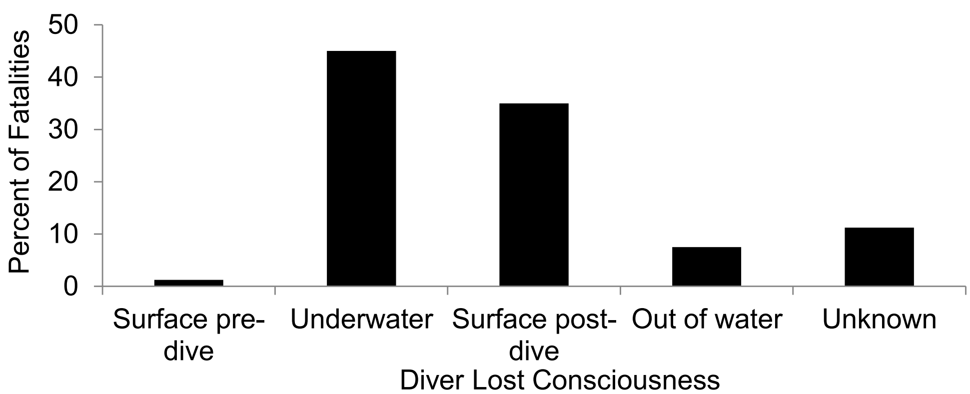

Figure 3.7.1-2 Dive phase when diver lost consciousness (n=80)

Figure 3.7.1-2 shows the distribution of fatalities by the phase in which the diver apparently lost consciousness.

The point at which the victim lost consciousness was reported in 71 cases (89% of total). Most victims (n=36; 45%) lost consciousness underwater. The victims were reported to have lost consciousness upon surfacing in 28 cases (35%), at the surface before they submerged in one case, and after exiting the water post-dive in six cases (8%).

There were five cases with first indication of problems occurring upon exiting water. Three cases appear to be related to an acute cardiovascular event. In one case, the diver lost consciousness after struggling to climb the boat's ladder. Another reported a sudden, severe pain in the upper back before collapsing. It turned out to be a dissecting aortic aneurysm. In the third case (#09-33), a diver with a history of severe cardiovascular disease reported chest pain and left arm numbness and tingling before cardiorespiratory arrest. In the remaining two cases, the cause of death was not obvious.

3.7.2 Causes of accidents, injuries and deaths

Determination of the causes was based on: a) autopsy findings and the underlying cause of death reported by the medical examiner; b) dive profile; c) reported sequence of events; d) equipment and gas analysis findings and e) expert opinion of DAN reviewers. The process is described in further detail in a published paper (Denoble et al. 2008).

Root causes, mechanisms of injuries and causes of death were not established in a large number of cases mostly because of missing information and inconclusive investigation. Based on available data, the most common known triggers were running out of breathing gas (13%) and rough seas (8%) (Table 3.7.2-1).

Table 3.7.2-1 Common triggers among recorded fatalities (n=83)

Triggers	**%**
Out of breathing gas	13
Rough seas	8
Buoyancy	1
Equipment problem	1
Entrapment	1
Other	14
Unknown	45

Table 3.7.2-2 Harmful events (n=83)

Harmful Event	**%**
Rapid ascent	16
Exertion	13
Wrong gas	2
Entrapment	2
Buoyancy	1
Equipment failure	1
Trauma	1
Insufficient air	1
Other	2
Unknown	44

The most common known harmful event were rapid ascent (16%) and exertion (13%) (Table 3.7.2-2).
The cause of death as established by medical examiners, in most cases, was drowning. However, according to expert reviewers, data indicated that the leading cause of disabling injuries was an acute cardiac event.

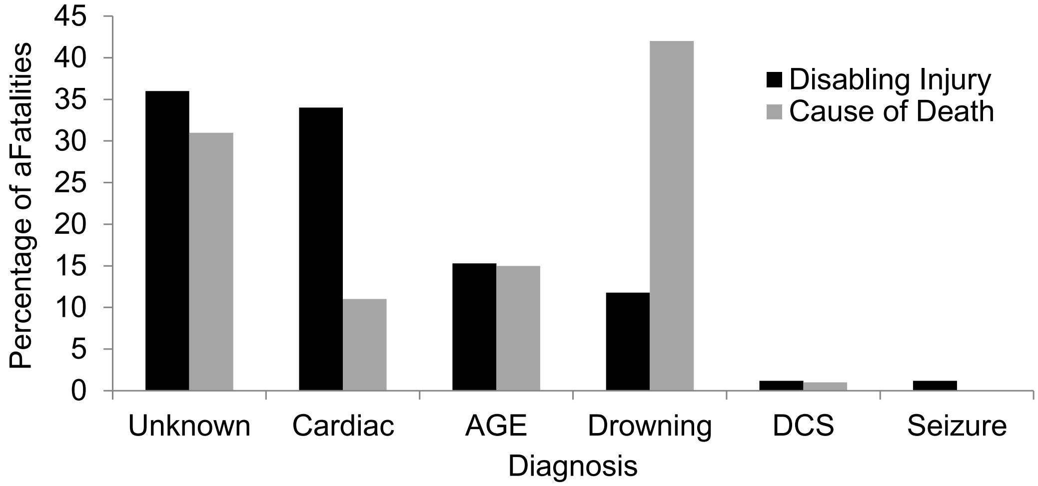

Figure 3.7.2-1. Distribution of disabling injuries (n=80)

3.8 Fatalities involving harvesting and spearfishing

Recreational harvesting was the second most frequent activity prior to an event leading to a fatality, as shown in Figure 3.8-1. Sightseeing was the most common activity with 52 cases (65%), recreational harvesting accounted for 14 cases (18%), nine divers (11%) were participating in training activities, four are unknown (5%), and one diver was involved in personal

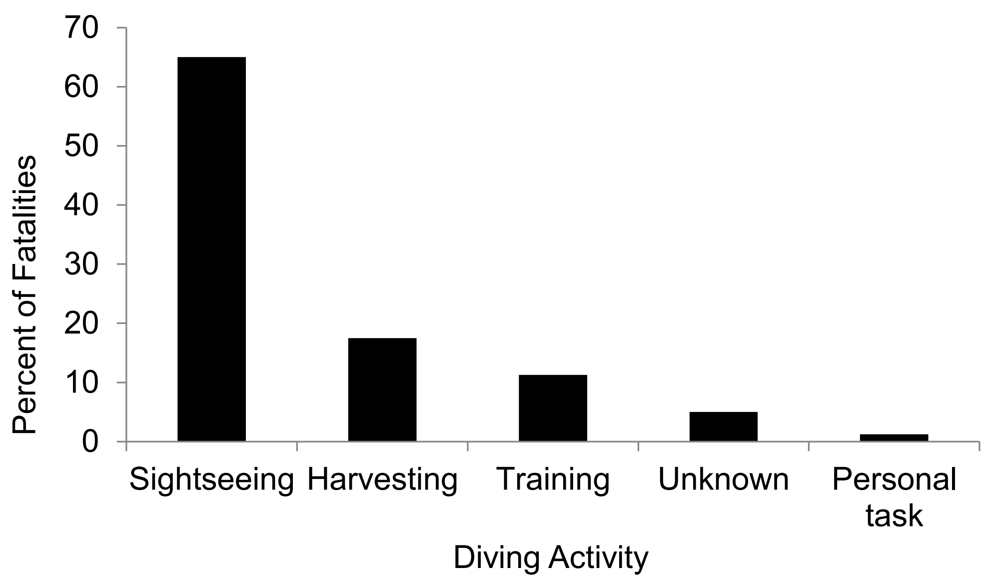

Figure 3.8-1 Diving activity (n=80)

equipment testing in a lake (1%).
The majority of the 14 victims who died while engaged in recreational harvesting were males between 19 to 67 years of age, and one 33-year-old female. The majority of the cases involved open-circuit scuba (11), but two involved surface-supplied air, and one a rebreather used for spearfishing. Five deaths (36%) occurred during the mini-lobster season in Florida. The mini-lobster season is the last consecutive Wednesday and Thursday in July. Florida has an eight month regular spiny lobster sport season typically from the beginning of August to the end of March (http://myfwc.com/fishing/saltwater/recreational/lobster/). Twelve fatality cases involving harvesting and spearfishing occurred in Florida, one in California, and one in New Jersey. Spiny lobster harvesting and spearfishing were the most common activities for the Florida incidents. The diver involved in the California fatality was diving for lobster, and the New Jersey diver was hunting lobster and scallops.

Buddy separation occurred in three cases, and three of the victims were intentionally diving solo.

The contributing factor to death was a cardiac event in three cases. In one case, the diver's past medical history was significant for severe coronary artery disease. Health issues other than cardiac were attributed to two deaths, for a total of five cases with health problems as contributing factors. According to BMI values, five divers (36%) were overweight, four (29%) were obese and one diver was morbidly obese. This is similar to the prevalence of obesity among recreational divers and in the general population. However, regarding exertion levels involved with a lobster hunt and usual association of poor fitness with obesity, this may have been a contributing factor in some cases. Mixed drug intoxication was a contributing factor in two fatalities.

Equipment failure contributed to two fatalities. In one case, the equipment was not assembled properly by the diver, as the inflator hose was found detached by investigators and a witness statement claimed the diver's tank strap was loose as he entered the water. In the second case, a diver on surface-supplied air became distressed when the hose became detached and he lost his fins.

Arterial gas embolism (AGE) was determined as the cause of death in one case. However, the investigation findings are not conclusive. The diver had been scuba diving earlier in the day, and then went breath-hold diving to spear fish. An autopsy was performed and the cause of death was determined to be an air embolism. This was based in the finding of gas in the heart. An air embolus would be suspected if the diver had taken air from someone else's regulator while breath-hold diving and then failed to exhale appropriately while ascending. In this case, the gas in the heart may have been post-mortally freed residual nitrogen from previous scuba diving.

One out of air/rapid ascent incident occurred, which resulted in an AGE. A propeller strike injury contributed to one cause of death. The diver surfaced away from the boat and more than 300 ft (91 m) from the dive flag. He was struck by the propeller of a passing boat and died as a result of those injuries.

The diver who died while diving with a rebreather to harvest lobsters and scallops was a 42-year-old male. He was an experienced diver. He dived at a wreck site using a scooter. After an uneventful first dive with a group, he went for a second dive alone. A fellow diver found the victim 1.5 h later on the bottom at 125 fsw (38 msw), already lifeless. Gear and scooter were still attached but one gas tank was missing. Two divers brought him to the surface and aboard the boat. CPR, first aid surface oxygen, and AED deployment were attempted but a shock was not administered. The Coast Guard airlifted him to the nearest station where he was pronounced dead. No additional details about the state of his equipment or possible causes were available. However, he reportedly suspected before the dive that the battery of his scooter may not last long enough. Diving with a rebreather, using a scooter and hunting for lobsters seem to be an overburdening multitasking situation for a diver and may be considered an unsafe diving practice.

Detailed description of cases is available in Appendix A. Table 3.8-1 shows the list of cases involved with harvesting and spearfishing.

Table 3.8-1 Fatality cases involved in harvesting and spearfishing

Case #	Cause of Death	Note
09-03	Drowning	Equipment problem
09-54	Drowning	Mixed drug intoxication
0002	Drowning	Using scooter, harvesting lobsters and scallops
09-32	Cardiac	Health problem
09-55	Drowning	Mixed drug intoxication
09-34	Drowning	Struggle with a large fish
09-33	Cardiac	Health problem
09-10	Drowning	Health issues
09-36	Drowning	Equipment problem
09-01	Cardiac	Health problem
09-16	Body not recovered	Uncertified diver using hookah for the first time
09-19	Drowning	Out of air, AGE
09-28	AGE	Breath-hold spearfishing after scuba dive

3.9 Rebreather fatalities

We learned of 24 rebreather cases in 2009 that occurred worldwide. The distribution of rebreather fatalities by country is shown in Table 3.9-1. DAN attempted follow-up in eight recreational cases that occurred in the US and one that occurred

Table 3.9-1 Number of rebreather fatalities by countries

Country	2006	2007	2008	2009
United States	6	3	6	10
United Kingdom	5	4	2	4
Greece	0	1	0	2
Canada	0	1	2	1
France	0	2	2	1
Italy	3	2	1	1
Israel	0	0	1	1
Thailand	1	0	0	1
Philippines	0	0	0	1
Malaysia	0	0	0	1
Cypress	0	0	0	1
Croatia	2	0	1	0

Country	2006	2007	2008	2009
Germany	1	0	1	0
Ireland	0	2	0	0
Switzerland	0	2	0	0
Belgium	1	0	0	0
Norway	1	0	0	0
Spain	0	1	0	0
Egypt	1	1	1	0
South Africa	0	1	0	0
Micronesia	0	0	1	0
Japan	0	1	0	0
Australia	1	0	0	0
New Zealand	0	0	1	0
Total	**22**	**21**	**19**	**24**

in Canada. Two cases that occurred in the US were not recreational, therefore follow-up was not pursued.
The nine cases followed up all involved male divers, ranging from 39 to 51 years of age. All were experienced rebreather divers except one who was in training. Diving activities included sightseeing (n=3), cave diving (n=2), wreck diving (n=1), spearfishing (n=1), and rebreather training (n=1). Dive activity was unavailable in one case. Four victims were diving solo, three with a buddy, and information was unavailable in two cases.

For six cases, there were witness statements describing when it was noticed that the victim was aware of an initial problem. All six described that the victims were first noticed to be in trouble at depth.

Four of the nine requests for medical examiner and investigative reports were granted, four were unavailable and one case did not have an autopsy performed. In the four cases where autopsy and investigation findings were available to review, two trigger events were equipment problems, one a health problem, and one loss of breathing gas. According to available BMI values, one victim was considered normal weight (18.5-24.9 $kg \cdot m^{-2}$), one overweight (BMI=25.0-29.9 $kg \cdot m^{-2}$) and two obese (BMI=35.0-39.9 $kg \cdot m^{-2}$). Two victims had a significant medical history of heart disease. One of which had triple bypass heart surgery months prior to the incident.

3.10 References

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4. BREATH-HOLD DIVE INCIDENTS

Neal W. Pollock

4.1 Introduction

Breath-hold diving is defined as in-water activity involving some diving equipment, but no self-contained or surface-supplied breathing gas. Breath-hold divers operate in a wide range of environments, pursue an assortment of goals, and wear various combinations and designs of suit, external weight, mask, snorkel and/or fin(s).

Common breath-hold activities include snorkeling, spearfishing, collecting and freediving. Snorkelers may remain completely on the surface with no purposeful breath-hold, or they may use breath-hold in typically limited surface diving efforts. Breath-hold spearfishing incorporates the act of underwater hunting for food into the breath-hold exercise. Collecting generally refers to underwater hunting without spear devices. Maximizing breath-hold time and/or depth is generally not the primary motivator for either spearfishing or collecting. The challenges of the hunt, however, can encourage divers to push their limits. Freedivers are explicitly employing breath-hold techniques, with or without descent from the surface. Increasing breath-hold time and/or dive depth are common goals. The nature of the dives will vary dramatically with the individual skill and training level of participants.

Competitive freediving has grown in popularity in the past two decades. Discovering a talent for breath-hold performance can rapidly catapult a competitor from novice to elite status. The field has developed rapidly as an extreme sport. The International Association for the Development of Apnea (AIDA; http://www.aida-international.org) recognizes numerous competitive disciplines. The organization tracks record performance and ensures compliance with accepted safety standards. The disciplines and current record performances are summarized in Table 4.1-1. These records are not shown to promote competition, only to demonstrate that breath-hold diving can be quite different from the classic view of skin diving activity.

Table 4.1-1 AIDA-Recognized Competitive Freediving Disciplines and Record Performance (current February 2015)

Discipline	Description	Record Performance Male	Record Performance Female
Static Apnea (min:s)	resting, immersed breath-hold in controlled water (usually a shallow swimming pool)	11:35	9:02
Dynamic Apnea - with fins (ft [m])	horizontal swim in controlled water	922 (281)	768 (234)
Dynamic Apnea - no fins (ft [m])	horizontal swim in controlled water	741 (226)	597 (182)
No-Limits (ft [m])	vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver	702 (214)	525 (160)
Variable Weight/ Ballast (ft [m])	vertical descent to a maximum depth on weighted sled; ascent by pulling up a line and/or kicking	476 (145)	417 (127)
Constant Weight - with fins (ft [m])	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	420 (128)	331 (101)
Constant Weight - no fins (ft [m])	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	331 (101)	230 (70)
Free Immersion (ft [m])	vertical excursion propelled by pulling on the rope during descent and ascent; no fins.	397 (121)	299 (91)

Extensive safety and disqualification protocols have kept the incident rate in competitive freediving extremely low (Fitz-Clarke 2006). The same level of safety does not always exist outside of organized events. The risk of injury or death is higher for breath-hold divers who do not have proper training or who fail to ensure the presence of adequate safety backups when pushing their limits. Educational efforts are critical since it requires little equipment to practice breath-hold. The lack of equipment definitely should not be equated to inherent safety. Breath-hold divers are susceptible to the physiological stress of immersion, hypoxia, hypercapnia, and, if diving vertically, to potentially immense squeeze forces. Loss of consciousness is the most obvious concern with breath-hold diving. Additional risks include entanglement, entrapment and problematic boat or animal interactions.

DAN began active collection of breath-hold incident case data in 2005. The initial effort included a retrospective review of cases from 2004 (those reported to DAN or found through active Internet searches). Automated keyword searches were then established to capture new reports as soon as they appeared online. A database was developed to target information of primary interest. Details on the structure of the database can be found in the proceedings of the 2006 breath-hold workshop (Pollock 2006). Unlike the data analyzed by DAN for compressed-gas diving accidents, the breath-hold incidents include cases without geographical restriction. Reviews of breath-hold incidents have been included in DAN annual diving reports since 2005. Electronic copies of these reports are available for download at no cost (http://www.diversalertnetwork.org/medical/report). The annual number of cases captured from 2004 through 2009 (mean±standard deviation) was 58±20 (range 30-80).

The purpose of incident data collection and analysis is not to assign blame but to learn from past events. Some accidents occur even when sound experience, planning, equipment and support are in place. Such events serve as reminders of the fundamental risks and encourage us to evaluate our behaviors accordingly. Other accidents arise from flaws in equipment maintenance, equipment use, training, or procedures. Incident analysis and program review can reduce the future risk for all participants.

A fundamental challenge in the study of accidents is incomplete information. The investigative effort can require a substantial amount of deductive reasoning and often some guesswork to interpret events. In this report, we summarize the available data and speculate when reasonable.

4.2 Cases in 2009

Most cases were initially identified through automated internet searches, typically as online newspaper articles. Some cases were reported to DAN directly by individuals involved in or aware of particular incidents. Complete details were rarely available.

A total of 79 breath-hold cases were captured in 2009, 56 fatal (71%) and 23 non-fatal (29%). This total was similar to the previous year, but 2009 brought in more non-fatal cases (up from 16 in 2008). Non-fatal cases provide access to insights and information rarely available in fatal cases. As is typical with incomplete data, it cannot be determined if these changes reflect a meaningful increase in the number of events or improvements in reporting and/or case capture.

Incidents were reported from 21 different countries, down from 28 in the previous year. Under half (n=36; 46%) occurred in the US, distributed between five states or territories. Multiple events occurred in three states: Florida (13 cases; 36%), Hawaii (11 cases; 31%) and California (10 cases; 28%). This concentration is similar to that seen in previous years and almost certainly reflects the popularity of water-related activities and possibly some reporting bias. It is highly unlikely that our fatal case capture reflects true total numbers. It is certain that some fatal events that could have involved breath-holding are not reported in such a way as to enter our database. This situation is even more marked for non-fatal cases. The non-fatal cases are viewed as examples, in no way representative of the frequency of related events.

The majority of incidents in which the environment is known occurred in the ocean (n=72; 94% of the 77 with known environment). Two cases occurred in swimming pools, one in a tidal river, one in a spring, and one in an aquarium.

The primary activity described for the incident dive was most frequently spearfishing (n=32; 41%), then snorkeling (n=26; 33%), freediving (n=13; 16%), and collecting (n=8; 10%). The utility of this categorization is probably limited for fatal cases. The presence of specific equipment, for example, a speargun, or a history or communicated plan for an outing provides weight for categorical assignment, but specific actions or events contributing to an incident can easily confound categorical distinctions, as can reporter bias.

Figure 4.2-1 presents the sex and age breakdown for the 2009 cases. The majority of victims were male (n=72; 91%). The mean age (±standard deviation) was 40±18 years, ranging from nine to 77 years (in cases with known age; n=68).

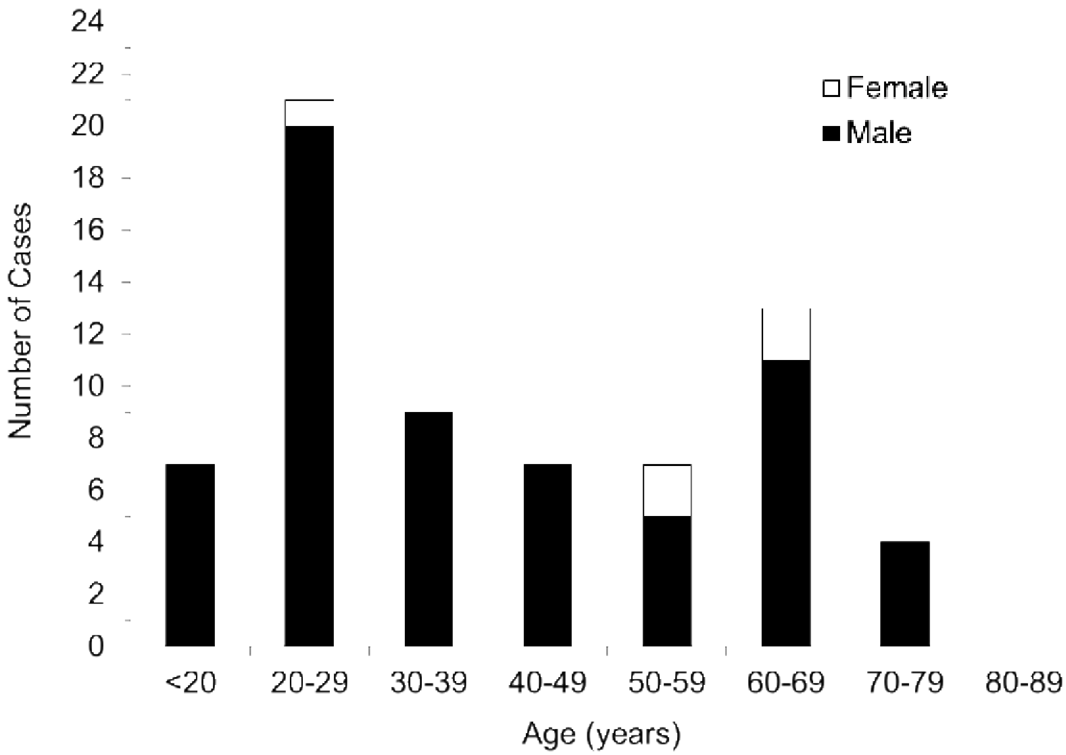

Figure 4.2-1: Age and sex distribution of breath-hold incident victims in 2009 (68 of 79 total)

Information regarding the support available to divers was captured in 81% of the cases. The most common patterns were diving with a partner (n=24; 38% of known), then solo or unsupported (n=21; 33%), diving in a group (n=15; 23% of known), and, finally, with oversight somewhat removed, as in two cases with observers positioned on a boat, one case with observers positioned on the beach, and one case with observers outside the aquarium on a day of competition. The effectiveness of oversight is difficult to evaluate in most cases. The delay to recognize a developing problem is generally the common thread in many accidents. There is no chance of someone else being able to recognize problems and render aid when diving alone. Close supervision and the capability to take immediate and appropriate action can resolve many potential problems before they become serious. This is best achieved by a partner or group immediately available to provide support.

Evaluating the assistance provided to stricken victims can be complex; not for the cases in which persons were completely alone, but very much so when there was some assistance. Immediately bringing an otherwise healthy but unconscious breath-hold diver to the surface to protect the airway can be highly effective in preserving life. A slower recovery would likely be less effective, but the determination of the impact of a delay is challenging if for no other reason than it is not known exactly when a problem arose. It should also be appreciated that even a quick response might not make a difference for a medically-compromised individual. Acknowledging that there is clear subjectivity in interpreting the value of assistance, the broadest categorization was deemed reasonable for 80% of cases. Of these, 57% (n=36) of victims appeared to receive support that could have been effective in the right circumstances; 43% (n=27) likely did not receive support or did not receive support that was likely to have changed the outcome.

Close and informed support is likely to improve outcomes, certainly over completely unsupervised activity and likely over poorly supervised activity. The informed partner or monitor can ask questions to more fully appreciate and be prepared for risk. The lack of informed supervision may grow if efforts to ban breath-hold activity in swimming pools continues to take root. It is easy for swimmers to hide such activities from lifeguards or other swimmers, leaving potential rescuers much less prepared if problems do occur. Rather than banning breath-hold, the prudent course would be to ensure that all swimmers, breath-hold divers, instructors, lifeguards, and parents appreciate the risks and the reasonable limits of safe practice. Understanding factors playing a role in incidents is one of the best ways to advance understanding.

4.3 Cause of Death or Injury and Contributing Factors

Cause of death is typically determined by medical examiners assigned to fatality cases. The usefulness of the finding is often limited, particularly if the cause of death is determined to be drowning. More important are the efforts to identify root causes, triggers that can initiate a cascade of events, factors contributing to the unchecked cascade, and/or specific disabling agents or injuries leading directly or indirectly to the outcome. The search for contributing factors is challenging, particularly in the case of unwitnessed events, because physical evidence is often not present or possibly confounding.

The findings of a medical examiner or coroner were available in 20 fatal cases (36% of all fatal cases). The primary cause of death was described as drowning in 15 cases, cardiac-related in two cases, and due to boat propellor injuries in two cases. Cardiac problems were described as co-morbidities or contributing factors in three of the cases.

The factors that lead to the inevitability of an incident are difficult to identify, but certainly of great value in preventing future occurrences. The available data for all 79 cases were reviewed to identify the primary disabling agents (Table 4.3-1). Such could not be established in 15 cases, which were most often unwitnessed events, some for which the body was not recovered, or those for which only minimal information was available. Solo activity is a particular concern. While it cannot be proven, it is very possible that the close support of a buddy or team could have changed the outcome in some of these cases.

Table 4.3-1 Primary disabling agent ascribed to 2009 breath-hold incidents

Disabling Agent	Count	Percentage
Hypoxic blackout	19	30
Medical health	16	25
Animal-involved injury	14	22
Drowning	8	13
Boat strikes	5	8
Entanglement	2	3
Total	**64**	**100**

Hypoxic Blackout

The most commonly identified disabling agent was hypoxic blackout (n=19; 30%). The age within this subset was 30±11, ranging from 16 to 65 years, reflecting a younger portion of all victims. It is likely that many of the problems in this group were consequences of intentional action. Outside of casual snorkeling, many breath-hold divers employ strategies to extend breath-hold time, most notably hyperventilation. It certainly increases breath-hold time, but by delaying or obliterating the normal warning system that keeps the breath-hold safe. The absence of physical evidence associated with fatal events involving apparently young and physically fit individuals has led some to speculate on the possibility of exotic conditions like long Q-T syndrome being contributing factors. While this is certainly possible, the much simpler and more likely explanation in most cases is that excessive hyperventilation was the trigger.

There is no simple formula to differentiate between safe and unsafe (excessive) hyperventilation. Breath-hold divers must be sufficiently informed to appreciate the risk and then encouraged to err on the side of safety since loss of consciousness typically develops without warning. Knowledge and thoughtful action are critical. Ignorance, or knowing but thinking that the physiological hazards can be avoided, can create a very high mortal risk that is evident in our fatality case reports every year.

Each normal respiratory cycle is followed by a brief interruption of breathing (apnea) prior to the next inspiration-expiration cycle. The duration of the apnea is primarily controlled by the partial pressure of carbon dioxide in the arterial blood. The range is fairly narrow during relaxed, involuntary respiration, from a high of 45-46 mm Hg at the start of the respiratory cycle to a low of approximately 40 mm Hg at the end of the cycle. Voluntary breath-hold can allow the carbon dioxide partial pressure to climb well into the 50 mm Hg range or beyond depending in large part on motivation. Eventually, however, a breakpoint is reached when the urge to breathe is overwhelming. Many breath-hold divers know that ventilating the lungs in excess of metabolic need, that is, hyperventilation, will flush carbon dioxide from the body and delay the point at which carbon dioxide accumulation reaches breakpoint during a subsequent breath-hold. The accumulation of oxygen stores associated with hyperventilation is trivial in comparison with the clearance of carbon dioxide since the normal concentration of carbon dioxide in the blood is 140-160 times the concentration found in the atmosphere. Without hyperventilation, there is a buffer in oxygen stores. The urge to breathe rises while consciousness is still stable. Any hyperventilation reduces carbon dioxide levels enough to erode the buffer. Very limited hyperventilation will not erode the buffer enough to create a high risk of loss of consciousness, but it is a soft line to where excessive hyperventilation can delay the urge to breathe long enough for the oxygen partial pressure to fall below the level necessary to maintain consciousness, before any urge to breathe is felt. It is critical to understand that the loss of consciousness associated with hyperventilation-augmented breath-hold can occur with absolutely no warning. There is no aura, instinct, or innate superiority that will preserve consciousness; generally just luck. The problem with experiencing good luck is that it can reset a sense of normal, or, in this case, respect of safe practice. Bad luck can just as easily follow good luck, with devastating outcomes.

Breath-hold physiology is more complicated when divers travel vertically through the water column. The increasing ambient pressure during descent increases the partial pressure of gases in the lungs and bloodstream. This effectively makes more oxygen available to the cells. While the partial pressure of carbon dioxide concentration is also increased by the ambient pressure increase, it will likely remain well below breakpoint in the first phase of the dive, particularly if hyperventilation was employed to lower it pre-dive.

The most critical phase of the breath-hold occurs during surfacing, when the partial pressure of oxygen falls at a dramatic rate due to the combined effect of metabolic consumption and the decrease in ambient pressure. A state of acute hypoxia can develop rapidly, particularly in the shallowest water where the relative rate of pressure reduction is the greatest. The carbon dioxide partial pressure will not help in this phase since it is also reduced by the reduction in ambient pressure, potentially moderating or reducing the urge to breathe. Ultimately, the risk of hypoxia-induced loss of consciousness without warning is elevated. The classic presentation of this condition – hypoxia of ascent – is seen in a diver who loses consciousness just before or shortly after surfacing. Losing consciousness after surfacing and takiing a breath is possible because it takes time for the newly inspired oxygen to reach the brain. Many will be familiar with the term ‘shallow water blackout,’ but this label is frequently misapplied to cases where the change in ambient pressure is not a factor, in addition to the fact that the term was originally coined to describe a very different condition of high carbon dioxide levels associated with scrubber failure in closed-circuit rebreather divers. For these reasons ‘hypoxia of ascent’ is preferred.

The categorization of cases of blackout as hypoxic loss of consciousness (HLOC) or, more specifically, as hypoxia of ascent is generally dependent on witness observations. Confirming where the loss of consciousness developed is generally not possible in unwitnessed events. A victim found on the bottom could have lost consciousness there, but it is more likely that consciousness was lost near the surface and was followed by a loss of airway gas (and the positive buoyancy it provides) that ultimately caused the victim to sink to the bottom.

Hyperventilation-induced blackout is probably the greatest single life threat in breath-hold diving. The 19 cases identified in 2009 almost certainly represents a marked underestimate of the problem even within our sample. At least some of the unwitnessed fatal cases likely involved hyperventilation-induced loss of consciousness, but this cannot be confirmed even with autopsy because there is no specific physical evidence left to be discovered. Most cases that are resolved with serious outcome are unlikely to be reported. We can still, though, use those that are as examples of what can happen. The following text was extracted from one such report:

> *“.... We were doing one-up/one-down [buddy system]. He blacked out and started sinking. I swam down about six feet and brought him back to the surface, and he regained consciousness pretty quick. I know I should have caught him sooner, at the surface, but he sank so darn fast. He was wearing eight pounds of lead, and he only had a skin on. When he woke back up, he didn’t even know anything was wrong. Anyway, a few more lessons learned this weekend. I am once again thankful for the knowledge gained from [a formal freediving class]. This guy also took the class, and he was willing to dive one-up/one-down with me, and it paid off. Interestingly, it was not the deepest/longest dive of the day for him.”*

It is very common for a diver rescued from blackout to wake within seconds and have no memory of the event. Some may initially argue that they did not blackout until they realize that they came to their senses in surroundings different from last recall. Those who experience these events firsthand (as victim or rescuer) realize how close anyone can be to loss of consciousness in a very unforgiving environment. Regardless of what some want to believe, there is no reliable warning prior to blackout. The effect of hyperventilation to increase breath-hold diving risk was described in the medical literature more than 50 years ago (Craig 1961a&b) and we are still losing divers to aggressive practice. It is likely that limiting hyperventilation to no more than the equivalent of two full ventilatory exchanges will increase breath-hold time but not will not remove enough carbon dioxide to inhibit the uncontrollable urge to breathe long enough for consciousness to be threatened. Hyperventilation in excess of this limit will produce an escalating risk of abolishing the vital drive to breathe.

Medical Health

The second most commonly identified disabling agent was health issues (n=16; 25%). Many of these presented with reasonable to strong evidence of cardiac involvement; some were more ambiguous and could have involved cardiac issues or physical fitness issues. Not having autopsy results for all of these cases makes confirmation difficult. The age within this subset was 59±14, ranging from 26 to 77 years, reflecting an older portion of all victims. The large difference in victim age distribution between classification of blackout and health issues suggests a pattern that we have seen over time; that incidents involving younger individuals may be strongly related to decision-making, while incidents involving older individuals may be influenced by health. The associations between age, health and fatal diving accidents have been described for divers (Denoble et al. 2008). It is important to point out that age was not considered in the determination of disabling agents in our case review (although it may have been considered in the coroner determinations). There were only two cases in the 2009 data in which health was described as the primary disabling agent in individuals less than 55 years of age. One 29-year-old male had a pre-existing heart condition; and one 26-year-old developed debilitating cramps during ascent.

While water activities can be healthful, they do create a physiological strain that can be problematic for individuals with compromised health. Immersion in water, regardless of depth, prompts an increase in blood returning to the heart that causes it to contract harder. Breathing resistance and physiological deadspace are increased by breathing through a snorkel. Wearing bulky equipment, and particularly a weight belt, can increase the strain of swimming, as can entry and exit requirements in rising sea state conditions. The initial exposure to immersion and any in-water activity is best done under benign conditions with easy ingress and egress and no pressure to continue should discomfort arise. It is not uncommon for vacationers to want to participate in 'once in a lifetime activities' that may expose them to more physiological stress than advertised or expected. Those who are medically or physically compromised can be at undue risk, a situation that may not be appreciated by them or by event organizers.

Animal-Involved Injury

The third most commonly identified disabling agent was animal-involved injury (n=14; 22%). Ten of the cases involved sharks, one involved a crocodile, one a large grouper, and one a speared fish, with the last arising from entanglement after the fish was speared. The majority of shark attacks involved spearfishermen, possibly reflecting an influence of being in the vicinity of animal catch. The animal-involved category is a class of incident most likely to be overrepresented in our database, given the physical evidence of the altercation and the substantial media attention. At the same time, it is certain that many minor animal-involved injuries will likely not be captured in our database. The age within this subset was 29±12, ranging from 14 to 50 years, also representing a relatively young portion of the group.

Boat Strikes

There was a jump in the number of these cases captured in 2009 (n=8; 13%). The physical trauma associated with boat strikes, typically involving propellers, can be devastating. It is possible that boat strikes are overrepresented in the database due to the greatest physical evidence and media attention. It is also possible that low visibility equipment in common use by breath-hold divers may work against surface safety.

Environmental Conditions

Environmental conditions were identified as the primary disabling agent in two cases; one involving a fast rising tide, and one rough water. It is possible that a lack of physical capacity was critical to the outcome of these cases; devlopment in the case of the child in one case, and marginal physical fitness in the other. Physical fitness is rarely well documented, but can play a huge role in helping individuals handle a range of conditions. High levels of physical fitness creates a reserve capacity that can be called upon whenever needed. Addressing emergent needs quickly and without pushing physical limits can stop the cascade of events that often lead to poor outcomes.

Entanglement

There were two cases in which entanglement was identified as the disabling agent, both involving kelp. It is possible that physical fitness and medical health played a role in these cases.

A cross-section of illustrative case studies is found in Appendix B. Most are drawn from the breath-hold incident database that forms the basis of this review, but some are drawn from Medical Services Call Center data and two are drawn from the fatality case reports.

4.4 Reducing Breath-Hold Risks

Breath-hold diving includes a wide range of activities. Some are appropriately described as extreme; others as relatively benign. The margin of safety can be quite narrow for extreme diving. In such activity, appropriate safety precautions and backups are essential. The safety procedures employed in competitive freediving are usually extremely effective. Shifting away from the tight controls of the competitive field or from the typical medically healthy, physically fit, and well-trained participant can increase the risk.

The medical and physical fitness of individuals must be considered prior to participation in any diving activity. Those with significant medical issues should be evaluated in advance, and may well be discouraged from participation. Those close to the low physical fitness end of qualification should participate only under the most benign conditions. An orientation in a shallow pool or confined water is much more appropriate than being dropped off the back of a boat in deep water with the possibility of current or wave challenges. Implementing an orientation step for persons of possible concern might encourage some to appropriately reconsider participation and others to participate with more comfort and confidence.

The blackout hazard associated with pre-breath-hold hyperventilation stands out as the greatest risk to generally healthy individuals participating in breath-hold activity. Efforts to discourage hyperventilation face quiet but powerful resistance because it is so effective at increasing breath-hold time. The risk of loss of consciousness without warning may be difficult for the enthusiast to appreciate. Competitive freedivers increasingly acknowledge the inevitability of blackout in association with hyperventilation-augmented dives. They protect themselves, however, by ensuring close support throughout and following every dive.

The greatest risk is to divers without extensive backup support, whether these are unmonitored novices who have discovered hyperventilation or experienced spearfishermen determined to not let the fish get away. Safety-oriented education and rational guidelines are required for both groups to keep them safe. Buddy-diving in a one-up, one-down manner in good visibility water shallow enough for all divers to get to the bottom easily can take the novice safely through the relatively high-risk phase of learning. A group of three (one-down, two-up) may be preferable as dive depths begin to increase. It is a typical rule of thumb to allow a recovery period of at least twice the dive duration for modest dives, progressively longer for deeper dives. A group of three or four, diving in series, facilitates this schedule and ensures that one or more of the divers available at the surface for backup is at least partially rested. This is important since it is highly unlikely that optimal performance will be achieved during the stress of a rescue. Establishing safe habits in the beginning will hopefully keep safe habits in place. Safety protocols become more complicated as dive depths are increased, potentially involving counterbalance systems or mixed-gas diver support, but a commitment to safety can keep personal and group practices evolving appropriately.

Freedivers should be defensively weighted, neutrally buoyant with empty lungs at 30 ft (9 m) or deeper, to ensure that if they have problems at or near the surface they are more likely to remain at the surface where they can be found and assisted more quickly and easily. Overweighting can cause a diver to sink; especially if gas is expelled from the airway during ascent. Momentum established during ascent can carry the diver to the surface even if consciousness is lost. Adequate support requires an appropriate network. Close support protocols that have divers shadowed during the final portion of their ascent and the first 30 seconds of the post-dive period can address the majority of issues. The risk of loss of consciousness continues post-breath-hold until the oxygen in an inspired breath reaches the brain to counter hypoxia. The critical first aid when a victim is reached immediately after losing consciousness is to hold the airway clear of the water. Consciousness is often quickly restored with no sequelae.

Another technique that creates some risk for breath-hold divers is lung packing. It is used to increase the volume of gas in the lungs above normal total lung capacity immediately prior to commencing breath-hold. While it can assist the diver, it also increases the likelihood of pulmonary barotrauma (Jacobson et al. 2006). The hazards of all techniques must be appreciated as well as the benefits. Each should be used thoughtfully and with caution foremost.

The solo freediver takes on much greater risk in all respects. The major price of independence is the loss of support in the moments upon which a life can turn. The sense of self-confidence, if not invincibility, often stands in the way of smart decision-making. The idea that blackout can occur without warning - while true - is a direct challenge to this self-perception.

There are a couple of ways to strike a compromise. The simplest is to carefully restrict pre-dive hyperventilation. Two or three deep inspiratory-expiratory exchanges prior to breath-hold will still reduce the carbon dioxide levels in the blood and increase breath-hold time, but without creating the high risk of hypoxia-induced blackout associated with more hyperventilation. The alternative is to hyperventilate freely, but then limit dive time. Butler (2006) reviewed published data and concluded that limiting breath-hold time to 60 seconds could accommodate varying patterns of hyperventilation and physical activity with minimal risk of loss of consciousness. While the time limitation might be too restrictive for some, it would be a good alternative for those making safety the top priority.

A freediver recovery vest is now available for breath-hold diving that will automatically inflate after a user preset time at depth or maximum depth or if another descent immediately follows surfacing. While such a device would not eliminate the risk of blackout or guarantee survival, it would improve the odds of survival by making sure that the diver was returned to the surface.

Breath-hold divers spend a lot of time on the surface. To reduce the risk of undesirable boat interactions, they should avoid boat traffic areas whenever possible and clearly mark their dive site with high visibility floats, flags and other locally-recognized markers. In addition, they should wear high visibility colors to mark themselves. The predominance of equipment in dark colors or, more recently, camouflage patterns, runs contrary to visual safety practices. The safest choice is high visibility throughout - suit, hood, snorkel, gloves, fins, and whatever else might break the surface. Underwater hunters may argue for the benefits of reducing their visibility underwater. Camouflaged divers have to rely more on the surface floats, support boats and tenders to warn surface traffic of their presence.

All divers need to be aware of the hazards they face and strategies to reduce their risk. Receiving initial training by qualified persons makes the transition into any activity smoother and safer. Ongoing education, which includes learning from the mistakes of others, is important to ensure that the risk of participation remains low. Further background can be found in a separate review (Pollock 2008). As a final note, it must be remembered that problems not unrelated to diving can develop during periods of diving activity. Appropriate and timely medical evaluation is at least prudent, but may also be critical for a good outcome.

4.5 Future Research

The greatest challenge in studying fatal events is that complete details are rarely available. DAN has established an online reporting system to expand the collection of cases, particularly non-fatal events for which more complete details may be available. It is expected that the additional insights will be extremely helpful in identifying additional factors contributing to incidents. Visit the site at: http://DAN.org/IncidentReport. Continued effort is required to promote awareness among breath-hold enthusiasts and community leaders.

4.6 Conclusion

A total of 79 breath-hold diving incidents occurring in 2009 were collected by DAN; 56 fatal (71%) and 23 non-fatal (28%). The victims were overwhelmingly male (91%). The most commonly identified disabling agents were hypoxic blackout (likely facilitated by excessive hyperventilation), health issues (primarily cardiac) animal-involved interactions (primarily between shark and spearfishermen), boat strikes, environmental conditions, and entanglement, respectively. Improving the appreciation of hazards may offer the greatest defense against future adverse events. Sharing incident information is an important part of that process. Our efforts will continue to expand case collection, both fatal and non-fatal, and to provide insights for the community.

4.7 References

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APPENDIX A. DIVE FATALITY CASE REPORTS

James L. Caruso

Proximate Cause: Air Embolism

09-19 Cause of Death: Drowning due to air embolism on rapid ascent due to insufficient air

This 33-year-old male had advanced open water certification with completion of 30 lifetime dives. He made a dive from a boat to an apparent maximum depth of 96 fsw (29 msw) though there are conflicting data in the investigative reports as another report stated the dive was to 30 fsw (9 msw). In any event, the diver and his buddy became separated and the diver ran out of air. He made a rapid ascent to the surface where he lost consciousness and was brought into the boat. The diver was taken to a recompression chamber, but resuscitation efforts were unsuccessful. The autopsy notes an air embolus as the cause of death but there were enough findings present that were consistent with drowning that it is likely the diver was incapacitated by the arterial gas embolism (AGE) and drowned as a result. The diver was obese but no other medical history is known.
BMI = 36.1 $kg \cdot m^{-2}$

09-37 Cause of Death: Air embolism due to rapid ascent due to panic

This 56-year-old female was a student in an advanced open water course. She received initial certification two years earlier and had made 20 lifetime dives. The diver's medical history was significant for problems equalizing her ears in the past and also for anxiety for which she took Xanax. During the deep dive phase of the AOW course, the diver performed the required tasks at 90 fsw (27 msw). She then ascended to 60 fsw (18 msw) where she panicked. She signaled to the instructor that she was out of air but the instructor noted that was not the case. The diver then made a rapid ascent to the surface, losing consciousness a few seconds after surfacing. The instructor had unsuccessfully tried to slow the diver's ascent. The stricken diver was taken to a recompression chamber but resuscitation efforts were unsuccessful. The autopsy demonstrated intravascular gas, including gas in the coronary arteries.
BMI = na

09-41 Cause of Death: Air embolism due to rapid ascent

This 51-year-old male was a certified divemaster and assistant instructor who had been diving for 20 years but only once or twice a year the past few years. His past medical history was significant for hypertension, diabetes, and prior transient ischemic events (mini strokes). He took medication for diabetes, elevated lipids, hypertension, and depression. He was on his first dive in a year and descended to 80 fsw (24 msw) on a breathing gas of air. After approximately 20 min on the bottom, the diver seemed to have some difficulty and made a rapid ascent from 60 fsw (18 msw) to the surface. On the surface, he complained of dizziness before collapsing. Resuscitation efforts were unsuccessful. The autopsy disclosed evidence of pulmonary barotrauma but no intracardiac gas. There was also cardiomegaly and moderate atherosclerosis of the coronary arteries. The pathologist concluded that the decedent was having cardiac-related symptoms at depth and made a rapid ascent, suffering an air embolism as a consequence.
BMI = na

09-44 Cause of Death: Air embolism due to rapid ascent due to insufficient air

This 58-year-old male was a certified diver but inexperienced. His medical history was significant for hepatitis C and depression requiring the use of antidepressant medications. The diver was part of a group of eight divers but there were no specific buddies assigned. During the planned dive to 100 fsw (30 msw) the diver descended to what appears to be 346 fsw (105 msw). He made a rapid ascent due to being out of air and he was unconscious on the surface. The autopsy disclosed evidence of pulmonary barotrauma but no intracardiac gas. An additional autopsy finding was cardiomegaly. Toxicological testing was positive for amphetamine and the antidepressant medicine. A urine screen noted the presence of a cocaine metabolite but that was not measured in the blood with more sophisticated testing. The death was attributed to an air embolism due to a rapid ascent because of insufficient air. At that depth, nitrogen narcosis and probably even a contribution from decompression sickness (DCS) would be expected as well.
BMI = na

Proximate Cause: Drowning/Air Embolism

09-02 Cause of Death: Drowning due to air embolus due to rapid ascent due to insufficient air.

This 42-year-old female had 17 lifetime dives with advanced open water certification. She made two dives, one to 100 fsw (30 msw) for 45 min and a second to 67 fsw (20 msw) for 38 min. The diver had a one hour surface interval. The diver ran low on air during the second dive and made a rapid ascent from 30 fsw (9 msw). She struggled on the surface and her buddy tried to render assistance. The diver's integrated weights were not successfully dumped and she was pulled from 25 fsw (8 msw) unconscious and with the regulator out of her mouth. Resuscitation efforts were successful enough to get the stricken diver to a hyperbaric chamber but she died the next day. The terminal event was a drowning but likely this was an air embolism due to a rapid ascent prompted by running low on air during the dive.
BMI = na

09-06 Cause of Death: Drowning due to air embolism due to rapid ascent

This 57-year-old male was a certified diver but his level of training and experience is unknown. He developed some problem at 90 fsw (27 msw) and made a witnessed, panicked and rapid ascent. The diver actually knocked his dive buddy's mask off in the process. On the surface, the diver lost consciousness and submerged again. An autopsy was performed but the results were not made available. Given the history, this was likely an air embolism due to a rapid ascent that resulted in drowning. The exact trigger, or the event that precipitated the uncontrolled ascent, is not known.
BMI = na

09-13 Cause of Death: Drowning due to air embolism and DCS due to rapid ascent

This 22-year-old male was a certified instructor and an employee at a dive shop. He and his dive buddies planned a dive to 225 fsw (69 msw) using open-circuit air and employing decompression stops. They made a shore entry and according to the dive computer, the diver went to a maximum depth of 251 fsw (77 msw) for seven minutes. The computer also related multiple ascents and descents between 216 fsw (66 msw) and 230 fsw (70 msw) as well as a rapid ascent from 199 fsw (61 msw) to the surface. The buddies became separated at the 190 fsw (58 msw) decompression stop and they surfaced. The deceased diver's body was found floating 400 ft (122 m) from shore on the surface. The autopsy disclosed extensive pulmonary and gastric barotrauma as well as contusions of the tongue. The tongue contusion likely occurred during a seizure that would have been a result of either the AGE or the drowning process. Toxicology was negative. This diver most likely sustained both an air embolus as well as DCS. The medical examiner determined that the terminal event was drowning with the decompression events as the likely cause. Nitrogen narcosis at depth would have been expected.
BMI = na

Proximate Cause: Cardiac

09-12 Cause of Death: Cardiac dysrhythmia due to coronary atherosclerosis

This 56-year-old male was a student in an initial open water certification class. He was a heavy smoker and took medication for a thyroid problem. The diver was among a group of students who submerged to 10 ft (3 m). He surfaced, called for help, and then submerged again. The diver was brought to the surface where resuscitation efforts were unsuccessful. The autopsy showed severe three-vessel coronary artery disease and dilatation of all four chambers of the heart. Death was attributed to a cardiac event. A small remote infarct in the brain was also noted.
BMI = na

09-14 Cause of Death: Cardiac dysrhythmia due to hypertensive heart disease

This 46-year-old male was believed to be an experienced, certified diver though the level of certification is unknown. He and three other divers made a shore entry dive in a strong surf area. At 30 fsw (9 msw) the diver indicated that he was having difficulties and he surfaced. He became very animated on the surface before losing consciousness. The other divers pulled him to shore where resuscitation efforts, including cardiopulmonary resuscitation (CPR), were unsuccessful. The diver's medical history included hypertension and obesity. This appears to be a cardiac death though an air embolus cannot be entirely excluded with the history provided.
BMI = na

09-20 Cause of Death: Dilated cardiomyopathy due to hypertensive heart disease

This 51-year-old male was an experienced, certified diver participating as a student in a rebreather training course. This diver, one other diver, and the instructor descended to 130 fsw (40 msw) for 90 min and at 97 fsw (30 msw) this diver signaled that he needed to ascend. The diver lost consciousness during the ascent and could not be resuscitated on the surface. There was omitted decompression time involved but the problem began on the bottom. The medical examiner felt confident that the decedent did not drown and signed the case out as a primary cardiac event. The autopsy disclosed dilated cardiomyopathy, hypertensive heart disease, coronary atherosclerosis, and obesity. The diver also had a medical history significant for sleep apnea and an incidental finding at autopsy was hepatic steatosis.
BMI = 38.6 $kg \cdot m^{-2}$

09-33 Cause of Death: Cardiac dysrhythmia due to coronary atherosclerosis, focally severe

This 39-year-old male was open water certified but inexperienced according to the investigative information. He had already completed a shallow dive, 10-15 fsw (3-5 msw) on average, hunting lobster when he complained of chest pain. The diver was in the boat and in addition to the pain he complained of left arm tingling and fatigue. The diver's past medical history is significant for severe coronary artery disease and he already had stents in his coronary arteries. He sustained a myocardial infarction four years earlier and he was currently overweight. The diver collapsed on the deck of the boat and could not be resuscitated. The autopsy demonstrated severe coronary artery disease, cardiomegaly, and the presence of stents in the coronary arteries. The heart was enlarged and there was scattered myocardial fibrosis on microscopic examination of the heart. An incidental finding was gallstones.
BMI = 31.1 kg·m^{-2}

09-39 Cause of Death: Drowning due to cardiac dysrhythmia due to coronary atherosclerosis

This 50-year-old male was a certified diver with significant experience, according to the investigative report. He made a dive down to a maximum depth of 120 fsw (37 msw) and then ascended to 50 fsw (15 msw). At that point, he signaled to the divemaster that he was not feeling well. They ascended together but at 10 fsw (3 msw) the diver let his regulator drop from his mouth. The diver was brought to the boat where resuscitation efforts were unsuccessful. The autopsy disclosed significant heart disease and the death was attributed to drowning secondary to a cardiac event.
BMI= 31.9 kg·m^{-2}

09-40 Cause of Death: Drowning due to cardiac dysrhythmia due to coronary atherosclerosis

This 57-year-old male was a certified diver with advanced certification who was participating in a rescue diver class setting in a quarry. He and another diver were supposed to be practicing rescue scenarios but during a surface swim the diver submerged below the surface. He was likely below the surface for approximately two minutes before being brought up where resuscitation efforts were employed. The diver regained vital signs and was brought to a hospital, but he died later that evening. Unfortunately, an autopsy was not performed. Not much is known about the diver but a bottle of nitroglycerin tablets was found in his pants pocket so it is presumed that he had ischemic heart disease. The cause of death was most likely drowning due to an acute coronary event resulting in a cardiac dysrhythmia but an autopsy should have been performed in any event. An evaluation of the equipment found a leak in the diver's buoyancy compensator, but that does not appear to have been contributory. He had 2500 psi (172 bar) of nitrox left in his tank.
BMI = na

09-45 Cause of Death: Aortic dissection due to atherosclerotic cardiovascular disease

This 61-year-old male was a certified divemaster who had been diving for twelve years. He was making his first dive of the New Year, which was a solo dive to a maximum depth of 111 fsw (34 msw) with a total bottom time of 45 min. By all reports, the dive was uneventful. The diver had no significant medical history and took no medications on a regular basis. While removing his gear, the diver complained of some upper back pain. The diver then collapsed and resuscitation efforts were unsuccessful. The autopsy demonstrated a dissecting aortic aneurysm as well as coronary atherosclerosis and cardiomegaly.
BMI = na

09-46 Cause of Death: Cardiac dysrhythmia due to coronary atherosclerosis, severe

This 63-year-old male was not a certified diver. He was participating in a scuba experience using surface-supplied air and a dive helmet while on vacation. The man's medical history was significant for hypertension and heavy smoking in the past. His current medications included an anticoagulant. According to the investigative report the man was anxious before the dive, went down to 15 fsw (5 msw) and became distressed on the bottom. The diver surfaced and exhibited seizure-like activity before falling back below the surface. He was pulled to the surface where resuscitation efforts were unsuccessful. The pathologist concluded that this was a cardiac event because no corroborating findings for AGE were noted at autopsy and the decedent had severe coronary artery disease. However, given the circumstances it is difficult to completely exclude an AGE.
BMI = na

09-52 Cause of Death: Cardiac dysrhythmia due to coronary atherosclerosis

This 46-year-old male was a certified, experienced diver who was diving with a group of friends. He surfaced from an apparently uneventful dive and signaled that he had a problem. The diver lost consciousness as friends came to assist him. Resuscitation efforts were unsuccessful. The medical examiner ruled this as a likely cardiac-related death. Nothing is known about the dive profile and dive equipment.
BMI = na

09-56 Cause of Death: Atherosclerotic cardiovascular disease

This 67-year-old female was diving with an instructor and making a shore-entry dive at altitude in a freshwater lake. Her certification and training status are unknown. Little is known about the diver's past medical history but her medication list included propoxyphene, codeine, and hydroxyzine. After surfacing, the diver complained of abdominal pain and was towed toward shore by the instructor. She lost consciousness as they approached shore and resusci-

tation efforts were unsuccessful. An autopsy was performed but the report was not released. The death was attributed to atherosclerotic cardiovascular disease. The results of toxicological testing, if performed, were also not released.
BMI = na

Proximate Cause: Drowning/Cardiac

09-01 Cause of Death: Drowning due to cardiac dysrhythmia and coronary atherosclerosis

This 67-year-old male recertified just prior to this dive trip. He was an experienced, open water diver. The diver was on a lobster hunt with a group when he failed to surface after the second dive of the day. He was brought to the surface by fellow divers and resuscitation efforts were employed, including transfer to a medical facility. The diver's medical history included chest pain two years previously but none recently. An autopsy disclosed focally severe coronary atherosclerosis. The major factor in this fatality was likely a cardiac event.
BMI = na

09-05 Cause of Death: Drowning due to cardiac dysrhythmia due to coronary atherosclerosis

This 65-year-old male was a recently certified diver with advanced open water certification but only 14 lifetime dives. During the second dive of the day, he lost consciousness and was brought to the surface. The investigative notes are inconsistent as in one place it was documented that he lost consciousness on the surface and in another it was stated that he lost consciousness on the bottom. In any event, the diver was brought into the boat unconscious and resuscitation efforts were unsuccessful. The autopsy disclosed coronary artery disease as well as pleural adhesions and a benign liver finding. The diver had a history of elevated serum cholesterol levels. This most likely was a drowning due to a cardiac event.
BMI = na

09-18 Cause of Death: Drowning due to cardiac dysrhythmia due to coronary atherosclerosis

This 59-year-old female was an experienced, certified diver who had several health problems. During the first dive of the day, the diver signaled to her buddy that she wanted to ascend from 35 fsw (11 msw). The buddy reached the boat but the diver did not. She was on the surface approximately 100 ft (30 m) from the boat and was assisted back to the boat by others. The diver was provided oxygen but she went into respiratory arrest as the boat headed to shore. After arriving at one hospital and being transferred to a higher level of care, the diver died. The final cause of death was drowning/near-drowning but the chain of events was likely initiated by a cardiac event. The autopsy demonstrated moderate coronary atherosclerosis, myxoid cardiac valves and obesity. Toxicology was positive for an anti-seizure medication, a prescription stimulant, a blood pressure medication, and an antidepressant. Incidental findings included cholelithiasis and hepatic steatosis.
BMI = 34.4 kg·m^{-2}

09-22 Cause of Death: Drowning due to cardiac dysrhythmia due to myocardial scarring due to coronary atherosclerosis

This 70-year-old male was a student in a refresher course. He obtained initial open water certification years earlier but had completed fewer than 20 lifetime dives. His medical history was significant for obesity and hypertension. The diver entered the water with a buddy but they became separated on descent. The dive instructor and other students found the diver unconscious on the surface and resuscitation efforts were unsuccessful. According to the decedent's dive computer, he never descended on the dive. The autopsy revealed changes associated with drowning as well as moderate three-vessel coronary artery disease and myocardial scarring. Toxicology was positive for blood pressure medication and the antihistamine diphenhydramine. An incidental finding was cholelithiasis. The medical examiner signed out the case as drowning due to coronary artery disease.
BMI = 34.0 kg·m^{-2}

Proximate Cause: Drowning/Insufficient Air

09-03 Cause of Death: Drowning due to insufficient air

This 25-year-old male had no formal certification but reportedly was an experienced diver. He was using surface-supplied air to hunt for lobster with his father. There was a complication during the dive that caused the hose to detach and the diver surfaced and lost his fins. The diver continued to struggle on the surface and then submerged. The medical examiner performed a full autopsy and signed the death out as an accidental drowning. Toxicology testing was negative.
BMI = na

09-07 Cause of Death: Drowning due to insufficient breathing gas

This 49-year-old male was an experienced technical diver making a wreck dive using a rebreather and a drysuit. He descended with a buddy and developed some sort of valve problem and decided to surface. The buddy stayed on the bottom and did not see the diver again. Witnesses on the surface saw the diver surface and then head back down. Apparently, some leak was fixed but an evaluation of the dive equipment revealed that the diver had not turned his oxygen cylinder back on. He likely lost consciousness on the bottom. The body was recovered two days later approximately 50 ft (15 m) from the wreck.
BMI = na

09-15 Cause of Death: Drowning due to insufficient air due to entrapment (kelp)

This 46-year-old male was an experienced, certified diver making a set of dives from a boat with a group of other divers. He apparently made an uneventful first dive but toward the end of the second dive, he was in a kelp bed with two other divers and he panicked. The divemaster offered help but the diver pushed him away. His buoyancy compensator would not inflate, likely due to an empty tank, and he ditched his tank and buoyancy compensator but left his weight belt on. The diver sank to the bottom where he was found approximately an hour later. His empty tank was found on the surface. The autopsy demonstrated changes associated with drowning as well as moderate coronary atherosclerosis and obesity. Complicating the situation the diver was also using too much weight.

BMI = 33.4 $kg \cdot m^{-2}$

09-27 Cause of Death: Drowning due to insufficient breathing gas

This 48-year-old male was a very experienced technical diver using a rebreather for wreck diving. The diver was on his sixth straight day of deep diving when he descended on a solo dive. After an hour another diver entered the water to check on the first diver. His body was found at 318 ft (97 m). The stricken diver's drysuit and buoyancy compensator could not be inflated and the body had to be recovered hours later. The computer showed that the diver had initially ascended to 200 ft (61 m) but then descended back to the bottom where he was found. The diver's diluent and argon tanks were empty and he only had oxygen remaining. The rebreather had been modified and it was difficult to assess its working condition. There appears to have been a flood-out and the diver's carbon dioxide scrubber was likely not working. The pathologist signed the case out as barotrauma complicated by drowning based on some of the autopsy findings. However, the ascent from 300 to 200 ft (91 to 61 m) would be unlikely to cause fatal barotrauma and what was observed at autopsy was likely artifact. The likely cause of death is drowning with insufficient breathing gas and probably hypercapnia as contributing factors.

BMI = na

09-32 Cause of Death: Drowning due to insufficient air

This 34-year-old male was open water certified with 10 years of diving experience though it is unknown how much experience he truly possessed. He made a solo dive from a boat to spearfish on a wreck. There was a large group of divers on the dive boat but this diver had no designated buddy. When all the other divers were accounted for after the dive, this individual was noted to be missing. According to the diver's computer, the maximum depth of the dive was 84 fsw (26 msw) and he made a rapid ascent from there to 51 fsw (16 msw) but no shallower and he did not surface. The diver's tank, regulator and buoyancy compensator were recovered on the day of the dive but his body was not found until the next day. He still had his mask and weight belt on. An equipment evaluation demonstrated an empty tank and significant leaks in the buoyancy compensator and regulator. The autopsy disclosed gas in the heart and ethanol was demonstrated in postmortem blood. Both of these findings are likely due to the delayed body recovery and are likely postmortem artifacts though consumption of ethyl alcohol prior to death cannot be entirely excluded. The rapid ascent from 84 to 51 fsw (26 to 16 msw) likely would not result in fatal barotrauma, though that was the cause of death as determined by the medical examiner. This diver most likely drowned due to insufficient air.

BMI = na

09-38 Cause of Death: Drowning due to insufficient air due to entanglement (rope)

This 41-year-old male had advanced open water certification with 50 lifetime dives. He had been diving for five years. His past medical history was significant for bipolar disease and sleep apnea. He was also obese. The diver was making a wreck dive to a maximum depth of 130 ft (40 msw) on air with a buddy when he became entangled in the buoy line. The diver panicked and his buddy attempted to render assistance. The diver's regulator may have been free-flowing so his buddy offered his octopus to him but the diver would not take it. Eventually the buddy had to surface and another diver cut the entangled diver loose and sent him to the surface. The diver was unconscious on the surface and could not be resuscitated. The death was signed out as a drowning. Entanglement and panic played roles as did nitrogen narcosis in all likelihood. An incidental note in the investigative report was that one diver was making this deep dive on enriched air nitrox, which is inappropriate for deep diving. It would have reduced the degree of nitrogen narcosis, but also reduced the threshold for oxygen toxicity.

BMI = na

09-47 Cause of Death: Drowning due to insufficient air

This 44-year-old male was an experienced, certified diver who was illegally hunting lobster while using scuba. The diver was down at 45 fsw (14 msw) and had become separated from his dive buddy. He then surfaced quickly and complained that he was low on air. The diver sank back below the surface before anyone could come to his aid. Resuscitation efforts were unsuccessful. The autopsy findings were consistent with drowning as a cause of death. Air embolism would have to be in the differential diagnosis. An equipment evaluation found that the decedent was over-weighted and would have been unable to jettison much of the weight. His tank contained less than 500 psi (34 bar) of air. There was also a leak in the buoyancy compensator.

BMI = na

09-53 Cause of Death: Drowning due to insufficient air

There is incomplete investigation information available on the death of this 48-year-old male. He was apparently a certified diver but his level of experience and diving frequency are unknown. The diver and a friend were testing out their scuba equipment at a lake where diving was prohibited. He entered the water alone and when he did not return, his friend called emergency services. The diver's body was recovered from a depth of about 15 ft (5 m), approximately 40 ft (12 m) from shore over three hours later. An evaluation of the equipment revealed that the air tank valve was still in the off position. The medical examiner signed out the case as a drowning with a major contributing factor as acute ethanol intoxication.
BMI = na

09-58 Cause of Death: Drowning due to insufficient air due to entrapment (cave)

This 39-year-old male was a certified technical diver but did not have cave diving certification. He and a buddy made a cave dive using trimix and a rebreather into a freshwater spring. They went approximately 500-700 ft (152-213 m) into the cave and descended to 270 ft (82 m). The diver had a possible equipment problem and seemed to panic. When the buddy attempted to render assistance the diver pushed him away. It appeared to the buddy that the diver's hose to the left lung of his rebreather had become detached. The buddy had to surface for help but he had over two hours of obligatory decompression time to manage. The diver's body was recovered approximately six hours later. The autopsy findings were consistent with drowning. Other significant findings at autopsy included cardiomegaly, hepatic steatosis, and obesity. Toxicological testing was negative.
BMI = 35.5 kg·m^{-2}

Proximate Cause: Drowning/Various Causes

09-04 Cause of Death: Drowning

This 32-year-old male had open water certification but had made only nine lifetime dives. He had been certified for a year. The diver made a shore entry using nitrox and descended to 46 fsw (14 msw) to a wreck. The diver experienced some mask trouble at depth and signaled to his buddy that he wanted to surface. Once on the surface he had difficulty breathing and eventually lost consciousness. Both the diver's buddy and a bystander attempted to resuscitate the diver but they were unsuccessful. This most likely represents a drowning death but immersion pulmonary edema cannot be excluded. An autopsy report was received but all useful information had been redacted.
BMI = na

09-08 Cause of Death: Drowning

This 47-year-old female was a certified diver with an unknown amount of diving experience. She was diving in a quarry with a buddy and after they surfaced the diver told her buddy that she could not breathe. The buddy tried to hand the diver another regulator but there was a bit of a struggle and the diver lost consciousness and sank to the bottom. The diver's medical history was significant for previous angioplasty as well as obesity. The diver was resuscitated and taken to a hospital but she died four days later. An autopsy was performed and the cause of death was determined to be near-drowning. It is quite possible that a cardiac event contributed to this death.
BMI = 36.6 kg·m^{-2}

09-09 Cause of Death: Drowning

This 44-year-old male was not a certified diver and was diving with an uncertified buddy. They were diving to gather fishing bait. The divers surfaced and attempted to get back into the boat but they struggled in a strong current and were swept away. Others on the surface rendered assistance but only the diver's buddy was rescued. The diver submerged after ditching most of his dive gear. Unfortunately, his weights were still on at the time he died. An autopsy was performed and showed hypertensive heart disease and changes consistent with drowning. The diver had a history of cocaine use, depression, hypertension and possibly a seizure disorder. Toxicology demonstrated cocaine metabolites in the diver's urine as well as a muscle relaxant in his blood.
BMI = na

09-10 Cause of Death: Drowning

This 58-year-old male was a certified diver with a moderate level of experience. He made two uneventful dives the day before. The diver's medical history was significant for smoking, obesity, and ethanol abuse. From a boat the diver and his buddy made their first dive of the day to 88 fsw (27 msw) in order to spearfish. The two divers surfaced away from the boat and drifted farther away in a strong current. The diver lost consciousness on the surface. He was eventually brought into the boat and resuscitation was attempted but unsuccessful. The autopsy demonstrated changes consistent with drowning, cardiomegaly, hepatic steatosis, cholesterolosis of the gallbladder, and diverticular disease. Cannabinoids were noted in femoral blood. The death was ruled to have been a drowning.
BMI = 32.2 kg·m^{-2}

09-11 Cause of Death: Drowning

This 58-year-old female became open water certified two months earlier. She and a buddy completed a dive, surfaced and began to swim to shore. The two divers became separated and other divers found the deceased diver uncon-

scious and floating on the surface. An autopsy was performed and along with changes consistent with drowning there was scarring of heart tissue and fatty change of the liver. The death was ruled an accidental drowning.
BMI = na

09-21 Cause of Death: Drowning
This 68-year-old male was using a drysuit and making a solo dive in a quarry. His medical history was significant for hypertension, chronic back pain, depression and he was also on an anticoagulant medication. The dive was to 30 to 40 ft (9 to 12 m) and during the dive he encountered other divers who recall that the diver was pointing to his buoyancy compensator but also gave the "OK" sign. The diver was later found floating on the surface unconscious. Resuscitation efforts were successful enough to get the stricken diver to a hospital but he died the next day. An autopsy was performed and the medical examiner concluded that the cause of death was drowning. Additional findings included cardiomegaly and interstitial fibrosis of heart muscle. A tongue contusion was noted, likely as a result of a hypoxic seizure. Toxicology was positive for an antihistamine, an antidepressant, and a benzodiazepine, narcotic pain medication, though some medications would have been administered in the hospital. The diver's equipment was configured so that separate tanks supplied the buoyancy compensator and the regulator. The tank supplying the buoyancy compensator was turned off. Buoyancy problems seem to be at the root of this fatality.
BMI = na

09-23 Cause of Death: Drowning
This 20-year-old male had been a certified diver for four years. His experience level is unknown. He made an unplanned solo dive in a freshwater lake with no thermal protection. The diver surfaced after 70 min but then submerged again during a surface swim. The body was recovered nine hours later, on the bottom, at a depth of 55 ft (17 m). The diver had ditched all of his gear. The primary tank was empty and the back-up tank contained 750 psi (51 bar).
BMI = na

09-25 Cause of Death: Drowning due to equipment malfunction
This 50-year-old male had advanced open water certification with 20 lifetime dives. He had been certified for approximately one year. He was using a new drysuit and making a wreck dive. The first dive in the series was completed the day before and the diver cut it short due to fatigue. The diver was overweight but otherwise had no known health problems. He used 38 lb (17 kg) of weight. The diver and his buddy planned to go to a wreck in 65 fsw (20 msw) but the max depth of the dive was recorded as 88 fsw (27 msw). Prior to the dive, the diver noted that his regulator was a bit difficult to breathe. The two divers descended and after an initial sign of "OK" the diver signaled that he had to ascend. The diver lost consciousness somewhere between 20 fsw (6 msw) and the surface. Resuscitation efforts were unsuccessful. The death was attributed to asphyxia by drowning. An evaluation of the diver's equipment revealed that the regulator's flow restriction device had malfunctioned to the extent getting air at depths greater than 60 fsw (18 msw) would be very difficult.
BMI = na

09-26 Cause of Death: Drowning
This 52-year-old female had received her initial open water certification five years earlier but had only made 10 lifetime dives. She had not made a dive in at least 18 months. The diver was with a large group as part of a cruise ship dive excursion. She was reported to have been apprehensive prior to the dive and also had symptoms of an upper respiratory tract infection. The sea state was reported to be rough. The diver descended with a buddy but they became separated from the group. It was reported that she had buoyancy problems all dive. The two divers were together at 90 fsw (27 msw) when they decided to ascend. The buddy turned away for a moment and then noticed that the diver was unconscious without the regulator in her mouth. Resuscitation efforts on the surface were unsuccessful. An autopsy was performed and the cause of death was determined to be drowning. The diver had no significant heart disease.
BMI = na

09-29 Cause of Death: Drowning
This 49-year-old male was a certified diver who had not made a dive in the previous three years. He made a shore entry dive with a buddy and descended to 12 fsw (4 msw). The divers noticed they were getting low on air and they surfaced. The diver panicked on the surface then lost consciousness. He was pronounced dead at a local hospital. The cause of death was determined to be drowning with additional findings of cardiomegaly and severe coronary artery disease. An air embolism cannot be completely excluded. The diver was also obese.
BMI = 36.5 $kg \cdot m^{-2}$

09-30 Cause of Death: Drowning
This 41-year-old male was a student in an initial open water certification class. A significant medical issue was that the diver was an amputee and only had one leg, his right. The diver complained of weakness in his right leg prior to entering the water and he was apprehensive according to witnesses. He made a shore entry with an instructor and another student. The diver wore 34 lb (15 kg) of lead. They descended to 15 ft (5 m) and spent about 14 min performing drills. For unknown reasons the diver panicked and spit his regulator out. The instructor first tried to hand the diver the diver's octopus but without success. The instructor had

no more success trying to provide his own octopus to the diver. The instructor held the regulator in the stricken diver's mouth and brought him to the surface where resuscitation efforts were unsuccessful. An autopsy was not performed and the death was most likely a drowning due to panic at depth while scuba diving.
BMI = na

09-31 Cause of Death: Drowning

This 67-year-old male was open water certified making his 33rd lifetime dive. His most recent dive was nine years ago. His medical history was significant for elevated serum lipids. The diver was on a boat, diving with a large group, with the intention of exploring a wreck. A series of dives was planned. The diver's buddy entered the water first and was followed by the diver. There was a strong current and the dive buddy had buoyancy problems. The two divers became separated and the diver was found floating face down and unconscious. Resuscitation efforts were unsuccessful. The death was ruled a drowning but a cardiac contribution is likely. The autopsy demonstrated focally severe coronary artery disease and cardiomegaly. Incidental findings included gallstones and benign prostatic hypertrophy.
BMI = na

09-34 Cause of Death: Drowning

This 35-year-old male was open water certified and experienced according to the investigative report. The diver had made two uneventful dives earlier that day and was hunting for lobster and spearfishing. He apparently struggled with a large grouper at 100 fsw (30 msw) and witnesses stated he appeared to have a seizure. The diver lost consciousness at depth and was brought to the surface where resuscitation efforts were unsuccessful. The cause of death was determined to be drowning due to air embolism based on a single finding of gas bubbles in the heart. Since the problem appeared to begin at depth it is unlikely that an air embolism would have initiated the fatal chain of events. Myocardial bridging and mild coronary atherosclerosis were also noted at autopsy, a finding that occasionally accounts for sudden death.
BMI = na

09-35 Cause of Death: Drowning

This 36-year-old male was an experienced diver with technical diving certification. He was using a rebreather apparatus and performing tasks as part of a research dive when he signaled to other divers that he was going to return to the habitat. The diver did not make it back to the habitat and was found unconscious on the bottom. Resuscitation efforts were unsuccessful. An evaluation of the equipment found that the diluents tank was empty and there was water in the scrubber canister. The rebreather was typically shared among divers so it is unclear if all pre-dive maintenance had been completed correctly. An autopsy was performed and the pathologist correctly determined that intravascular gas was likely an artifact. The death was ruled a drowning.
BMI = na

09-36 Cause of Death: Drowning

This 32-year-old male was a certified diver with an unknown amount of diving experience. He had obtained certification six years ago and had not made a dive in two years. The diver was performing a shore entry dive in a canal to gather lobster. He did not have a dive buddy. A witness on shore pointed out to the diver that his tank was loose but the diver dismissed it and entered the water without adjusting his equipment. Approximately five minutes into the dive, the diver surfaced and called for help. He sank back below the surface while others came to his aid. The water was murky and approximately 11 min elapsed before the diver was found on the bottom, unconscious and without the regulator in his mouth. The depth of the canal was only 17 ft (5 m). Resuscitation efforts were unsuccessful. The autopsy demonstrated changes associated with drowning and an incidental, large renal cyst. An examination of the equipment demonstrated that the inflation hose to the buoyancy compensator had not been attached and the buoyancy compensator itself had evidence of dry rot. The tank was also out of inspection standards.
BMI = na

09-42 Cause of Death: Drowning

This 37-year-old male was an experienced, certified diver. He had made a solo dive from shore, likely the evening before, and was found floating on the surface the next morning. The body was recovered and it was obvious that the diver had been deceased for at least several hours. The equipment checked out fine and there was abundant air remaining in the tank. An autopsy was performed that showed no significant natural disease processes. The cause of death was determined to be drowning. Toxicological testing showed a minimal amount of ethanol in blood but none in vitreous fluid. This most likely represents postmortem production due to decomposition. The diver apparently had a history of making solo dives in the evening. There was nothing cited in the investigation that may have contributed to the drowning.
BMI = na

09-43 Cause of Death: Drowning

There is minimal information about the circumstances surrounding the death of this 44-year-old female. She was a certified diver but very inexperienced. In fact, this was apparently her second or third open water dive after receiving certification. The investigation information noted that the diver was out of air but made a low risk ascent. On the surface she panicked and was in distress. She was picked

up by the boat but lost consciousness shortly thereafter. Resuscitation efforts were unsuccessful. Nothing about the diver's past medical history is known. The autopsy report was not made available but it was reported that the death was ruled a drowning. Despite the comment on the ascent, an air embolism cannot be entirely excluded.
BMI = na

09-49 Cause of Death: Drowning due to entrapment in a cave

This 58-year-old male was a certified cave diver who was exploring a freshwater cave system. The diver entered the water with a buddy but they became separated. The buddy surfaced ahead of the diver and waited but the diver never ascended. His body was located approximately three hours later, away from both the planned entrance and exit points. It is thought that the diver used an incorrect guide rope and became disoriented. The autopsy findings were consistent with drowning. Additionally, the diver had cardiomegaly, was obese, and had mild atherosclerotic cardiovascular disease. Toxicological testing was positive for cocaine and a cocaine metabolite.
BMI = na

09-51 Cause of Death: Drowning

There is insufficient information on the death of this 46-year-old male. His training and certification status are unknown. The diver made a shore entry into a lake and was found floating unconscious by other divers. The diver had apparently been on a solo dive. He was taken to a local hospital where he died the next day. The pathologist signed out the death as due to hypoxic encephalopathy though by forensic standards it can be ruled a drowning since the diver did not survive 24 hours. Toxicological testing was positive for prescription narcotics, a muscle relaxant, an antidepressant medication, and a beta-blocker drug. He was also obese and had an enlarged heart.
BMI = 31.1 $kg \cdot m^{-2}$

09-54 Cause of Death: Drowning

This 29-year-old male was spearfishing with a group. He was reported to be an experienced, certified diver. During the second dive of the day he was seen to struggle while ascending to the surface and he sank back down. His body was recovered in 80 fsw (24 msw) the next day. The autopsy findings were consistent with drowning and toxicology was positive for ethanol, a benzodiazepine, a narcotic pain medication, and a cocaine metabolite. The medical examiner called the death a drowning with a significant contributing factor being mixed drug intoxication.
BMI = na

09-55 Cause of Death: Drowning

This 48-year-old male was diving on the first day of lobster season. His certification and training status are unknown. The diver disappeared below the surface and was not seen again until a recovery team pulled his body from the water two and one-half hours later. The autopsy findings were consistent with drowning. An additional finding was that of hepatic steatosis. Toxicological testing was positive for a benzodiazepine, hydrocodone, and a cocaine metabolite. The medical examiner called the death a drowning with a significant contributing factor being mixed drug intoxication.
BMI = na

Proximate Cause: Unspecified or Body Not Recovered

09-16 Cause of Death: Body not recovered

This 33-year-old female was not a certified diver and it was her first time using a surface-supplied diving apparatus. She was diving with a buddy who was tied into the same surface-supplied rig. The buddy had apparently already exited the water when the diver surfaced and called for help. The buddy went back into the water without any dive gear but the regulator had already drifted away from the diver and the investigative report indicates that the hose had detached. Visibility was poor and while the diver's weights and a fin were recovered, her body was not.
BMI = na

09-50 Cause of Death: Unknown

There is very little information about the death of this 46-year-old male. He was known to be a technical diver and a newspaper article stated that the autopsy showed that he did not drown. That is a fairly inaccurate statement regarding what can be determined at autopsy. The diver was apparently using a rebreather according to the investigative information made available.
BMI = na

09-57 Cause of Death: Body not recovered

This 68-year-old female was a certified diver with an unknown amount of experience. She had a history of "minor strokes" in the past. The diver was diving with a divemaster on a coral reef. She began to descend down the wall and pushed the divemaster away when assistance was offered. The diver was last seen at approximately 100 fsw (30 msw) continuing to descend. A body was not recovered.
BMI = na

Proximate Cause: Other

09-17 Cause of Death: Near-drowning due to entanglement (line)

This 30-year-old male was a student in a commercial diving class using surface-supplied air and a full-face mask. The dive was to 40 fsw (12 msw) and a drysuit was used. It is unclear in the investigation reports if the communications system was working but the diver apparently became entangled in the umbilical and the umbilical was wrapped around a piling. Other divers went in to render assistance, but the diver was found on the bottom with his mask and hood off. The diver had apparently tried to use his bailout bottle during his attempt to extricate himself. The diver was brought to the surface and taken to a medical treatment facility where he died two days later. The investigation notes that the dive equipment, including the communications system, worked fine and that an autopsy was not performed. This appears to be a near-drowning due to entanglement.
BMI = na

09-24 Cause of Death: Anoxic brain injury due to air embolism

This 45-year-old male was reported to have been a certified diver but his experience level is unknown. He and a buddy were completing their second dive of the day in a freshwater lake when they became separated on ascent. The diver was found unconscious and floating on the surface. He died at the hospital after six months of complications. There are not many details but it appears he sustained a pneumothorax initially and eventually succumbed to complications of an anoxic brain injury. The most likely event resulting in this death under the circumstances presented would be an air embolism.
BMI = na

09-48 Cause of Death: Propeller injuries

This 60-year-old male was with a group of divers hunting lobster. His experience and certification level are unknown. The diver surfaced away from the boat and far from the dive flag. He was struck by the propeller of a passing boat and died as a result of those injuries. The autopsy also disclosed cardiomegaly, steatosis of the liver, cholesterolosis of the gallbladder, and a kidney cyst.
BMI = na

APPENDIX B. BREATH-HOLD INCIDENT CASE REPORTS

Neal W. Pollock, Niles W. Clarke, James L. Caruso

Hypoxic Blackout

09-0301

This 33-year-old male was freediving alone from a commercial dive boat. He did not describe any health issues to the group. He was reportedly diving in the 70-75 ft (21-23 m) depth range, within his capabilities. He was found unconscious on ledge at a depth of 75 fsw (23 msw) by group of scuba divers that brought him to the surface. Resuscitative efforts were unsuccessful.

The available details are limited, making any interpretation speculative. Assuming normal health, the most likely explanation was blackout, most probably hypoxia of ascent. Regardless of the agent, the lack of a partner or team to provide close supervision and rescue support, the life threat was much higher.

09-0302

This 23-year-old male was freediving from a private vessel with two friends who apparently lost sight of him. He was observed on the bottom at approximately 80 fsw (24 msw) after a five minute search but his friends were unable to reach him. Local emergency services personnel recovered him using scuba. Resuscitative efforts were unsuccessful.

No health issues were known, making diving-induced loss of consciousness most likely. The diver could have lost consciousness at the bottom if he had employed extreme hyperventilation, but it is more likely that he experienced hypoxia of ascent, losing consciousness as he approached the surface from a dive, when the oxygen partial pressure in his blood would fall fastest. Being out of sight of his friends meant that they were unable to aid him near the surface where it would be easiest and carry the greatest likelihood of success. Even if the depth he was observed at was within the performance range of the others, the stress and rush of the moment would undoubtedly compromise performance. The lack of continuous close support and limited capability increased the life threat in this situation.

09-0303

This 38-year-old male was freediving alone in a freshwater spring. He was found unresponsive at a depth of 10 ffw (3 mfw) by another group of freedivers. Resuscitation efforts were unsuccessful. The medical examiner ruled it an accidental drowning.

See comments in case 09-0302

09-0304

This male was freediving with a partner. They were employing a one-up/one-down pattern so the partner could watch the diver throughout his or her dive. The diver was seen to stop moving in the final portion of the ascent, and immediately begin to sink. His partner was able to catch him at about six feet (two meters) of depth, bring him back to the surface, and then keep his airway clear of the water until he regained consciousness. He regained consciousness quickly, with no awareness of the problem. No sequelae were reported. The partner noted in reporting the case that this was not the deepest/longest dive completed by the victim that day.

This case provides a great example of how a life-threatening can be quickly managed by effective close supervision. The fact that hypoxia of ascent usually occurs when approaching or at the surface makes it easy to resolve by a partner with modest breath-hold ability. The most important step is for a partner to be there, watchful and ready. The one-up/one-down pattern can work well in good visibility and modest depth diving. Alternatives such as a surface counterweight system will provide additional protections for low visibility operations or when the depth exceeds the reliability of the one-up/one-down system. The fact that the dive that ended in blackout was not the most extreme of the day raises another important point. The physiological demands of any dive is unique. The complex combination of comfort, relaxation, oxygen stores, carbon dioxide level, physical effort required, psychological comfort, drag, thermal comfort, and a host of other subtle factors all interact to determine the final state of the diver and the performance limits of the dive. Limited hyperventilation is often used to reduce the carbon dioxide content of the blood to delay the urge to breathe. The cost of this is a reduction in the time buffer between the urge to breathe and a state of hypoxia that drives blackout. The erosion of the buffer time will not be noticed when all goes well. The problem is that there is no indicator to say how much of the buffer (if any) remains and what the true demands of the dive will be. Not having a problem with a given level of hyperventilation on one dive provides no assurance that the same outcome will follow another dive. It is critical that divers who choose to employ hyperventilation realize that it creates a substantial risk in what is by its nature a very dynamic set of circumstances. Hyperventilation should be used with great restraint and only when reliable close supervision by competent partners is available. Limiting hyperventilation to the equivalent of no more than two full vital capacity exchanges appears to be relative safe, that is, it does not erode the safety buffer so much that loss of consciousness is expected. There is no line for absolute safety, though, so all breath-hold divers should appreciate the risk and keep it as low as feasible. Any dive is a good dive only if everyone comes back alive.

09-0305 (MSCC)

This male diver was breath-hold diving to approximately 80 ft (24 m) to free an anchor for a reported time of three minutes. Upon surfacing, the diver reported a euphoric feeling during his first breath, his heart rate increasing during the second and third breaths, and then losing consciousness. He received immediate support on the surface to protect his airway until he regained consciousness. He did so with no apparent residual issues. He called DAN to learn about what happened and the underlying physiology.

This is almost certainly a case of hypoxia of ascent. The diver hyperventilated prior to the breath-hold, driving down the partial pressure of carbon dioxide in his blood, and delaying the urge to breathe. He was fortunate to have sufficient oxygen to reach the surface at the end of the dive. While he did begin breathing on the surface, there was not sufficient time for the oxygen in the blood to reach his brain before the existing degree of hypoxia caused him to lose consciousness. The tachycardia he felt was likely a physiological response to the hypoxic stress. The euphoria could have been a physiological response to the hypoxia, a physiological response to localized cerebral hypercapnia (high levels of carbon dioxide are intoxicating), a psychological response to making it to the surface, or a combination of these effects. The hypoxic and psychological drives may be more likely, but the hypercapnia could have been high enough to play a role. This diver was extremely fortunate. Immediate and effective support to protect the airway can result in rapid and complete recovery with no sequelae. The absence of such support makes it likely that such a case will be fatal. Safety is increased by limiting hyperventilation, diving with close supervision by an able and ready support system, and defensive weighting to reduce the risk of sinking from the surface.

Medical Health

09-0311

This 62-year-old male was spearfishing with a partner. An observer on shore noticed that the diver appeared to be motionless on the surface for a prolonged period and alerted the diver's partner. The partner pulled the victim to shore where attempts at resuscitation were unsuccessful. The preliminary suspicion was cardiac issue. No follow up was available.

The details in this case are insufficient for confident interpretation. It is possible that health issues or breath-hold blackout played a role.

09-0312

This 61-year-old female was snorkeling with a group at a popular tourist site when she was found unconscious at the surface. Resuscitative efforts were unsuccessful.

The details are extremely limited, but the benign conditions and surface-based activity make it possible that medical health played a pivotal role. Many vacationers with no diving experience consider snorkel tours as an alternative to experience the water. It is generally not well appreciated or communicated that even benign conditions impart a significant physiological load. Immersion in water causes a shift in the blood volume from the periphery to the central circulation, putting an additional burden on the heart that has to pump harder to manage the increased load. Breathing through a snorkel adds ventilatory deadspace and breathing resistance. Ballast weight given to the snorkeler increases the work that must be done to move with the load, more so if the extra ballast creates poor trim and increases frontal surface area during swimming. Inefficient kicking technique can demand more effort than would otherwise be required. The stress of the experience, particularly if all factors are not optimal, can add an additional physiological burden. Ultimately, while snorkeling can be a desirable activity, it is not without risk and may not be appropriate for health-compromised individuals. Close supervision and fast response to any situations that arise is necessary to keep the risk low.

09-0313

This 61-year-old female was snorkeling near shore at a vacation resort. She was noticed to be unmoving and confirmed to be unresponsive. Attempts to resuscitate her were unsuccessful. Autopsy assigned the cause of death to drowning, with contributing factors of enlarged heart, enlarged spleen, and obesity (BMI 35.3 $kg \cdot m^{-2}$).

See comments in case 09-0312

09-0314

This 61-year-old male was with a group of friends, but was snorkeling alone. He was found unresponsive on surface by boaters two hours after he was last seen.

See comments in case 09-0312

09-0315

This 63-year-old male was participating in an open season of abalone diving. Upon leaving the water after about two hours of activity he collapsed in shallow water and stopped breathing. A medical health issue was suspected.

The physical demands of immersion alone are significant. The demands increase much more in colder and rougher water conditions, and with the effort required for active, let alone competitive collection strategies. The risk is likely highest for those not maintaining year round activity and physical fitness practice, but instead only participating during short open seasons. It is common for a number of fatalities to occur during open season for both abalone and lobster.

09-0316

This 58-year-old male was diving for abalone from a boat with a friend. His friend found him unresponsive at the surface, pulled him into the boat, and motored to shore to meet emergency personnel. Resuscitation efforts were unsuccessful. Autopsy confirmed drowning due to sudden cardiac event due to pre-existing hypertensive and atherosclerotic disease (also liver cirrhosis)

See comments in case 09-0315

09-0317

This 62-year-old male was snorkeling recreationally with a partner. Upon exiting the water he had trouble breathing and was coughing before he collapsed. Resuscitation efforts were unsuccessful.

See comments in case 09-0315

09-0318

This 76-year-old male was snorkeling at a popular near-shore tourist site with a partner when he complained of a choking sensation. Lifeguards removed him from the water and began unsuccessful efforts at resuscitation.

See comments in case 09-0315

09-0319 (MSCC)

This 25-year old male spearfisherman completed two breath-hold dives to about 100 ft (30 m) and then up to five dives to between 45 ft (14 m) and 100 ft (30 m). He cocked the speargun (by pulling back the bands) about eight times over the course of the day. He reported feeling tingling and pain in his left hand after cocking the speargun after the second dive. They symptoms did not change over the course of the diving day, but did apparently improve somewhat if he balled up his hand into a fist. He reported waning but still residual tingling in his hand days after the diving. A primary care physician found no clear explanation and referred him to a neurologist. He called DAN for a referral to a physician trained in diving medicine. No further follow up was available.

The natural question is whether this could be a case of decompression insult or musculoskeletal irritation. There are a sufficient number of anecdotal reports of symptoms consistent with DCS during deep and particularly deep repetitive breath-hold diving to discourage ruling it out automatically. The depth and number of exposures prior to symptom development in this case, however, were not extreme. The observation that the symptoms did not improve during subsequent dives but they did approve through the effort of making a fist could be seen to reduce the likelihood of decompression-induced symptoms. Alternatively, the effort required to cock a speargun can be substantial. It is very reasonable to expect that this could result in musculoskeletal irritation, possibly taking a substantial recovery period for full resolution.

09-0320 (MSCC)

This 44-year-old male diver went snorkeling two days after completing his open water scuba certification dives. After snorkeling, the diver developed a sharp pain in his left shoulder upon inspiration that hindered his breathing. After evaluation, it was revealed to be caused by pulmonary emboli that clotted in his pulmonary artery.

Not all injuries that arise during diving will be a result of the diving. Medical issues may well arise that could be influenced by the activity, or completely unrelated to it. The contribution of various factors can rarely be confirmed with complete confidence. Knowing that non-diving problems can result during diving is one of the reasons why divers are encouraged to not automatically plan for care at a hyperbaric medical center over a closer medical center. Appropriate and rapid medical evaluation is important to ensure that the right care is provided.

09-28 Cause of Death: Air embolism due to hypertensive heart disease

This 19-year-old male was an experienced, certified diver who was reported to be freediving during this fatal mishap. The diver had made a scuba dive earlier but the group he was diving with were taking turns using dive equipment. His scuba dive was to 44 fsw (13 msw) for 32 min followed by a 30 min surface interval before he started freediving. The diver was spearfishing when he was seen to sink to the bottom. He was brought to the surface where resuscitation attempts were made but were unsuccessful. The only known medical issue was a childhood history of asthma. An autopsy was performed and the cause of death was determined to be an air embolism. This was based in the finding of gas in the heart. An air embolus would only have been possible if the diver had taken air from someone else's regulator while freediving and then failed to exhale appropriately while ascending. There is nothing conclusive in the investigation.

Boat Strikes

09-0321

This 26-year-old was spearfishing with a number of friends from a commercial dive boat. A recreational motorboat entered the area at high speed, striking one diver, resulting in the subsequent amputation of both of his legs.

Breath-hold divers spend more time on the surface than compressed gas divers. Safety from boat traffic must be considered in activity planning. Flying appropriate and recognized dive flags, staying close to marked and staffed safety platforms, avoiding all but low traffic areas, wearing high visibility equipment, watchfulness, and public education are all important elements to promote safety.

09-0322

This 52-year-old male was snorkeling with a partner when he was hit by a passing boat. There were no marker buoys in the area.

See comments in case 09-0321

Poor Practice

09-0331

This 51-year-old male was spearfishing with friends on a private vessel. The details are incomplete, but the vessel apparently developed engine trouble while the diver was in the water. Those on the boat contacted the US Coast Guard when the diver was no longer visible. The missing diver was located two hours later by a rescue helicopter crew, continuing to spearfish close to shore and in no distress.

The incomplete detail presents a challenge, but it seems certain that communications and planning were inadequate. Keeping the boat and diver together would have eliminated the need to allocate a Coast Guard helicopter to the search.

09-0332

This 23-year-old male went spearfishing with a partner who decided to return early. The victim failed to return home; his body was found the next day. No autopsy results were available.

The details are extremely limited, but the diver's decision to continue diving without his buddy removed a major source of potential support.

09-59

This 52-year-old male was freediving with a friend in the ocean. The friend surfaced and upon not seeing the diver he departed the area only to return later when he realized that the diver had not returned to his residence. The body was recovered the next day and the autopsy findings were consistent with drowning. Toxicological testing was negative. No cause or contributing factor to the drowning were identified.

See comments in case 09-0332

09-0333 (MSCC)

This male diver called DAN with questions after he experienced short-lived epistaxis (nose bleed) during a static breath-hold practice dive. Upon further questioning, it was revealed that he had been practicing breath-hold for the previous couple of days and had been forcing Valsalva maneuvers for equalization. He reported no additional symptoms or past medical history. He was counseled to improve his equalization techniques and advised to seek medical evaluation if the condition persisted.

This was likely a case of localized blood vessel rupture in response to forceful equalization techniques. This can happen to both breath-hold and compressed gas divers. A surprising amount of blood can be released, often raising the stress of the person seeing it in his or her mask. A single, short-lived episode will generally be of minimal concern. Focusing on methods to reduce the stress of equalization can usually avoid recurrence. Bleeding that does not immediate stop or that occurs repeatedly requires medical evaluation.

09-0334 (MSCC)

This 20-year-old male was breath-hold diving to approximately 20 ft (6 m) to recover a piece of equipment. He was unable to equalize the pressure in his mask during descent. He felt sinus pain and surfaced to find that his eyes were bloodshot, but with no apparent changes in vision. He called DAN to learn about the severity of the condition and what to expect for the course of recovery and/or treatment.

Failure to equalize mask pressure during descent will produce the negative pressure circumstance known as a 'squeeze.' The rapid change in relative pressure near the surface make this an important consideration even in swimming pool depths. It is possible to enucleate the eyes as a partial vacuum is produced in the space if goggles are worn. With dive masks that incorporate the nose in the air space, blood vessels in the nose will usually rupture fairly quickly, partly filling the mask with fluid and reducing the negative pressure. The negative pressure acting on the eye can lead to the rupture of superficial vessels, and the bloodshot appearance. Localized swelling in the skin that was within the mask space can also be seen. Mild cases of mask squeeze normally resolve without treatment, the skin swelling within minutes or hours and the bloodshot eyes within a short number of days. Cases that include any visual changes require immediate medical evaluation.

09-0335 (MSCC)

This 56-year-old male diver completed a breath-hold dive to approximately 25 ft (8 m) in which he reported hearing a "loud horn-like sound" accompanied with pain in one ear. He reported a feeling of fullness immediately after the event and began taking Motrin® and Sudafed® until he saw his doctor two days later. The physician saw fluid behind the diver's tympanic membrane (eardrum) and advised him to continue on the medications he was taking.

Ineffective equalization stresses tissues within the middle ear. It is possible for blood vessels to rupture, partly or completely filling the space with blood. This can initially reduce the pain since the pressure in the space is effectively equilibrated. The sense of fullness and impaired hearing also result from the presence of the fluid. In uncomplicated cases, the fluid will typically be resorbed over a period of days with no complications. Medical evaluation is advised, as are efforts to optimize equalizing. The optimal method of equalization will differ between individuals. A slow rate of vertical travel in the water column and, for some, a head up orientation will reduce the degree of stress and make for much easier equalization. Practice will reduce the risk of future problems.

APPENDIX C. AUSTRALIAN WATERS DIVE FATALITY CASE REPORTS

John Lippmann, Christopher Lawrence, Andrew Fock, Thomas Wodak, Scott Jamieson, Richard Harris, Douglas Walker

DAN Asia-Pacific (AP) collects information on diving and snorkeling fatalities throughout the Asia-Pacific region. However, the effectiveness of this data collection varies greatly between countries.

In Australia, dive fatalities are comparatively well investigated and most are logged on a National Coronial Database to which DAN AP has access. It often takes several years before the coronial investigations are completed and for detailed information to become available.

Dive fatality reporting plays an enormously important role in accident prevention, and DAN AP is committed to providing substantial resources in pursuing this task. The reports shown here are only brief summaries of the cases for 2009. Detailed reports of these deaths have been published in the journal of the South Pacific Underwater Medical Society (SPUMS).* We are very grateful to the various Australian State Coroners and the NCIS for their assistance with this project, and to the members of the public who have provided information. We need divers to contact us when they hear of diving-related fatalities so that we can collect as much information as possible.

*Lippmann J, Lawrence C, Wodak T, Fock A, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2009. *Diving Hyperb Med.* 2013; 43(4):194-217.

Introduction

Each year in Australia there are deaths associated with snorkeling and with diving using compressed-gas. Although some accidents are unavoidable, many might have been prevented through better education about the proposed activity and/or associated risks, proper medical screening, greater experience, common sense, improved supervision, or better equipment maintenance and design. This report includes the diving-related fatalities between January 01 and December 31, 2009 recorded in the DAN AP database.

Breath-hold and snorkeling fatalities

BH 09/01

This 63-year-old male was described as a fit and healthy non-smoker and light drinker who attended the gym regularly. He was a strong swimmer and a very experienced spearfisherman. He and his buddy went spearfishing at a familiar site in choppy seas with a slight swell and visibility of about 6 m (20 ft). The pair separated soon after entering the water and, after about an hour when the buddy returned to the entry point, a bystander told him that his friend was lying dead on the nearby rocks. Earlier, the bystander had found the victim floating face-down, unconscious in the water and had brought him onto the rocks. CPR was commenced by bystanders and continued until paramedics arrived. The victim died despite these efforts. The autopsy revealed that the victim had significant cardiovascular disease and likely became unconscious in the water as a result of a heart problem, and then drowned.

BH 09/02

This 56-year-old male had a history of sleep apnea and hypertension but was described by his wife as a "well-rounded athlete who could swim OK," and he was an inexperienced snorkeler. He was on a day trip on the Great Barrier Reef. That morning he had snorkeled, played beach cricket and hiked up a hill, all prior to lunch. At no stage had he appeared, or complained to his wife, of feeling unwell. He later went snorkeling with others in relatively good conditions. However, a short time later, a lookout on the boat noticed that he appeared to be unconscious. After entering the water and reaching the victim just as he began to sink, the lookout gave two rescue breaths and towed the victim to the vessel. He was dragged on board and CPR commenced. There was no supplemental oxygen available. Resuscitation was unsuccessful. It is possible that this death resulted from an abnormal heart rhythm (cardiac arrhythmia) due to pre-existing heart disease.

BH 09/03
This 26-year-old male appeared to be fit and healthy but was a relatively poor swimmer. Late one afternoon, he and a friend went snorkeling from the bank of a very large river which was murky with a fast current that increased further away from the shore. The victim began to struggle to stay afloat and his friend tried to support him but was forced to let go due to a cramp. Some bystanders responded to the victim's call for help and entered the water to assist. However, before they could reach him, the victim had submerged and they were unable to find him. His body was found well downriver four days later. The cause of death was drowning.

BH 09/04
This 71-year-old male was described by his doctor as "fit and healthy." He had suffered from back stiffness (from ankylosing spondylitis) for the past 30 years but was no longer taking any regular medications. He and his wife swam daily during summer months at their local ocean beach. He was described as "not a bad" swimmer who wore "goggles" and a snorkel as his back condition made it difficult for him to lift his head while swimming. On this occasion, the victim and his wife were having their regular swim in calm, shallow water. After a short time, as the wife was leaving the water, she heard a strange sound and turned to see her husband removing his goggles and gasping for breath. She went back into the water and, with the assistance of another swimmer, helped the victim onto the beach. A nearby tourist, who happened to be a doctor, began CPR but this proved to be unsuccessful. The cause of death was given as drowning, possibly caused by a heart condition.

BH 09/05
This 61-year-old female was described by her husband as "in good health," although she was obese and was taking medication for hypertension. Her husband reported that she was a competent snorkeler although she had apparently got into "some difficulty" while snorkeling on another occasion. She did not declare any medical condition to the snorkel operator when asked. She went snorkeling from an island beach fringed by coral reef, which began about 20 m (66 ft) from the shore. There was a buoyed line at the extremity of the snorkeling area, beyond which the current was thought to be too strong. There was little current initially but this quickly changed and there was soon a current, which likely ranged in speed from less than 1 knot near the beach to 5 knots further out. The victim entered the water, accompanied by another passenger (a weak swimmer who was using a 'noodle' buoyancy aid), and snorkeled towards the buoyed area. When she encountered a strong current she became anxious and began to panic. Her buddy shared his 'noodle' with her and they were towed to chest-deep water by a tender. She became unconscious soon after reaching shore. CPR was provided by some doctors who were bystanders, supplemental oxygen was administered, and an AED was attached but no shock was indicated. CPR was continued for almost an hour before she was pronounced dead. The cause of death was a cardiac problem, likely precipitated by exertion against a strong current and the anxiety this caused.

BH 09/06
This 76-year-old male had a history of hypertension for which he was prescribed medication. He had previously suffered from diabetes but no longer took medication for this and did not declare any medical condition prior to participating in a resort-based snorkeling activity. He was a weak swimmer with no previous snorkeling experience. He and some others entered the water from a sandy beach. He was wearing a mask and snorkel, shorts and a t-shirt. Flotation aids had been offered but he had not taken any. He also had not buddied-up with another snorkeler. The weather was clear and the sea calm. A short time later, the lookout became concerned when he noticed that the victim had not moved or responded to his calls. After going to the victim and finding him to be unconscious, the lookout quickly towed him to shore where he placed him into the recovery position and a large amount of water and froth flowed from the victim's mouth. As the victim remained unconscious and was not breathing, CPR was commenced, supplemental oxygen was soon provided, and an AED was attached but advised that no shock be given. A nurse from the nearby resort arrived and assisted with resuscitation efforts but these were unsuccessful. It seems likely that this victim drowned as a result of a heart arrhythmia due to severe pre-existing heart disease.

BH 09/07
This 31-year-old male was apparently very healthy with no known significant medical history. He was an experienced spearfisherman and underwater photographer who had been learning some apnea diving techniques to extend his breath-hold capability. He was practicing breath-holding while doing underwater laps of a pool which was located in a gymnasium complex. He was wearing a mask and long freediving fins and was carrying a 1 kg (2 lb) weight (described as "looking like a dumbbell") in his hands. He was alone in the pool. He was found unconscious on the pool bottom with a plume of bloody fluid coming from his mouth and nose. CPR was begun by a bystander and continued by paramedics but was unsuccessful. The cause of death was given as drowning, which may have resulted from a "breath-holding blackout" or possibly from a heart arrhythmia.

BH 09/08

This 28-year-old male was an apparently healthy non-swimmer. He had used a mask and snorkel for the first time two days earlier while standing in shallow water watching fish. He and two friends went to a popular snorkeling area off a sandy beach. There was a weak current. The friends snorkeled for a while and the victim stood in waist-deep water with his face on the surface watching fish through his mask while breathing through his snorkel. He was wearing board shorts and had no floatation aid. After they all returned to the beach, the friends went for a walk and the victim re-entered the water alone. Shortly afterwards another snorkeler found the victim motionless on the seabed at a depth of 1.8 m (6 ft) and about 20 m (66 ft) from shore. His mask was nearby but his snorkel was not visible. He was brought to shore and CPR was begun and continued despite the outflow of large amounts of froth and water from the victim's mouth. When paramedics arrived more than an hour later, the victim was pronounced dead. The cause of death was likely to have been drowning after stepping into deeper water and not being able to stay afloat, or possibly sudden death from brain malformation.

BH 09/09

This 31-year-old male was apparently healthy with no significant medical history. He was a good swimmer, an assistant scuba Instructor, and a highly-experienced and regular spearfisherman. He went spearfishing with three friends in relatively good conditions. After over two hours, the other pair of divers left the water and the victim's buddy exited 15 min later, noticing his friend's buoy bobbing in the water at that time and presuming that he was fine. A while later, they became concerned when they noticed that the float had not moved for some time and they could not see any sign of their friend. A search was begun and the victim's spear was soon retrieved, embedded in what was described as a 2.5 m (8 ft) wobbegong (carpet) shark. The victim's body was found underwater the next day. The cause of death was reported to be drowning (possibly subsequent to "breath-holding blackout").

BH 09/10

This 20-year-old male, a highly accomplished surf lifesaver and ironman competitor, was extremely fit and healthy and had been spearfishing infrequently for about two years. He joined a group from a local spearfishing club on a five-day spearfishing trip on a large liveaboard vessel. One of the victim's companions noticed that he would lie on the seabed at 22 m (72 ft) for about two minutes waiting for fish to swim by. The companion expressed concern that this technique was risky due to "not being aware of your depleting oxygen stock." The next day, the victim and two others drifted in the current, at times up to 100 m (330 ft) apart. Several hours later when the others boarded the dinghy, they watched the victim's float and became concerned when the victim did not surface. He was soon found unconscious at a depth of about 10 m (33 ft). He was brought to the surface, CPR was begun and continued for at least an hour before being stopped on the advice of a doctor. The victim's dive watch/computer indicated that he had dived to a maximum depth of 15 m (50 ft) for a total time of more than eight minutes. The record indicates that he began to ascend to the surface after 1:44 min:s but, after reaching a depth of 2 m (6 ft), appears to have sunk to the bottom over a one minute period and remained there for almost six minutes before being rescued. The cause of death was given as drowning (possibly subsequent to "breath-holding blackout")

BH 09/11

This 68-year-old male was reported to have been generally healthy. He was on a day-trip on a large sight-seeing vessel on the Great Barrier Reef. He was a competent swimmer but his snorkeling experience was unknown. He reportedly looked pale and unwell that morning. After a briefing, he and others entered the water. He was wearing board shorts, a t-shirt and a mask and snorkel but there is no mention if he was wearing fins. He did not take a buoyancy aid. The conditions were described as calm with a light wind, and some current. Shortly after entering the water, the victim was seen dog-paddling towards the boat but then put his face down and snorkeled with his arms beside him. He was not noticed again and, when the group returned to the vessel some 45 min later, a head-count revealed that he was missing. The victim was found about 10 min later floating face-down on the surface about 70 m (230 ft) from the vessel. A person on the tender quickly gave him some rescue breaths and dragged him aboard and began CPR while the victim was transferred to the main vessel. CPR was continued with ventilations now being provided using a bag-valve mask and supplemental oxygen. The victim regurgitated water and other stomach contents. CPR continued for almost an hour before efforts were abandoned when a nurse declared him to be dead. The cause of death was given as drowning.

BH 09/12

This 64-year-old female was severely overweight (BMI = 42.5 $kg \cdot m^{-2}$) and had an extensive medical history including asthma and allergies, hypertension, among other conditions. She was a poor swimmer who had only very recently taken lessons. Her snorkeling experience is unknown. She failed to declare any health conditions or medications on the pre-snorkeling medical declaration and waiver form. At the site, the conditions were described as good. The victim was wearing mask and snorkel, a stinger suit and carried a 'noodle' floatation device. She entered the water and was soon seen by the lookout snorkeling alone about 7 m (23 ft) from the boat. However, about five minutes later crew members became concerned to see her motionless and apparently unconscious. No-one had heard any splashing or call for help. She was brought aboard and found to be unconscious and not breathing so CPR was commenced by the crew. Supplemental oxygen was provided and an AED was attached but it is appears that no shock was given. Paramedics soon arrived and declared the victim to be dead. This silent drowning could have been precipitated by a heart arrhythmia, asthma, or simply by aspiration of water and sudden unconsciousness.

Scuba diving fatalities

SC 09/01

This fit-looking 47-year-old male dived for crayfish or abalone regularly, usually alone and had been diving for around 20 years. When undergoing a pre-employment medical, he reported to the doctor that he had a history of epilepsy but had been fit-free for many years. However, the doctor prescribed medication for this. He went diving alone from shore at a popular site with rocky reef and kelp and which was subject to a large swell and surge. Prior to going, he called a friend to enquire about the conditions and was told it was not ideal but that he should be OK. Searchers found his body the next morning about 10 m (33 ft) from shore, floating in shallow water with waves washing over him and his high pressure hose snagged in rocks. There was still plenty of air in the tank. The demand valve's mouthpiece had a 5 mm (0.5 inch) cut on its underside, which could have possible been caused by the clenching of teeth during a seizure but there is no evidence for this. The regulator was tested and found to be acceptably functional and the remaining air was not contaminated. The doctor who performed the pre-employment medical had no training in dive medicine and was unaware that the victim was a diver, so had not discussed the relevant risks of diving with epilepsy with him. The cause of death was reported to be drowning. It is possible that this occurred as a result of an epileptic seizure.

SC 09/02

This 17-year-old male was apparently fit and healthy, a good swimmer but an inexperienced diver who but had logged little more than four hours of diving. He and a friend went diving for abalone from a beach in a small bay. There was a one-meter (3 ft) swell and also some surge in shallower water. After snorkeling for a while, they descended and the victim swam behind his buddy, towing the float with flag and carrying the catch bag. They became separated and the buddy surfaced, located the float about 50 m (165 ft) away and swam over to it. The victim was not there. The buddy eventually located his friend lying unconscious at a depth of around 6 m (20 ft). His mask was full of bloodied water and his regulator was out of his mouth. The buddy brought his friend to the surface and towed him to some rocks. Two bystanders began CPR, repeatedly rolling the victim onto his side to drain the blood and water coming from his mouth and nose. CPR was then continued by others and an AED was attached but no shock was advised. An ambulance paramedic arrived and pronounced him dead. The victim's dive computer record indicated that, after separating from his buddy, he had made a direct ascent to the surface where he remained for about one minute before descending quickly to a depth of around 6 msw (20 fsw) where he remained motionless for 75 min before recovery. No problem was found with his equipment or breathing air. The cause of death appears to have been drowning, secondary to a lung barotrauma and cerebral arterial gas embolism.

SC 09/03

This 20-year-old female was apparently healthy but an inexperienced swimmer. She and some friends went on an introductory scuba dive. A dive briefing (in English, which was not her primary language) was given during the boat trip to the dive site. The victim was wearing a weight belt with 9.5 kg (31 lb) of weight. The group swam on the surface to shallow water near the shore of a small island where they were taught basic skills while standing or swimming in water of a depth of around 1.5 m (5 ft). The sea was reportedly choppy and waves disrupted the training from time to time. The water was murky, with visibility ranging from 1-1.5 m (3-5 ft), and there was a current. When satisfied with their skills, the instructor led the group into deeper water to a depth of around 2.5 m (8 ft) and the students "crawled along the bottom" in a line, with the instructor just ahead, reportedly checking them regularly. The instructor could see the faces of the students but not their entire bodies. After a while, the instructor noticed that the victim was missing and aborted the dive. Prior to the group surfacing, others saw the victim surface alone, call for help and then sink. Her body was found on the seabed about 40 min later. Her weightbelt was in place and her BCD deflated. She was recovered and CPR was attempted unsuccessfully by police and paramedics. On later inspection it was found that the regulator mouthpiece was perforated, potentially enabling water aspiration. The instructor was charged with manslaughter and, at the committal hearing, representatives for the police, Workplace Health and Safety, among others, argued that the victim was overweighted, that her regulator was poorly maintained and that the instructor erred in taking a group of four totally inexperienced divers in such poor visibility. However, the magistrate determined that the evidence was insufficient to support charges of unlawful killing and the charge was dismissed. The cause of death was unreported but is likely due to drowning alone, or possibly as a result of cerebral arterial gas embolism.

SC 09/04

This 59-year-old male, apparently healthy, had logged a total of 30 dives over three years. He did not declare any medical conditions on the pre-dive medical questionnaire. He went diving with two others from a vessel on the Great Barrier Reef. The sea was calm, visibility at least 15 m (50 ft) and no mention was made about the presence or strength of any current. After about 20 min of diving, during which the victim became separated (for the second time), his buddies ascended and found him holding onto a mooring line and breathing from his extra second stage ('octopus'). He told them that he was "OK," and did not appear to be in any distress, but he wanted to swim back to the boat (60-70 m [200-230 ft] away) on the surface. The divers signaled to the lookout on the boat that everything was "OK." After one of them checked the victim's gauge (100 bar [1550 psi]) and helped to place his primary regulator into his mouth, the others descended to return to the boat underwater. The lookout initially saw the victim swimming towards the boat but, when he was about 25 m (80 ft) away, although he signaled that he was "OK," the victim appeared to be swimming aimlessly and then turned and began to swim away from the boat. Eventually, a tender was sent to retrieve the then unconscious and partly submerged victim. He was dragged aboard and CPR commenced by one of the buddies (a paramedic). He was rolled onto his side several times in order to clear stomach contents from his airway. About an hour later, a doctor arrived on a rescue helicopter and declared the victim dead. It is likely that this man had a cardiac arrhythmia or angina during the dive or swimming on the surface, became disoriented, then unconscious, and drowned.

SC 09/05

This 50-year-old male had logged approximately 75 dives. He suffered from a chronic back condition and was being treated for hypertension and a variety of other problems. He went to the gymnasium about four times a week, swam regularly and appeared to be relatively fit although "solid-looking and carrying a bit of fat." He was assessed as "fit to dive" three months earlier by a doctor trained in dive medicine. He was doing some surface rescue drills during a rescue diver course and had acted as both the rescuer (towing another diver about 30 m [100 ft]), and the rescuee, which was the last role he had undertaken. A short time later he began thrashing and turning over in the water before becoming motionless, face-down. When one of the instructors went to him and rolled him over, he was unresponsive with froth coming from his mouth, although he appeared to be breathing. While being towed towards the shore he appeared to have a seizure, stopped breathing and his face became cyanotic (blue). One of the rescuers began rescue breathing and, on reaching shore, one of the instructors began CPR. Paramedics arrived 16 min later and continued resuscitation and, although he responded briefly to defibrillation, he was pronounced dead on arrival at hospital. The cause of death was likely a cardiac arrhythmia due to his existing heart disease.

SC 09/06

This 52-year-old male was an active and competitive wood-chopper who was described as fit and healthy, although "a bit overweight." He was taking regular medication for hypertension and high cholesterol. Five months earlier he had an exercise stress test, which was showed no problems and he last saw his doctor two months earlier to monitor his hypertension and was reported to have been in good health. He had logged 65 dives, although he had not dived for the past 3.5 years. He and two friends went diving from a small boat anchored in the lee of a small island where the depth was around 4 m (13 ft). The water was calm with no significant current or swell and visibility was about 12 m (40 ft). The victim entered the water last and appeared to be relaxed although he had trouble with a leaking mask. After some time, the buddy realized that he could not see the victim and, while swimming back to the boat, he found the victim's mask and snorkel and became concerned when he surfaced and could not see his friend anywhere. The victim was found quite a while later floating face-down and unconscious on the surface, approximately 200 m (660 ft) away from the boat. He was not wearing his weightbelt. He was brought aboard and resuscitation was started, but was unsuccessful. The cause of death appeared to have been cardiac-related.

SC 09/07

This 53-year-old male appeared to be very fit and healthy despite a strong family history of heart disease. He was not known to be taking any medications and it was reported that he avoided doctors. He had dived for 39 years, logging over 2000 dives, and qualified as an instructor 20 years earlier. He was on a day trip on a large charter boat and did not declare any medical conditions to the dive operator prior to diving. The victim and his inexperienced buddy had done an uneventful earlier dive and now dived again, this time on a wreck at a depth of around 25 m (82 ft). The sea was calm and there was a current of approximately 0.5 knot. After ascending the anchor line of another boat, the victim decided that he and his buddy should swim to their boat, possibly up to 200 m (660 ft) away. The buddy was unable to swim unaided against the current so the victim towed him for several minutes until the buddy was able to make headway, unaided. The divers reached the current (or mermaid) line from the boat and began to pull themselves along it. However, the victim began to float away, face-down and motionless. A tender came over to assist, and the victim was dragged aboard and CPR commenced. This was continued with supplemental oxygen on the main vessel and later by a paramedic on a nearby resort, without success. Although this highly experienced diver appeared to be fit and healthy, cardiovascular disease may well have led to an arrhythmia, triggered by the heavy exertion of swimming and towing his buddy against a current.

SC 09/08

This 33-year-old male was reasonably fit and had no known health conditions. He was certified two months earlier and had only done three open water dives. He went diving for crayfish with three friends, two of whom were also inexperienced divers. They dived from rocks in a relatively calm bay and, although their entry point was sheltered from the wind and looked calm from their vantage point, there was a strong wind, a 2 m (6 ft) swell and strong current on the other side of the rocks. The divers surfaced on the seaward side of the rocks where the conditions were rough, with breaking waves and a strong current. Unable to access their planned exit point, they swam towards the nearest rocks, reaching them about 20 min later. Two of the divers managed to scramble onto the rocks, while the victim and one friend struggled against the waves and current. The victim managed to climb onto the rocks but, while attempting to stand, was knocked over by a breaking wave into the water. He swallowed some water and was coughing and struggling and calling for help. One of the divers told him to put his regulator in his mouth, which he did, before descending under the breaking waves without his mask on. One diver tried to jump in to help but was dashed against the rocks by the waves and retreated, losing his mask and fins in the process. Some of the others also lost equipment, and one sustained a broken finger. The divers waited for a short time, in the hope that he might surface away from the waves but, when they accepted that this was unlikely, they called the police. The victim's body was later found close to where he had last been seen at a depth of 11 m (36 ft). His mask was missing, his regulator was out of his mouth, but other equipment in place. No attempts were made to resuscitate him due to the delay. The cause of death was drowning.

Surface supplied breathing apparatus diving fatalities

SS 09/01

This 36-year-old male was described as fit and healthy. Two years earlier, he had suffered what had been reported as a possible seizure but there had been no known further events. He had been a recreational diver for 13 years but his experience was unreported. He was assessed as fit-to-dive by a qualified diving medical examiner five months earlier when he began working at a pearl farm. He was using a tow-line surface-supplied breathing apparatus and was spreading some pearl shell panels across the seabed. There was a supervisor on board the dive tender which was tethered to a platform. After a bottom time of eight minutes, he ascended directly to the surface, ditched his weightbelt and waved for help before sinking to the bottom. The supervisor recalled the other divers and pulled the victim onto the platform by the airline. His mask was removed and there were froth and stomach contents coming from his mouth. CPR was begun by the others and supplemental oxygen was added when the equipment was brought to the vessel. Resuscitation attempts continued for an hour until a doctor advised that they stop. Given his history of what was thought to have been a seizure, it is possible that he had another seizure and subsequently drowned. It is also possible that he simply aspirated water accidentally, although this seems to be unlikely.

LESSONS TO LEARN FROM THESE DEATHS

Pushing one's breath-holding limits is a potentially dangerous practice and sudden unconsciousness can occur with or without hyperventilation. Ascent from depth increases the chance of this due to the rapid reduction in pressure and the drop in partial pressure of oxygen in the blood and tissues. However, "breath-holding blackout" can also occur as a result of extended breath-holding with minimal ascent

A recurring theme in dive fatality reports is the absence, or breakdown, of the 'buddy system.' It is important to remember that an unconscious, non-breathing diver needs to be rescued and resuscitated swiftly in order to have a chance of survival. This is extremely unlikely in the absence of a vigilant buddy or close supervision, and sometimes impossible even if there is. One of the victims was doing an introductory scuba program under the supervision of an instructor in circumstances where it was, at least, arguable that the instructor-student ratio was inappropriate.

In commercial snorkeling situations there are often too few lookouts relative to the number of snorkelers and this makes adequate supervision difficult.

Diving with a history of epilepsy can be very risky. Diving and snorkeling may involve a variety of factors that can increase the chance of a seizure. These include stress, exercise, sensory deprivation, hypercapnia, hyperventilation and hypothermia. Seizures can occur while taking anti-epileptic medication or may reoccur many years after stopping medication.

It is very important that a diver who is at risk of becoming unconscious underwater gains positive buoyancy by inflating their BCD and/or ditching their weights. This is an important training drill, which needs to be practiced, embedded and periodically re-visited. The need to locate a diver, especially underwater, delays the opportunity for relatively early resuscitation efforts so it is far better for an unconscious diver to be at the surface, rather than to have to be searched for and recovered from underwater.

Divers should adjust their weights so that they are "neutrally buoyant" on the surface (or at their safety or decompression stop). Despite this, it is common practice for instructors to make their students negatively buoyant as it usually makes them less likely to float to the surface during a dive without the instructor's knowledge. However, it also makes achieving good trim and buoyancy control more difficult, resulting in students kicking or stirring up the bottom, which can increase fatigue and reduce visibility. Overweighting can also make it more difficult for a diver to ascend and remain on the surface. Ultimately, this practice is dangerous, especially for inexperienced divers.

Instructor-to-student ratios are set for ideal conditions and should be reduced accordingly if conditions are less than ideal. Instructors/Dive operators should seriously consider whether introductory dive programs should be cancelled in poor environmental conditions, on the basis of both participant pleasure and safety.

Heart-related factors appear to have contributed to at least six, and possibly up to 12 of the 21 fatalities for this year. The snorkeling and diving environment places a variety of stresses on the heart and 'older' divers are more likely to have these problems. Obesity is also known to increase the chances of a heart-related problem. It is important that divers over about 45 years of age discuss their 'heart-health' with a doctor (preferably one with training in dive medicine).

APPENDIX D. ASIA-PACIFIC (EXCLUDING AUSTRALIA) DIVE FATALITY CASE REPORTS

Scott Jamieson, John Lippmann

Note: Relatively little information is often available at all, or readily accessible by DAN Asia-Pacific (AP), for fatalities in most countries in the Asia-Pacific. Australia is the greatest exception and these are reported separately. In addition, in some of the developing counties autopsies are often not conducted, or are done by examiners without diving medical knowledge expertise. For this reason, the possible disabling injuries or causes or death are not suggested here.

COOK ISLANDS

This 37-year-old man was a known diabetic and described as obese. He had never previously snorkeled. The boat he was snorkeling from had moved out into deeper water and he was snorkeling across the reef to return to the boat when he got into trouble. Another couple who were in the snorkeling group saw him struggling and provided assistance. After the victim stopped breathing and his face became blue, they delivered rescue breaths for the 5-7 min it took the boat to reach them. He was transported to the hospital but could not be saved.

FIJI

FJ-BH09/01

The 47-year-old tourist went snorkeling alone in an area that was frequented by boats. A boat operator returning home from a neighboring village was travelling at speed when he felt that he had hit something. He could not see anything in the water and returned to shore, notifying others that he thought he might have hit someone. The victim's body was found near the spot where the boat driver had directed them.

FJ-BH09/02

This 53-year-old European tourist was snorkeling in shallow waters near a resort's private beach. When resort staff noticed that he was not moving, they immediately rushed to attempt a rescue but resuscitation attempts were unsuccessful.

FJ-SC09/01

While scuba diving with friends at night, this elderly victim went missing and failed to surface. His body was found nearby the following day. It was speculated that he may have been swept away by strong currents and subsequently drowned. There was no autopsy results available to determine otherwise.

HONG KONG

HK-SC09/01

This 44-year-old man was night diving with friends spearfishing around a pier, as they had done several times before. He was an experienced diving instructor who had been diving for more than 10 years and was known to always "suck the last breath of air from his tank," often staying down two hours. On this occasion, the water was clear and they left a spotlight on the shore to guide them back. After an hour the buddies returned to shore leaving the victim diving alone. When he failed to return to shore after a further 90 min they alerted the authorities. He was found 50-100 m (165-330 ft) from shore, floating mid-water at a depth of about 2.5 m (8 ft). His tank was empty.

HK-SC09/02

This 45-year-old man was an inexperienced diver who dived once or twice a year in the three years since obtaining his open water certification. He was doing the second dive of the day using hired equipment. The group had planned to dive as two groups of three but when they entered the water and discovered the visibility had dropped to less than 1 m (3 ft) they decided to pair up based on the color of their fins.

All the divers submerged and dived to a depth of around 6 m (20 ft) for 45 min. After returning to the boat the group noticed that the victim was missing. His body was found three days later and there was 145 bar (2250 psi) of air remaining in his tank. The combination of poor visibility, communication problems due to some of the group speaking different languages, and confusion about fin color contributed to the separation.

HK-SC09/03

This veteran 50-year-old male diver was diving with a buddy. The pair surfaced less than 50 m (165 ft) from shore in water only 3 m (10 ft) deep. The victim complained of feeling unwell and had difficulty breathing on the swim back to shore. When they reached the shore the buddy called the marine police who arrived 5 min later. At this stage the victim was semi-conscious. He was taken to a local hospital where he was declared dead a short time later. There is some speculation that he may have suffered from a cardiac condition.

INDIA

IND-SS09/01

This 35-year-old man was a commercial diver with more than 10 years of experience. He was diving using surface-supply when he became trapped in a submerged chamber at a depth of approximately 50 m (165 ft) when his leg was sucked into a drainage pipe. He survived trapped for 33 h before finally becoming unconscious and subsequently drowning. Rescue divers took more than 24 h to arrive at the scene but were then unable to free his leg in time as the victim was panicking and lunging at rescuers, not allowing them near his trapped leg. The victim's body was bought to the surface after 72 h after recovery divers finally amputated his leg above the knee to free him.

INDONESIA

IN-BH09/01

This 25-year-old male tourist was visiting this island location with his partner and friends. He left the other three shortly after breakfast to go snorkeling alone. He was a strong swimmer and extremely fit and healthy. He was known to be able to dive underwater holding his breath for a very long time. He was reported missing when he failed to return by the next day, His body was found four days later. Although the cause of death was not determined' the examining pathologist speculated that he might have suffered from "breath-holding hypoxia" and subsequently drowned.

IN-SC09/01

This tourist, a 45-year-old man, was diving in a marine park with three friends and a divemaster. After diving to a maximum depth of 25 m (82 ft), the group returned to the surface where, several minutes later, the victim was noticed to be experiencing difficulty breathing. He died, despite emergency measures being taken.

IN-SC09/02

This European tourist, who was believed to have been about 50 years old, was holidaying and diving with a group that included three other divers and two guides. The site they were visiting was highly current-prone and some down currents were present. While on the safety stop one of the guides noticed that he was missing. About one hour later another divemaster found his body caught on coral at a depth of about 25 m (82 ft). When found, the victim had blood coming from him mouth and ears, his regulator was out of his mouth, his tank was empty and he was missing one fin. His dive computer showed a maximum depth of 61 m (200 ft).

MALAYSIA

MY-RB09/01

This 37-year-old male was a fit, healthy and experienced diver who had been diving for more than seven years. He was on a CCR trimix course diving on a wreck at a depth of 55 m (180 ft). After a bottom time of 12 min, he and his instructor ascended to 39 m (128 ft) where the victim signaled that he was 'out of air.' After changing to his open-circuit bailout system and they continued the ascent but he lost buoyancy control and ascended rapidly. At the surface he was initially conscious although quite distressed. However, after climbing onto the boat he collapsed with no signs of life. CPR was commenced immediately, without success.

MY-SC09/01

This 29-year-old woman was stuck by the propeller of the boat she had been diving from. She sustained severe and extensive injuries and died from blood loss.

MY-SC09/02

This 41-year-old man was a rescue department diver who was involved in an operation to locate a missing body. During the dive he became entangled in the branches of a submerged tree and drowned.

MY-SC09/03

After surfacing from a 19 m (62 ft) dive in good conditions with no current, this 36-year-old male divemaster (reported to have been "quite overweight") became breathless and drifted from the surface line. He was brought onto the boat complaining of difficulty breathing. He reported no pain but was breathing very rapidly. He was given oxygen via a constant flow mask but after several minutes he collapsed, unconscious and not breathing. He failed to respond to CPR. Autopsy showed signs of a heart attack.

NEW ZEALAND

NZ-BH09/01

This 59-year-year-old male was snorkeling and diving for mussels with family members on a notorious but commonly used site along a rock bank that extends out from the shore. The tide at this location can create rips very quickly and the deceased got into difficulty. His brother and emergency services attempted rescue and resuscitation without success.

NZ-BH09/02

After entering the water mid-afternoon for a solo snorkel swim, this 70-year-old man was reported missing about 90 min later by family who were on the shore waiting for him. A rescue helicopter found and recovered his floating and lifeless body approximately three hours later, about 1400 m (4600 ft) from where he had entered the water.

NZ-BH09/03

This victim was 55-year-old man who was amongst a group who were snorkeling for paua. He was found floating unconscious in the water and could not be resuscitated. Post-mortem examination confirmed that he died as a result of drowning subsequent to heart attack.

NZ-BH09/04

This 68-year-old man had been an active diver for over 30 years. He was currently described as “not in good health” although he was not taking medication. Conditions were poor with rough seas. Wearing a wetsuit, he entered the water from a wharf with a rope tied to him. At some point during the dive he got into difficulty and a friend tried to pull the victim out of the water. Another person arrived on the scene and together they succeeded in removing the victim from the water. There was froth coming from his mouth and CPR was unsuccessful.

NZ-SC09/01

A 45-year-old male, this victim was diving as part of a group of seven people. When he failed to surface with the group, the alarm was raised. After a 15-min search, the victim was found, but resuscitation attempts were unsuccessful. It was found that he dived with an almost empty tank and, after running out of air, he tried to surface holding his breath.

NZ-SC09/02

This 52-year-old man had been scuba diving from a boat. However, immediately after surfacing, he collapsed with no signs of life. He failed to respond to resuscitation provided by medical personnel on the boat, and later by an advanced life support paramedic.

NZ-SC09/03

The victim was an active 65-year-old diver with more than 45 years of experience who was described as fit and healthy. Shortly after he and his buddy had entered the water the buddy realized that the victim was no longer with him. He organized a search and the victim was found a short time later on the seabed with his regulator out of his mouth. The equipment he used for the dive was in poor condition but it was not believed to have contributed to his death. The cause of death was determined to have been drowning.

NZ-SC09/04

The victim was a 50-year-old man who diving solo on scuba in 4 m (13 ft) of water while his friends snorkeled around him. When he failed to surface the friends discovered him lying on the sea floor and dived to retrieve him. The victim did not regain consciousness despite CPR provided by the friends and a rescue helicopter crew.

NZ-SC09/05

This 38-year-old man had been a scuba diver for 16 years, but was thought not to be very competent. He failed to surface after diving for crayfish. His body was found the next day at a depth of 37 m (121 ft). His mask and regulator had been displaced but the rest of his equipment was intact and there was still plenty of air remaining in his tank. It was noted that he was overweighted and that his BCD needed to be inflated orally as there was no power inflator hose. His dive computer record indicated that 5 min into the dive the victim suddenly descended to the seabed where he was later found. It was postulated that he may have tried to orally inflate his BCD and aspirated some water, either during this action or on replacing the regulator, possibly causing him to panic and subsequently drown.

NZ-SC09/06

This 17-year-old youth with a history of epilepsy went diving using borrowed equipment, which may have been in poor condition. He was not wearing a wetsuit but was wearing a weightbelt and was believed to be overweighted. He surfaced alone and complained to those in the boat that he was having trouble with his mask but remained in the water. When his buddy surfaced he found him floating face-down and unconscious. CPR was unsuccessful. It was speculated that epilepsy may have contributed to his drowning.

PHILIPPINES

PH-RB09/01

This 41-year-old male, using a closed-circuit rebreather, descended to 130 m (427 ft) while his buddy waited at 100 m (330 ft). The buddy noticed the victim having some problems and descended to 110 m (360 ft) to assist him. The buddy offered his bailout but the victim refused this. The victim then became unconscious and his mouthpiece fell from his mouth. The buddy placed his bailout regulator to the victim's mouth and ascended with him to 50 m (165 ft) where a guide on open-circuit scuba was waiting. The guide inflated the victim's BCD to prevent them sinking. However, he over-inflated and caused both of them to ascend rapidly. The buddy and guide both required recompression therapy. The victim died.

PH-SC09/01

This male victim was a veteran spearfisher of more than 20 years. He had a history of two previous cardiac incidents and was known to dive solo and deep while spearfishing using scuba. On this occasion, he was diving alone using twin cylinders filled with air. His body was later found at a depth of 58 m (190 ft). There was 140 bar (2200 psi) of air remaining in his tanks and he had a 12 kg (26 lb) fish attached to his spear.

PH-SC09/02

This double fatality involved two men, aged 28 and 44 years conducting the last dive of their holiday. They were with a group of divers diving in an area known for deep wall dives, strong currents and fierce surge. The dive was planned to be to 40 m (130 ft) for 30 min but when the group surfaced the two victims were missing. Their bodies were later recovered. The disabling injury remained unknown.

PH-SC09/03

This 52-year-old woman was a tourist who was diving with a group led by an instructor. They were diving near a floating platform but did not have a dive flag or any other surface marker to indicate their position. As they surfaced the victim was struck by a speedboat and suffered fatal head injuries.

PH-SC09/04

This 45-year-old technical diver and recreational dive instructor was on holidays with his buddy. They were ascending from a deep technical dive and had already completed a stop at 21 m (70 ft). While at the 16 m (50 ft) stop, the victim indicated that something was wrong before suffering from a seizure and spitting out his mouthpiece. As his jaws were locked, his buddy was unable to replace the mouthpiece. The buddy sent the victim to the surface where the boat quickly located him. Resuscitation was attempted without success. It appears that each diver was planning to carry one cylinder of 50% O_2 and one of 100% O_2 for decompression. It was speculated that the victim may have accidentally taken two bottles of 100% O_2, resulting in him switching to 100% at 16 m and suffering from oxygen toxicity. The oxygen partial pressure at this depth would be nearly 2.6 ATA.

SINGAPORE

SG-SC09/01

This 21-year-old male, was a recreational dive instructor who had been freelancing as a commercial diver. He was working on an oil-rig at a depth of 20 m (66 ft) when he indicated to his more experienced buddy that he needed to share air. After taking two breaths he began to ascend. The buddy followed but lost sight of him. The victim's body was found 54 h later. There was substantial remaining air in his cylinder. It seems that the divers were using safety lines but somehow the victim had become separated from his.

THAILAND

TH-BH09/01

This male 40-year-old tourist entered the water near his hotel to go snorkeling. That evening his body was found floating face down in the sea. No further information was available.

TH-BH09/02

An unknown (middle-aged) woman of European appearance washed up on the beach wearing a wetsuit, weight belt (with at least 4 kg [9 lb] of weight) mask and snorkel. No further information was available.

TH-BH09/03

This man described as "in his thirties," was a European tourist with no significant medical history. He had been snorkeling without incident the day before. On this day he was snorkeling in a group with an instructor present when he showed signs of distress. The instructor swam to him and found him unconscious and not breathing. CPR was performed for 20 min at the scene and an automated external defibrillator (AED) was attached, but a doctor pronounced the victim dead at the scene.

TH-SC09/01

An experienced instructor, this 60-year-old male European expatriate had had dived to 50 m (165 ft) and beyond many times. He was on a "fun dive" to 50 m with a buddy when he experienced an out-of-air situation. When they started their ascent, the buddy noticed that the victim was breathing from his deco tank of EAN36 and so offered him an alternate air source. The victim refused this and ascended rapidly to the surface from 42 m (138 ft). His death certificate reported that he had died from a heart attack (although, this is possible, it is likely that the medical examiner was unfamiliar with diving medicine and the possibility of a cerebral arterial gas embolism may not have been considered). The victim's twinset manifold was later found to be in the closed position with one of his two main cylinders still full. It was reported that the victim had been refused decompression diving training by two instructors three years prior due to declaring "a heart condition" and "panic attacks" on his medical form.

TH-SC09/02

This incident resulted in two fatalities; a 35-year-old male diving instructor and a 25-year-old student, both Thai nationals. There were four students on the course and one panicked during a mask-clearing exercise. The student swam towards the surface and the instructor followed. The three other students surfaced but the instructor and the first student were not to be found. The body of the student was found three days later on the seabed at a depth of 50 m (165 ft). A body, possibly that of the instructor, washed ashore one month later.

TH-SC09/03

This 45-year-old male was an experienced diver with more than 300 dives. The dive was planned to 45 m (148 ft) on air with deco gases of EAN36 and 100% O_2. After a bottom time of 28 min, the victim and his buddy started to ascend. On completing his 31 m (102 ft) stop, the victim swapped to his 36% mix and started to ascend to his next stop at 19 m (62 ft). However, the buddy and other divers found him at 21 m (69 ft), unconscious and with his regulator out of his mouth. They tried unsuccessfully to replace the regulator and then did an emergency ascent with the victim. After leaving the victim with the boat crew, the buddy descended to complete his decompression obligation. CPR was unsuccessful.

TH-SC09/04

This female was a young European tourist who had experienced an unknown event during her dive which caused her to rapidly ascend. She was taken to a nearby hospital and stabilized while waiting for air transport to a larger hospital. She died en route. The cause of death was given as cerebral arterial gas embolism.

TH-SC09/05

This foreign national was diving with four friends in an area restricted for boat traffic about 300 m (1000 ft) from the beach. He surfaced and was struck by a boat's propeller, suffering severe lacerations to his torso and legs. Search and recovery divers recovered his body from the sea floor.

VIETNAM

VN-SC09/01

Dynamite fishing is an illegal, but still relatively common, practice in parts if Vietnam. In this case, the fishermen saw bubbles and, believing that these were caused by a large fish, threw dynamite into the water. They tried to flee the scene when they realized that they had killed a diver.

VN-SS09/01

This 57-year-old male was a respected deep-sea commercial diver and former navy clearance diver. He was diving used mixed gases at a depth of 57 m (187 ft), working solo from a diving bell. During the dive his umbilical line, which included the gas line, became fouled on heavy piece of steel on the seabed. After more than 11 min, the standby diver managed to get the victim back to the bell but rescue attempts were unsuccessful.

APPENDIX E. PUBLICATIONS (2014-2009)

2014

Refereed Articles (primary literature)

Buzzacott P, Pollock NW, Rosenberg M. Exercise intensity inferred from air consumption during recreational scuba diving. Diving Hyperb Med. 2014 June; 44(2): 74-8.

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Pollock NW. Carrying fresh water while diving. Alert Diver. 2009; 25(2): 6-7.

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APPENDIX F. PRESENTATIONS BY RESEARCH AND MEDICINE PERSONNEL (2014-2012)

List of abbreviations

AAUS - American Academy of Underwater Sciences
CME - continuing medical education
DEMA - Diving Equipment and Marketing Association
DMT - Diver Medic Technician
EDAN - Divers Alert Network Europe
EUBS - European Underwater and Barometric Society
HTNA - Hyperbaric Technician and Nurses Association
IDAN - International Divers Alert Network
JSHUM - Japanese Society of Hyperbaric and Undersea Medicine
NOAA - National Oceanic and Atmospheric Administration
UHMS - Undersea and Hyperbaric Medical Society
UJNR - US-Japan Cooperative Program in Natural Resources

2014

Pollock NW. Altitude and diving. National Parks Service Diving Control Board. Shepherdstown, WV (06 Feb 2014).

Pollock NW. Nucleation study review. NASA Human Research Program Investigator's Workshop. Galveston, TX (13 Feb 2014).

Pollock NW. Diving and diver protection. Wilderness Medical Society Student Elective. Townsend, TN (18-20 Feb 2014).

Pollock NW. Cardiorespiratory and exercise physiology I. CBI 206. Durham, NC (26 Feb 2014).

Pollock NW. Thermal physiology. CBI 206. Durham, NC (18 Mar 2014).

Ranapurwala SI. Cultivating safe behaviors in recreational scuba divers: A cluster randomized trial of pre-dive checklists. 65th Annual Society of Public Health Education (SOPHE) conference, Baltimore, MD (18-21 March 2014).

Pollock NW. Altitude and diving. National Parks Service, Lake Powell. Page, AZ (20 Mar 2014).

Denoble PJ. Chronic diseases and safety of diving – DAN Membership Health Survey. Beneath the Sea, Seacaucus, NJ. (28-30 March 2014)

Denoble PJ. Pre-dive checklists and the culture of dive safety. Beneath the Sea, Seacaucus, NJ (28-30 March 2014)

Pollock NW. When pressure is not about diving. DAN Public Lecture Series. Durham, NC (02 Apr 2014).

Pollock NW. Aviation physiology. CBI 206. Durham, NC (16 Apr 2014).

Pollock NW. Controlling decompression stress. DAN Dive Medicine (75th). Little Cayman (04 May 2014).

Pollock NW. Physical fitness and diving safety. DAN Dive Medicine (75th). Little Cayman (05 May 2014).

Pollock NW. Research diving in Antarctica. DAN Dive Medicine (75th). Little Cayman (05 May 2014).

Pollock NW. Thermal physiology. DAN Dive Medicine (75th). Little Cayman (06 May 2014).

Pollock NW. Special population divers. DAN Dive Medicine (75th). Little Cayman (07 May 2014).

Pollock NW. Flying after diving and high altitude decompression. DAN Dive Medicine (75th). Little Cayman (08 May 2014).

Pollock NW. Physiological aspects of breath-hold diving. DAN Dive Medicine (75th). Little Cayman (09 May 2014).

Pollock NW. Ambulation increases decompression sickness in altitude exposure. Aerospace Medical Association annual scientific meeting. San Diego, CA (14 May 2014).

Pollock NW. Concerns of the aging diver. TEKDiveUSA. Fort Lauderdale, FL (17 May 2014).

Pollock NW. Myths and misconceptions of thermal stress and physiology. TEKDiveUSA. Fort Lauderdale, FL (18 May 2014).

Denoble P, Covington D, Ebersole D. PFO study progress. SPUMS Annual Meeting, Bali, Indonesia (18-25 May 2014).

Denoble PJ. Cadiovascular risk factors and diving. Scuba Show. Long Beach, CA (07-08 June 2014).

Denoble PJ. DAN Membership health survey. Scuba Show. Long Beach, CA (07-08 June 2014).

Denoble PJ. Pre-dive checklists – culture of dive safety. Scuba Show. Long Beach, CA (07-08 June 2014).

Clarke NW. Pulmonary function response to recreational-technical closed-circuit rebreather trimix diving. Annual UHMS conference and Symposium on Medical Examination of Diving Fatalities, St Louis, MI (18-22 June 2014)

Denoble PJ. Factors affecting adherence to pre-dive checklists: a nested study. Annual UHMS conference and Symposium on Medical Examination of Diving Fatalities, St Louis, MI (18-22 June 2014)

Trout BM. Divers Alert Network fatality database review for breathing gas contamination: 2004-2012. Annual UHMS conference and Symposium on Medical Examination of Diving Fatalities, St Louis, MI (18-22 June 2014)

Pollock NW. Dive computer algorithms tutorial. University of Virgin Islands scientific diving program. (14 July 2014)

Vann RD. Decompression fundamentals. Duke Hyperbaric fellows, Durham, NC (29 July 2014)

Pollock NW. Managing decompression stress: beyond the algorithm. EUROTEK. Birmingham, England (20 Sep 2014).

Pollock NW. Thermal physiology and protection. EUROTEK. Birmingham, England (21 Sep 2014).

Denoble PJ. Cardiac health and diving. Cozumel Divers Day, Cozumel, Mexico (06 Oct 2014)

Pollock NW. Physiology and pathophysiology of immersion. NOAA Dive Medicine Course for Physicians. Seattle, WA (06 Oct 2014).

Pollock NW. Thermal stress and protection. NOAA Dive Medicine Course for Physicians. Seattle, WA (07 Oct 2014).

Pollock NW. Altitude and diving. National Parks Service 40 h Course. Jackson Hole, WY (08 Oct 2014).

Pollock NW. Thermal stress and protection. National Parks Service 40 h Course. Jackson Hole, WY (09 Oct 2014).

Pollock NW. Interpreting dive profiles. National Parks Service 40 h Course. Jackson Hole, WY (09 Oct 2014).

Denoble PJ. Lessons learned from rebreather diving fatalities in recreational diving. Underwater Interventions, Dalian, China (17 Oct 2014)

Pollock NW. Physical fitness and diving safety. UHMS Canada. Quebec City, Quebec (18 Oct 2014).

Pollock NW. Physiology and safety of extreme breath-hold diving. UHMS Canada. Quebec City, Quebec (19 Oct 2014).

Pollock NW. Diving for Science in Antarctica. Durham Academy Assembly. Durham, NC (12 Nov 2014).

Denoble PJ. What do you trust with your life: mnemonics or physical checklists? Diving Equipment and Marketing Association annual meeting. Orlando, FL (19-22 Nov 2014).

Denoble PJ. What is your risk of heart attack while diving? Diving Equipment and Marketing Association annual meeting. Orlando, FL (19-22 Nov 2014).

Denoble PJ. Thirteen ways to run out of gas and how not to. Diving Equipment and Marketing Association annual meeting. Orlando, FL (19-22 Nov 2014).

Denoble PJ. Have you ever had skin DCS? Diving Equipment and Marketing Association annual meeting. Orlando, FL (19-22 Nov 2014).

Pollock NW. The true impact of buoyancy control in diving safety. Diving Equipment and Marketing Association annual meeting. Orlando, FL (19 Nov 2014).

Pollock NW. Accident case studies: lessons learned from DAN data. Diving Equipment and Marketing Association annual meeting. Orlando, FL (19 Nov 2014).

Pollock NW. Bubbles and diving - facts and fallacies. Diving Equipment and Marketing Association annual meeting. Orlando, FL (20 Nov 2014).

Pollock NW. Diabetes - a growing challenge for divers and leaders. Diving Equipment and Marketing Association annual meeting. Orlando, FL (20 Nov 2014).

Pollock NW. Accident case studies: lessons learned from DAN data. Diving Equipment and Marketing Association annual meeting. Orlando, FL (21 Nov 2014).

Pollock NW. The true impact of buoyancy control in diving safety. Diving Equipment and Marketing Association annual meeting. Orlando, FL (21 Nov 2014).

Pollock NW. Diabetes - a growing challenge for divers and leaders. Diving Equipment and Marketing Association annual meeting. Orlando, FL (22 Nov 2014).

Pollock NW. Bubbles and diving - facts and fallacies. Diving Equipment and Marketing Association annual meeting. Orlando, FL (22 Nov 2014).

Denoble PJ. PFO and DCI. International Congress on Hyperbaric Medicine. Buenos Aires, Argentina (02-06 Dec 2014).

Denoble PJ. Use of pre-dive checklist. International Congress on Hyperbaric Medicine. Buenos Aires, Argentina (02-06 Dec 2014).

Denoble PJ. Technical diving fatalities. International Congress on Hyperbaric Medicine. Buenos Aires, Argentina (02-06 Dec 2014).

Pollock NW. Managing decompression stress. International Congress on Hyperbaric Medicine. Buenos Aires, Argentina (02 Dec 2014).

Pollock NW. Thermal stress and protection. International Congress on Hyperbaric Medicine. Buenos Aires, Argentina (03 Dec 2014).

Pollock NW. Physical fitness and diving safety. International Congress on Hyperbaric Medicine. Buenos Aires, Argentina (05 Dec 2014).

Brittany T. Does Sex Matter in Diving? DAN Public Lecture Series, Durham, NC (03 Dec 2014).

2013

Pollock NW. Physiology and pathophysiology of immersion. DAN Public Lecture Series. Durham, NC (06 Feb 2013).

Pollock NW. Research diving in Antarctica. Down Under Dive Club. Cary, NC (12 Feb 2013).

Pollock NW. Diving and diver protection. Wilderness Medical Society Student Elective Program. Townsend, TN (18 Feb 2013).

Pollock NW. Cardiorespiratory and exercise physiology I. CBI 206. Duke University. Durham, NC (20 Feb 2013).

Pollock NW. Scuba and freediving - avoid becoming a statistic. Blue Wild Exposition. Fort Lauderdale, FL (23 Feb 2013).

Pollock NW. Cardiorespiratory and exercise physiology II. CBI 206. Duke University. Durham, NC (04 Mar 2013).

Pollock NW. Getting fit to dive. DAN Webinar (Albany Aquanauts). Durham, NC (07 Mar 2013).

Pollock NW. Breath-holding - physiology, hazards and community education. National Drowning Prevention Symposium. Fort Lauderdale, FL (14 Mar 2013).

Pollock NW. Thermal physiology. CBI 206. Duke University. Durham, NC (18 Mar 2013).

Bird N. Managing DCS in remote locations. DAN Public Lecture Series. Durham, NC (03 Apr 2013).

Pollock NW. Aviation physiology. CBI 206. Duke University. Durham, NC (15 Apr 2013).

Denoble PJ. PFO and scuba diving. DAN DMT course. Durham, NC (01 May 2013).

Pollock NW. Diving safety fundamentals. 73rd DAN Dive Medicine CME program. St. Lucia (05 May 2013).

Pollock NW. Physical fitness and diving safety. 73rd DAN Dive Medicine CME program. St. Lucia (06 May 2013).

Pollock NW. Thermal physiology. 73rd DAN Dive Medicine CME program. St. Lucia (07 May 2013).

Pollock NW. Special population divers. 73rd DAN Dive Medicine CME program. St. Lucia (08 May 2013).

Pollock NW. Flying after diving and high altitude decompression. 73rd DAN Dive Medicine CME program. St. Lucia (09 May 2013).

Pollock NW. Breath-hold diving. 73rd DAN Dive Medicine CME program. St. Lucia (10 May 2013).

Pollock NW. Influence of repeated daily diving on decompression stress. Aerospace Medical Association meeting. Chicago, IL (13 May 2013).

Pollock NW. Decompression stress and outcomes in extreme diving. Inner Space. Grand Cayman (25 May 2013).

Pollock NW. Pathophysiology of immersion. Inner Space. Grand Cayman (25 May 2013).

Denoble PJ. Chronic diseases and diving. DAN Public Lecture Series. Durham, NC (06 Jun 2013).

Ranapurwala SI. A pre-dive safety checklist may prevent diving mishaps - results from a grouped randomized trial. Society of Epidemiologic Research annual meeting. Boston, MA (18 Jun 2013).

Pollock NW. Diving in the 21st century. Southeast Wilderness Medical Society meeting. Chattanooga, TN (23 Jun 2013).

Pollock NW. Dive medicine practicum. Southeast Wilderness Medical Society meeting. Chatanooga, TN (25 Jun 2013).

Denoble PJ. Chronic diseases and safety of diving - results from DAN membership health survey. Richmond Dive Club. Richmond, VA (09 Jul 2013).

Denoble PJ. Medical issues of rebreather diving. Brazilian Hyperbaric Medicine Course. São Paulo, Brasil (21 Aug 2013).

Denoble PJ. Recreational scuba diving fatalities. Brazilian Hyperbaric Medicine Course. São Paulo, Brasil (21 Aug 2013).

Denoble PJ. Pulmonary barotrauma. Brazilian Hyperbaric Medicine Course. São Paulo, Brasil (21 Aug 2013).

Ranapurwala SI. A pre-dive safety checklist prevents diving mishaps: results from a grouped randomized trial. UHMS Pacific Chapter Annual Meeting. Las Vegas, NV (06-07 Sep 2013).

Ranapurwala SI. Diving injury rates: results from an online survey. UHMS Pacific Chapter Annual Meeting. Las Vegas, NV (06-07 Sep 2013).

Denoble PJ. Checklists work! Preventing diving mishaps, injuries, and fatalities. Down Under Scuba club meeting. Raleigh, NC (08 Oct 2013).

Denoble PJ. Rebreather diving for open-circuit divers. Divers' Day. Cozumel, Mexico (17 Oct 2013).

Denoble PJ. Chronic diseases and diving. DAN Membership Health Survey. Public Hospital. Cozumel, Mexico (18 Oct 2013).

Pollock NW. Managing decompression stress: beyond the algorithms. Undersea and Hyperbaric Medical Society Canada. Halifax, NS (03 Nov 2013).

Pollock NW. Pathophysiology of immersion. DEMA. Orlando, FL (06 Nov 2013).

Pollock NW. Measuring decompression stress. DEMA. Orlando, FL (06 Nov 2013).

Pollock NW. Measuring decompression stress. DEMA. Orlando, FL (07 Nov 2013).

Pollock NW. Myths and 'facts' in diving physiology. DEMA. Orlando, FL (07 Nov 2013).

Vann RD. Evidence-based decompression. DEMA. Orlando, FL (07 Nov 2013).

Pollock NW. Pathophysiology of immersion. DEMA. Orlando, FL (08 Nov 2013).

Vann RD. Project Dive Exploration: 1995-2008. DEMA. Orlando, FL (08 Nov 2013).

Pollock NW. Myths and 'facts' in diving physiology. DEMA. Orlando, FL (09 Nov 2013).

Denoble PJ. Rebreather diving for physicians. JSHUM. Tokyo, Japan (09 Nov 2013).

Pollock NW. Antarctica and polar diving. Durham Academy. Durham, NC (04 Dec 2013).

Ranapurwala SI. Cultivating safe behaviors in recreational diving. DAN Public Lecture Series. Durham, NC (04 Dec 2013).

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Pollock NW. Extreme diving and diver protection. Wilderness Medical Society Student Elective in Wilderness and Environmental Medicine. Townsend, TN (14 Feb 2012).

Bird N. (Dive accident symposium panel member). Dive accidents and their management and stacking the deck - dive safety. Our World Underwater. Chicago, IL (17-19 Feb 2012).

Denoble PJ. Decompression sickness: recognition, treatment, prevention. Boston Sea Rovers. Boston, MA (Mar 2012).

Denoble PJ. Controversies of in-water recompression. Boston Sea Rovers. Boston, MA (Mar 2012).

Bird N. How good is your emergency action plan? Beneath the Sea. Secaucus, NJ (23 Mar 2012).

Bird N. Mechanisms and management of diving emergencies. Danbury Hospital. Danbury, CT (14 Apr 2012).

Pollock NW. Diving safety fundamentals. 71st DAN Dive Medicine CME program. Dominica, West Indies (28 Apr 2012).

Pollock NW. Physical fitness and diving safety. 71st DAN Dive Medicine CME program. Dominica, West Indies (29 Apr 2012).

Pollock NW. Thermal physiology. 71st DAN Dive Medicine CME program. Dominica, West Indies (30 Apr 2012).

Pollock NW. Special population divers. 71st DAN Dive Medicine CME program. Dominica, West Indies (01 May 2012).

Pollock NW. Flying after diving and high altitude decompression. 71st DAN Dive Medicine CME program. Dominica, West Indies (02 May 2012).

Pollock NW. Breath-hold diving. 71st DAN Dive Medicine CME program. Dominica, West Indies (04 May 2012).

Denoble PJ. Recreational scuba diving fatalities by the numbers. Rebreather Forum 3.0. Orlando, FL (18 May 2012)

Pollock NW. Thermal physiology and protection. Rebreather Forum 3.0. Orlando, FL (18 May 2012).

Pollock NW. Decompression stress and outcomes in extreme diving. Inner Space. Grand Cayman, Cayman Islands (26 May 2012).

Denoble PJ. Recreational scuba diving fatalities by numbers. Interns training. DAN. Durham, NC (Jun 2012).

Bird N. Mechanisms of dive accidents. Wilderness Medicine Congress Meeting. Whistler, BC (13 Jul 2012).

Bird N. Dive accident management in remote locations. Wilderness Medicine Congress Meeting. Whistler, BC (13 Jul 2012).

Pollock NW. The deep end of diving science. DAN Public Lecture Series. Durham, NC (01 Aug 2012).

Bird N. Decompression sickness - initial management. Science of Wound Care. Diving and Hyperbaric Medicine. Palm Beach Gardens, FL (02-05 Aug 2012).

Bird N. Treatment, mechanisms of dive accidents and fatalities. Science of Wound Care. Diving and Hyperbaric Medicine. Palm Beach Gardens, FL (02-05 Aug 2012).

Bird N. Treatment of DCS in remote locations. Science of Wound Care. Diving and Hyperbaric Medicine. Palm Beach Gardens, FL (02-05 Aug 2012).

Bird N. The demise of emergency HBOT services in the US. Science of Wound Care. Diving and Hyperbaric Medicine. Palm Beach Gardens, FL (02-05 Aug 2012).

Pollock NW. Hyperbaric pathophysiology of immersion. NOAA/UHMS Physician Training in Hyperbaric Medicine Course. Seattle, WA (06-07 Aug 2012).

Pollock NW. Diving-related physiology. NOAA/UHMS Physician Training in Hyperbaric Medicine Course. Seattle, WA (06-07 Aug 2012).

Pollock NW. Thermal considerations I and II. NOAA/UHMS Physician Training in Hyperbaric Medicine Course. Seattle, WA (06-07 Aug 2012).

Pollock NW. Diabetes and recreational diving. HTNA. Christchurch, New Zealand. (24-25 Aug 2012).

Pollock NW. Research diving in Antarctica. HTNA. Christchurch, New Zealand. (24-25 Aug 2012).

Denoble PJ. Overview of research at DAN. DAN DMT Course. Durham, NC (Sep 2012).

Denoble PJ. Delay to recompression and the outcome of DCI. How it may affect your dive plan. EDAN Divers' Days. Belgrade, Serbia (Sep 2012).

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APPENDIX G. GLOSSARY

Neal W. Pollock

Absorbent (rebreather)
Chemical compound used to remove carbon dioxide from breathing gas. See "Scrubber."

Acetaminophen
Tylenol, paracetamol, N-acetyl-p-aminophenol, APAP. A non-prescription drug that is used as an alternative to aspirin to relieve mild pain and to reduce fever.

Adult Respiratory Distress Syndrome (ARDS)
Severe inflammation of the alveoli (air sacs) of the lungs, inhibiting gas exchange, and carrying a high threat to life.

Advair
Prescription drug that prevents the release of substances in the body that cause inflammation. It is common used to prevent asthma attacks and flare-ups or worsening of chronic obstructive pulmonary disease (COPD) associated with chronic bronchitis and/or emphysema. Advair contains the steroid fluticasone and the bronchodilator salmeterol. Salmeterol works by relaxing muscles in the airways to improve breathing.

Aerobic Capacity (VO_2 max)
The maximal amount of oxygen that can be consumed per unit of time. Determined through a short, graduated test to exhaustion while expired gases are captured and analyzed. Often reported in weight-indexed units of milliliters of oxygen consumed per kilogram body weight per unit time ($mL \cdot kg^{-1} \cdot min^{-1}$).

Agonal Breathing
An abnormal pattern of breathing characterized by sporadic gasps with audible effort. Possible causes include cerebral ischemia and severe hypoxia. Agonal breathing often progresses to complete apnea and death.

Albuterol
A prescription drug (also known as salbutamol) used to prevent and treat wheezing and shortness of breath caused by breathing problems (e.g., asthma, chronic obstructive pulmonary disease). It is also used to prevent asthma brought on by exercise. Albuterol belongs to a class of drugs known as bronchodilators. It works in the airways by opening breathing passages and relaxing muscles. Nervousness, shaking (tremor), mouth/throat dryness or irritation, cough, dizziness, headache, trouble sleeping, or nausea may occur. Serious side effects include fast/pounding heartbeat, muscle cramps/weakness. Rare but very serious side effects include chest pain and irregular heartbeat. Rarely, this medication has caused severe, sudden worsening of breathing problems/asthma (paradoxical bronchospasm).

Alternobaric Vertigo
Dizziness and disorientation resulting from unequal pressures in the two middle ears. Usually transient.

Ambiguous DCS
A case where the diagnosis of DCS is not certain; for example, a case with sufficient decompression exposure but minimal, atypical symptoms or symptoms of short duration that spontaneously resolve.

Antiemetic
A drug that prevents or treats nausea and vomiting, typically used to treat motion sickness.

Antihistamine
Drug that may be part of some over-the-counter (OTC) medicines for allergies and colds. Some antihistamines cause drowsiness. See "Over-the-Counter."

Annual Fatality Rate (AFR)
The annual fatality rate is a count of deaths occurring within one year in a specified population (incidence) divided by the number of persons in the specified population (the denominator). AFR is usually expressed as the number of deaths per 100,000 persons.

Arterial Gas Embolism (AGE)
Gas in the arterial circulation. In divers this may be caused by a sudden reduction in ambient pressure, such as a rapid ascent without exhalation that causes over-pressurization of the lung and pulmonary barotrauma. The most common target organ is the brain, and the usual signs and symptoms include the rapid (<15 min) onset of stroke-like symptoms after reaching the surface.

Arterionephrosclerosis
Patchy, wasting scarring of the kidney due to narrowing of the lumen (cavity) of the large branches of the renal artery.

Aspiration
The drawing of a foreign substance, such as water or gastric (stomach) contents, into the respiratory tract during inhalation.

Ataxia
A gross lack of coordination of muscle movements. Examples include: unsteady gait (walk), tendency to stumble, slurred speech, difficulty with fine-motor tasks (e.g., buttoning a shirt), slow eye movements, and difficulty swallowing.

Atherosclerosis
Thickening and hardening of the arteries caused by the accumulation of plaque.

Atmosphere (atm)
Measure of atmospheric pressure indexed to the normal conditions at sea level. Normal sea level pressure is 1.0 atm, 1.013 bar, 14.695 pounds per square inch, 101.3 kilopascals or 760 mm Hg.

Atmosphere Absolute (ATA)
Ambient pressure, including the barometric pressure of the air above the water.

Auscultation
The act of listening for sounds made by internal organs, for example, the heart and lungs, to aid in diagnosis.

Automated External Defibrillator (AED)
A portable electronic device that automatically assesses patients for life-threatening cardiac arrhythmias (dysrhythmias) of ventricular fibrillation and ventricular tachycardia. If identified, the device can be activated to provide a shock to interrupt the dysrhythmia and allow the heart to reestablish an effective rhythm. The device will not recommend a shock in the absence of a target dysrhythmia.

Barotrauma (BT)
A condition caused by a change in ambient pressure in a gas-filled space due to the effects of Boyle's law. When gas is trapped in a closed space within the body, the gas will be compressed if the depth increases and will expand if the depth decreases. Barotrauma injuries of descent include ear squeeze, tympanic membrane rupture or sinus squeeze. Injuries of ascent include pulmonary barotrauma, which can result in air embolism, pneumothorax or pneumomediastinum. See "Boyle's Law."

Benzodiazepine
A class of drugs that act on the central nervous system as tranquilizers, such as Librium and Valium.

Body Mass Index (BMI)
BMI is measure of body weight:height proportionality used to predict body composition. It is computed by dividing body weight in kilograms by the squared height in meters. BMI is often used as a convenient surrogate for actual body composition measures. Categorization by BMI (in $kg \cdot m^{-2}$): <18.5 = underweight; 18.5 to <25.0 = normal; 25.0 to <30.0 = overweight; 30.0 to <35.0 = grade 1 obesity; 35.0 to <40.0 = grade 2 obesity; and ≥ 40.0 = morbid obesity.

Bounce Dive
Any dive where the diver returns to the surface with little or no decompression. This is opposed to a saturation dive, where decompression can require many days, depending on the depth.

Boyle's Law
Under conditions of constant temperature and quantity, there is an inverse relationship between the volume and pressure for an ideal gas. Volume increases as pressure decreases and vice versa.

Bradycardia
Unusually slow heart rate.

Breathing Bag
See "Counterlung."

British Sub-Aqua Club (BSAC)
The club-based organization that serves as the governing body of sport diving in the United Kingdom.

Buoyancy Compensator (BC)
Device used to regulate buoyancy during diving activity. Necessary given the buoyant changes associated with gas compression and expansion.

Carbon Monoxide (CO) Poisoning
Carbon monoxide binds to hemoglobin 200-250 times more effectively than oxygen, effectively reducing the oxygen carrying capacity of the blood.

Cardiomegaly
Enlargement of the heart, either due to thickened heart muscle or an enlarged chamber.

Cardiopulmonary Resuscitation (CPR)
Treatment protocols employed when a person's heart and/or breathing stops.

Catalina Oxygen Treatment Table
An 11:52 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks to treat severe decompression sickness. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw), with a second step at 30 fsw (9 msw). Conceptually, it is a super-extended US Navy Treatment Table 6.

Cause of Death (COD)
The medically determined reason for death. This is often distinct from the factors leading to the situation in which death occurred.

Cerebrovascular
Pertaining to the blood vessels of the brain.

Channeling (rebreather)
Improper operation of a scrubber bed that allows passage of gas without effective removal of carbon dioxide. May be caused by scrubber material compression or inadequate packing.

Chi Square (statistics)
A non-parametric statistical test that compares outcome patterns expected by chance with outcome patterns that are observed.

Chokes
Pulmonary decompression sickness. Respiratory distress after a dive characterized by sore throat, shortness of breath, and/or the production of pink, frothy sputum. The cause of chokes is poorly understood but may result from low-pressure pulmonary edema resulting from large quantities of bubbles in the venous circulation that damage the cells of the blood vessel wall leading to pulmonary capillary leakage, circulatory blockage and respiratory dysfunction due to impaired gas exchange.

Cholelithiasis
Formation of gallstones.

Cholesterolosis
An intracellular accumulation of lipids (cholesterol). Sometimes associated with inflammation of the gallbladder (cholecystitis) and gallstones (cholelithiasis). At gross examination, 1-2 mm yellow micropolyps contrast the red aspect of the surrounding mucosa, explaining the term “strawberry gallbladder.”

Ciguatera
Poisoning caused by the ingestion of marine fish with flesh contaminated by dinoflagellate neurotoxins.

Clonus
An abnormal form of movement marked by rapid succession of contractions and relaxations of a muscle.

Closed-Circuit Rebreather (CCR)
A breathing set that delivers oxygen and recycled gas from which carbon dioxide has been chemically removed from the expired breath.

Computed Tomography (CT)
Medical imaging technique that uses a large series of two-dimensional X-ray scans to generate detailed three-dimensional images.

Coronary Artery Disease (CAD)
A disease with many causes resulting in the thickening, hardening and narrowing of the medium to large-sized arteries of the heart.

Counterlung (rebreather)
The flexible compartment of a rebreather that serves as a volume reservoir for the breathing diver.

Cyanosis
Appearance of a blue or purple coloration of the skin or mucous membranes due to the tissues near the skin surface having low oxygen saturation.

Decompression Dive
A dive that requires decompression stops during ascent; limits vary with the dive tables or computer model used.

Decompression Illness (DCI)
The broad term that encompasses both decompression sickness (DCS) and arterial gas embolism (AGE). DCI is commonly used to describe any disease caused by a reduction in ambient pressure. It is used because the signs and symptoms of DCS and AGE can be similar and because recompression is the treatment for both.

Decompression Sickness (DCS)
A disease caused when the total dissolved gas tension in a diver’s tissue exceeds ambient hydrostatic pressure and gas bubble formation occurs and promotes biochemical effects/reactions. Symptoms may include itching, rash, joint pain, muscle aches or sensory changes such as numbness and tingling. More serious symptoms include muscle weakness, paralysis or disorders of higher cerebral function, including memory and personality changes. Death can occur from DCS, although very rarely in modern times. See “Type I DCS,” “Type II DCS” and “Type III DCS.”

Decompression Stop
An obligatory stop in the ascent from a dive required by a decompression model. The duration and depth can vary by model. Stops are mathematically determined and may not reflect the actual decompression stress experienced by the diver. See “Safety Stop.”

Depth-Time Profile
See “Dive Profile.”

Diabetes
A disease characterized by improper production or improper use of insulin in the body. Most common form is Type II (non-insulin-dependent diabetes mellitus; NRDM), largely controllable by diet and exercise. Less common is Type I (insulin-requiring diabetes mellitus; IRDM), which demands insulin therapy.

Diaphoresis
The state of sweating profusely.

Diluent
Gas used in a rebreather to reduce (dilute) the fraction of oxygen in the breathing gas. See "Mixed Gas."

Diphenhydramine
An antihistamine compound used for the symptomatic relief of allergies.

Disabling Injury
In diving, an injury that renders a diver unable to survive in a subaquatic environment or that directly causes death.

Diuretic
Agent that stimulates urine production and subsequent reduction in the body fluid volume.

Dive Computer
Personal electronic device that continually measures time and pressure during a dive, calculates remaining no-decompression dive time according to the embedded mathematical algorithm and provides instructions for decompression as applicable. Dive computers may employ one or more of a number of mathematical models to compute decompression status. Some dive computers integrate breathing cylinder pressure to estimate time remaining for the gas supply.

Dive Log
The dive log is a document maintained by divers in which relevant information about dives is recorded. The amount of information depends on personal interest of divers. See "Dive Log-7" for the computerized dive log information collected by DAN for studies of decompression safety.

Dive Log-7 (DL-7)
A standard computer format for recording dive profile information that can be uploaded directly to DAN.

Dive Profile
A set of depth-time-gas points describing the dive. The number of points depends on the minimal recording interval of the dive recorder and can vary from one second to one minute. A recording interval of five seconds or less provides sufficient detail for DAN studies of decompression safety.

Dive Recorder
An electronic device that records depth and time during the dive. The recorder does not calculate saturation of the body with inert gas and does not provide any instruction for decompression. Some recorders are designed as "black boxes," with no visible display, while others have a display to indicate current depth and time of dive.

Dive Safety Lab (DSL)
A project to collect computerized dive profiles and dive outcome information, developed and conducted by DAN Europe, designed to share goals and methodology with DAN's Project Dive Exploration. See "Project Dive Exploration."

Dive Series
Dives conducted in rapid enough succession that they are not independent. Project Dive Exploration (PDE) defines a series as all dives not followed by 48 hours without diving or flying exposure.

Diving Accident Report Form (DARF)
A form used by DAN from 1987 through 1997 to collect information about injured divers treated in recompression chambers.

Diving Injury Report Form (DIRF)
A form used by DAN from 1998 through 2004 to collect information about injured divers treated in recompression chambers.

Dwell Time (rebreather)
The length of time expired gas in a rebreather remains in the carbon dioxide scrubber.

Dysarthria
A motor speech disorder resulting from neurological injury of the motor component of the motor-speech system. It is a condition in which the muscles that help produce speech are effectively impaired, making it very difficult to pronounce words.

Dyspnea
Difficulty breathing, often described as unpleasant or uncomfortable; often referred to as air hunger.

Emergency Medical Services (EMS)
System responsible for providing pre-hospital or out-of-hospital care by paramedics, emergency personnel, emergency medical technicians, and medical first aid responders.

Enriched-Air Nitrox (EAN; Nitrox; Oxygen-Enriched Air)
A nitrogen/oxygen breathing gas mixture containing more than 21% oxygen, usually made by mixing air and oxygen. The most commonly used mixture contains 32% oxygen.

Epistaxis
Nosebleed.

Equivalent Air Depth (EAD)
The underwater depth at which air would provide a similar absolute content of nitrogen to that found in a given enriched-air nitrox breathing mixture.

Facial Baroparesis (Alternobaric Facial Nerve Palsy)
A reversible paralysis of the facial (seventh cranial) nerve resulting from pressure introduced through the middle ear.

Feet of Freshwater (ffw)
A unit of pressure synonymous with depth in freshwater. Thirty-four feet of freshwater is equal to approximately 1.0 atmosphere, 1.0 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure. The differences in density of seawater and freshwater result in small pressure differences at the same absolute depth.

Feet of Seawater (fsw)
A unit of pressure synonymous with depth in seawater. Thirty-three feet of seawater is equal to approximately one atmosphere, 1.0 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure. The differences in density of seawater and freshwater result in small pressure differences at the same depth. The fsw term is commonly used by the dive industry. For metric users, the reference is meters of seawater (msw); 1.0 fsw = 0.3048 msw (arithmetic conversion).

Field Research Coordinator (FRC)
A trained volunteer who helps DAN collect data for Project Dive Exploration (PDE).

First Aid Oxygen (FAO_2)
See "Surface Oxygen Treatment"

Fisher Exact Test (statistics)
A non-parametric statistical test similar to Chi Square except that it calculates an exact p value; useful if the marginal is very uneven or if the value in a single cell is a very small value. Exact p values tend to be more conservative than most approximate estimates such as Chi Square or t-test.

Flying After Diving (FAD)
Flying after diving involves exposure of divers to a secondary decompression stress. Pressurized commercial airliners are required by law to be able to maintain the cabin altitude at 8,000 ft (2,438 m). The actual cabin pressure is typically greater than this. In one study the average was around 6,000 ft (1,800 m), approximately 80% of the atmospheric pressure at sea level. Unpressurized aircraft may reach altitudes in excess of 8,000 ft. Following diving, there can be enough residual nitrogen dissolved in the body for the secondary decompression stress of flying to cause decompression sickness. For this report, all flights within 48 hours after diving are considered "flying after diving." Practically, divers can also be exposed to secondary decompression stress post-dive by driving to altitude.

Freediving
Breath-hold diving conducted while wearing a mask and some form of fin or fins. Freedivers generally dive to depth and train to increase their range. Freediving is typically conducted in open water settings. See also "Breath-Hold Diving" and "Snorkeling."

Gradient Factors
Used to mathematically adjust decompression limits to a chosen degree of conservatism. They are typically applied to the Buhlmann algorithm. Gradient factors limit the fraction of M-value achieved during ascent. M-values represent the theoretical maximum allowable gas pressure computed for tissues intended to avoid bubble formation, although it is now known that bubbles commonly form below M-value. Gradient factors are assigned in two parts. For example, a 30/70 setting would require a first stop at 0.3 (or 30%) of the M-value, and then control the ascent to bring the diver to the surface at 0.7 (or 70%) of the M-value.

Hart-Kindwall Oxygen Recompression Treatment Table
A 2:30 h:min recompression protocol used to treat decompression sickness. Oxygen is breathed throughout, typically in a monoplace chamber. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw). Decompression travel is at 1 $ft \cdot min^{-1}$ (2 $ft \cdot min^{-1}$ if all symptoms were mild and cleared within the first 10 min of reaching 60 fsw).

Hazard
A condition, event or circumstance that could lead to or contribute to an unplanned or undesirable event and cause injury or material damage.

Health Insurance Portability and Accountability Act (HIPAA)
US Federal legislation designed to protect the privacy and interests of individuals and their families. DAN collects dive injury and fatality information in compliance with HIPAA.

Heliox
See "Mixed-Gas."

Hematocrit
A measure of red blood cell volume in a sample volume of blood. Normal ranges are 40-53% for males and 35-46% for females.

Hemoptysis
The coughing up of blood or bloody sputum from the lungs or airway.

Hyperbaric Oxygen (HBO)
The therapeutic administration of oxygen under conditions of substantially increased atmospheric pressure. See also "Hart-Kindwall Oxygen Recompression Treatment Table" and "US Navy Treatment Table."

Hypercapnia
Condition in which the level of carbon dioxide in the blood is higher than normal.

Hyperglycemia
Condition in which blood glucose (sugar) is higher than normal.

Hyperoxia
Condition of higher-than-normal partial pressure of oxygen. In medicine, it refers to excess oxygen in the lungs or other body tissues, which can be caused by breathing air or oxygen at pressures greater than normal atmospheric pressure.

Hyperreflexia
A condition in which the deep tendon reflexes are exaggerated.

Hypertension
High blood pressure. A medical condition associated with the development of heart disease and stroke.

Hyperventilation
Voluntary ventilation of the lungs in excess of metabolic need (achieved by increasing depth of breaths and/or rate of breathing). Often used to lower carbon dioxide content of the bloodstream and increase breath-hold time. Excessive hyperventilation will increase the risk of loss of consciousness due to hypoxia. See "Hypoxia of Ascent."

Hypocapnia
Condition in which the level of carbon dioxide of the blood is lower than normal. This state is typically produced by hyperventilation.

Hypoglycemia
Condition in which blood glucose (sugar) is lower than normal.

Hypoventilation
Ventilation of the lungs at an abnormally slow rate, not meeting metabolic needs, resulting in a net accumulation of carbon dioxide in the blood, which will drive the urge to breathe in a healthy person.

Hypoxemia
Condition of lower-than-normal partial pressure of oxygen in the blood. See "Hypoxia of Ascent."

Hypoxia
Condition of lower-than-normal partial pressure of oxygen. May be experienced by breathing a gas mixture at the surface that was intended for a deep bottom. See "Hypoxemia" and "Hypoxia of Ascent."

Hypoxia of Ascent
Unconsciousness resulting from hypoxia compounded by surfacing at the end of a breath-hold dive. The reduction in pressure associated with returning to the surface causes the oxygen partial pressure to fall faster than through metabolism of the gas alone. This condition is commonly called shallow water blackout in North America, but this term was previously used in the UK to describe a different problem. See also "Hyperventilation," "Hypoxia," and "Hypoxic Loss of Consciousness."

Hypoxic Loss of Consciousness (HLOC)
Loss of consciousness resulting from an acute state of hypoxia.

Immersion Pulmonary Edema (IPE)
A shift of fluid into the alveolar space of the lung, secondary to water immersion. The cause is multifactorial; factors that may play a role in addition to immersion include fluid loading, cold stress, suit and breathing system resistance, exercise and high gas density. The net effect is an increase in pulmonary pressure and membrane permeability, which drives fluid out of the bloodstream.

Incidence Rate
The number of new cases in a defined population in a given time period.

Incident
An event or occurrence.

Inner Ear Barotrauma (IEBT)
Trauma to inner ear frequently caused by a rapid rise of middle ear pressure causing an inward bulge of the round window and an outward bulge of the stapes foot plate. Implosion of the round window is possible. IEBT is usually associated with significant middle ear barotrauma.

International Association for the Development of Apnea (AIDA)
The Worldwide Federation for breath-hold diving, established in 1992. AIDA manages and oversees the recognition of records, organizes competitions, and promotes standards for freediving education.

In-Water Recompression
Practice of returning a diver back underwater as an emergency treatment of decompression sickness. Logistical and safety issues make therapeutic treatment in a recompression chamber the standard of care for decompression sickness symptoms.

Infiltrates
Abnormal regions of opacity (non-transparency) with poorly defined margins visible in the lung (typically seen in X-rays).

Intracardiac
Within the heart.

Ischemia
Inadequate delivery of blood to a local area due to a blockage of blood vessels in the area.

Kruskal-Wallis (statistics)
A nonparametric statistic used to compare three or more samples. The null hypothesis is that the groups have comparable distributions; the alternative hypothesis is that at least two of the samples differ (with respect to median). It is analogous to the F-test used in analysis of variance (para-

metric). While analysis of variance tests depend on the assumption of normal distribution, the Kruskal-Wallis test is not so restricted.

Lasix
A prescription medication, furosemide (trade name Lasix) is a commonly used as a diuretic to treat hypertension and edema.

Lung Barotrauma
See "Pulmonary Barotrauma."

Mean (statistics)
The arithmetic average calculated by taking the sum of a group of measurements and dividing by the number of measurements. See "Median."

Median (statistics)
The middle value in a range of numbers. Half the numbers are higher than the middle value and half are lower. The mean and median will be extremely similar if the group of numbers is normally distributed. See "Mean."

Mediastinal Emphysema (Pneumomediastinum)
Air that surrounds the heart (not within the heart or blood vessels). This is usually the result of pulmonary barotrauma.

Medical Services Call Center (MSCC)
The computerized logging system, introduced in 2006, that captures all calls, emergency and information, and emails received by the DAN Medical Services Department.

Meniere's Disease
A disorder of the inner ear that can affect hearing and balance. It is characterized by spontaneous episodes of vertigo, tinnitus (perception of roaring, buzzing or ringing in the ears) and hearing loss.

Metabolic Demand
The energetic requirement of the body; typically measured indirectly by the amount of oxygen consumed in respiration.

Meters of Seawater (msw)
Metric unit of length or depth; 1.0 msw = 3.28084 fsw (arithmetic conversion). See "Feet of Seawater."

Middle Ear Barotrauma (MEBT)
Caused by an inability to equalize middle ear pressure with that of the ambient (surrounding) pressure. The insult may occur on compression ('squeeze') or ambient pressure reduction ('reverse block'). See "Otitis Media."

Mixed-Gas
Any breathing gas made by mixing oxygen with other gases. Mixed-gas usually consists of oxygen plus nitrogen and/or helium. Heliox refers to helium and oxygen mixtures, nitrox to nitrogen and oxygen mixtures. Trimix refers to mixtures containing helium, nitrogen, and oxygen.

Multi-Day Diving
Dives spread out over a period longer than 24 hours but where the surface interval between successive dives is less than 24 hours.

Multi-Level Dive
A dive where the diver spends time at several different depths before beginning his or her final ascent to the surface. Usually associated with dive computers that allow a diver to ascend gradually from maximum depth while tracking the decompression status.

Myocardial Infarction
Heart attack. Death of some of the cells of the heart from lack of adequate blood supply resulting from constriction or obstruction of the coronary arteries.

Myxoid Tumor
A connective tissue tumor with a 'myxoid' background, composed of clear, mucoid substance.

Nitrogen Narcosis
Euphoric and anesthetic effect of breathing nitrogen at greater than sea level pressure. All gases except helium have an anesthetic effect when their partial pressure is increased. Because nitrogen is the principal component of air, its anesthetic effect is the most pronounced in divers at depth and may cause serious impairment of mental abilities. Nitrogen narcosis is often first noticed when breathing air at depths beyond 60-100 fsw (18-30 msw).

Nitrox
See "Enriched-Air Nitrox" and "Mixed-Gas."

No-Decompression Dive or No-Stop Dive
A dive where direct ascent to the surface is allowed at any time during the dive without an obligatory decompression stop.

Non-Steroidal Anti-Inflammatory Drug (NSAID)
Medications used primarily to treat inflammation, mild to moderate pain, and fever.

Normal Distribution (statistics)
A group of numbers is normally distributed when the majority is clustered in the middle of the range with progressively fewer moving out to both extremes. The frequency plot of a normal distribution appears as the classic bell-shaped curve.

Nystagmus
A rapid, involuntary, and oscillatory movement of the eyeball, usually from side to side.

Obesity
See "Body Mass Index."

Otitis Externa
Inflammation of the outer ear and ear canal. May be caused by active bacterial or fungal infection or secondary to dermatitis only with no infection. Also known as swimmer's ear.

Otitis Media
Inflammation of the middle ear, in diving frequently caused by difficulties in equalizing middle ear pressure. See "Middle Ear Barotrauma."

Over-the-Counter (OTC)
Medications/Drugs purchased legally without a prescription.

Oxygen-Enriched Air
See "Enriched-Air Nitrox."

Oxygen Sensor (rebreather)
A sensor used to measure the partial pressure of oxygen in the closed-circuit.

Oxygen Toxicity
Syndrome caused by breathing oxygen at greater than sea level pressure. Primarily affects the central nervous system (CNS) and lungs. CNS oxygen toxicity may come on immediately and be manifested by seizures, twitching, nausea and visual or auditory disturbances. It may occur in a highly unpredictable manner at partial pressures greater than 1.4 to 1.6 atm in an exercising diver. Pulmonary oxygen toxicity can take much longer to develop (hours) but may occur at lower partial pressures of oxygen (>0.50 atm). Pulmonary oxygen toxicity is caused by inflammation of the lung tissue, resulting in shortness of breath, cough and a reduced exercise capacity.

p Value (statistics)
Level of significance established to denote a significant difference in statistical tests; also known as alpha. Often set at $p<0.05$.

Paraparesis
Partial paralysis of the lower limbs.

Paresthesia
Numbness or tingling of the skin; a common symptom of DCS in recreational divers.

Partial Pressure
The pressure exerted by a single component gas, typically in a mixture of gases.

Patent Foramen Ovale (PFO)
An opening between the right and left atria of the heart. Normally closed and sealed by tissue growth after birth, almost 30% of the adult population retain some degree of patency (openness). 'Probe patency' describes the ability to work a blunt probe through the opening during autopsy. Such openings may be small and functionally irrelevant. 'Physiologic patency' describes an opening large enough to allow meaningful flow of blood directly between the two chambers. A small portion of those with a PFO will have the highest degree of patency. Blood passing from right to left through a PFO bypasses lung filtration. Any bubbles present in such blood would be distributed throughout the body, potentially increasing the risk of serious decompression sickness if the bubbles impinged upon sensitive tissues. Some divers investigate the option of medical closure of PFOs. The risk of PFO in divers can also be mitigated by conservative dive profiles that do not produce bubbles.

Paua
A large, edible abalone found in New Zealand.

Perceived Severity Index (PSI)
A measure of the severity of decompression injury.

Pleural Space
The small potential space between the parietal and visceral layers of the pleura that lines the thoracic cavity. It is a potential space since there is no actual space, instead it is filled with a lubricating fluid that reduces the friction between the pleural layers as the lungs expand and contract.

Pneumomediastinum
See "Mediastinal Emphysema."

Pneumothorax
A collection of gas in the pleural space (the fluid-filled potential space surrounding the lungs), which results in the collapse of the lung on the affected side.

Project Dive Exploration (PDE)
A long-term study developed by DAN to collect computerized profiles of diving exposures and information on the health outcome (symptomatic or asymptomatic). The accumulated data can be useful to model decompression risk.

Protected Health Information (PHI)
Information that could disclose the identity of a research subject, patient or decedent according to the Health Insurance Portability and Accountability Act (HIPAA). PHI includes names, address, birthdate, social security numbers, etc. DAN does not disclose PHI to any party other than employees, representatives and agents of DAN who have a need to know.

Pulmonary Barotrauma (PBT)
Damage to lungs from expanding gas. See "Barotrauma."

Pulmonary Emphysema
A medical condition commonly caused by smoking that leads to abnormal distension of the lungs resulting from the destruction of its supporting and elastic internal structure.

Pulmonary Overinflation Syndrome (POIS)
A group of barotrauma-related diseases caused by the expansion of gas trapped in the lung, or over-pressurization of the lung with subsequent over-expansion and rupture of the alveolar air sacs. It includes arterial gas embolism, tension pneumothorax, mediastinal emphysema, subcutaneous emphysema and rarely pneumopericardium.

Pulmonary Overexpansion
Abnormal distension of the lungs. In divers, pulmonary overexpansion usually results from the effects of Boyle's law. It can cause rupture of alveoli and penetration of gas into various surrounding spaces, causing mediastinal emphysema, pneumothorax or arterial gas embolism. See "Pulmonary barotrauma."

Rales
Wet, clicking, rattling or crackly lung noises heard on auscultation of (listening to) the lung during inspiration. The sounds are caused by the opening of small airways and alveoli collapsed by fluid in the air spaces.

Rapid Ascent
An ascent rate fast enough to put a diver at increased risk of decompression illness (DCI), usually at rates in excess of 60 fsw (18 msw) per minute.

Rebreather
Self-contained breathing device that recirculates some or all of the expired gas to increase efficiency. Systems may be semiclosed or fully-closed-circuit.

Recompression Treatment
Treatment involving a return to pressure. Typically completed in a recompression chamber but, in some cases, may involve an in-water return to pressure. Well-established, standard treatment tables exist for recompression chamber therapy. See "United States Navy Treatment Tables 5 and 6 (USN TT5 and TT6)" and "Hart-Kindwall."

Repetitive Dive
A dive in which residual nitrogen remaining from a previous dive affects the decompression requirements of the subsequent dive. Some decompression computers carry over information from previous dives for 24 hours or longer, depending on the decompression model used. For the purposes of DAN's injury reporting, a repetitive dive is any dive occurring within 24 hours of a previous dive. See "Residual Nitrogen."

Representative Sample (statistics)
A group selected from a population for testing that reasonably represents the characteristics of the population.

Residual Nitrogen
Nitrogen content in excess of the ambient levels as a result of recent diving exposure. See "Repetitive Dive."

Residual Symptoms
Symptoms remaining at the conclusion of treatment. May respond to additional treatments, be refractory to further treatment but eventually resolve spontaneously, or remain permanently.

Resolution of Symptoms
Symptoms resolving (disappearing) at some point after appearance. Resolution may be spontaneous or in response to treatment and partial or complete.

Reverse Block
Overpressure developing in a blocked middle ear space during ascent as ambient pressure falls and internal pressure cannot be equalized. Symptoms include pain and dizziness; tympanic membrane rupture may result if equalization of space is not possible.

Rhomberg (Sharpened)
The Sharpened Rhomberg test is intended to detect ataxia, commonly used for diver assessment. The subject stands erect on a firm, level surface with feet aligned in a tandem (heel-to-toe) position. The arms are then folded across the chest. Once stable, the subject is instructed to close his or her eyes and to maintain the position for 60 seconds. The measured score is the time in seconds the position is held. The end is marked by opening of the eyes or movement of the hands or feet to maintain balance.

Risk
The chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard. It may also apply to situations with property or equipment loss.

Safety Stop
A recommended halt in the planned ascent to the surface (usually for 3-5 min at 10-20 ft [3-6 m) intended to reduce the risk of decompression injury. A safety stop is not an obligatory decompression stop required by tables or a dive computer. See "Decompression Stop."

Sarcoidosis
A chronic disease of unknown cause characterized by the enlargement of lymph nodes in many parts of the body and the widespread appearance of granulation tissue (granulomas, typically produced in response to infection) derived from the reticuloendothelial (macrophage) portion of the immune system.

Scrubber (rebreather)
Refers to the chemical compound (absorbent) used to remove carbon dioxide from breathing gas.

Scuba
Self-contained underwater breathing apparatus.

Scuba Epidemiological Reporting Form (SERF)
An injury recording system for DAN that replaced the DIRF. It emphasizes collection of recorded dive profiles.

Semiclosed-Circuit Rebreather (SCR)
A type of rebreather that injects a mixture of nitrox or mixed gas into a breathing loop to replace that which is used by the diver for metabolic needs; excess gas is periodically vented into the surrounding water in the form of bubbles.

Sequelae
A pathological condition that is a consequence of a previous disease or injury.

Setpoint (rebreather)
The oxygen partial pressure to be maintained by the device. Oxygen is added to the circuit when the oxygen partial pressure falls below the setpoint. Often user-adjustable within a limited range. See "Solenoid."

Shallow-Water Blackout
The term was initially coined to describe impaired consciousness associated with the use of closed-circuit oxygen rebreathers, likely due to inadequate carbon dioxide scrubbing. It was subsequently usurped to describe hypoxia of ascent in breath-hold divers. The ambiguity of usage makes it an out-of-favor name, particularly for the breath-hold application, where hypoxia of ascent is recommended. See "Hypoxia of Ascent."

Snorkeling
Swimming with mask, snorkel and fins. Snorkelers may remain at the surface or conduct breath-hold dives. See also "Breath-Hold Diving" and "Freediving."

Solenoid (rebreather)
Electromagnetic valve that opens to inject oxygen into mixed-gas closed-circuit rebreathers. Activated automatically or manually to maintain the setpoint.

Spearman Rank Coefficient (statistics)
Statistical test that measures the relationship between two variables when data are in the form of ranked orders.

Square Dive
A dive in which the descent is made to a given depth and where the diver remains for the entire dive before ascending to the surface or stop depth.

Standard Deviation (SD) (statistics)
A measure of the variability within a group of numbers reported with discussion of means, appropriate for a close to normally distributed sample. Approximately 68% of the values will be within one SD of the mean (half above the mean and half below), approximately 95% within two SD, and approximately 99% within three SD. Outlier values, deviants from the norm, are conservatively identified as those more than two SD from the mean.

Steatosis
A process resulting in the abnormal retention of lipids within cells. Also known as fatty or adipose degeneration.

Subcutaneous Air (Subcutaneous Emphysema)
Air under the skin after pulmonary barotrauma. The most frequent location is around the neck and above the collarbones where the gas may migrate after pulmonary overexpansion.

Sudden Hearing Loss (SHL)
Sudden hearing loss (SHL) is defined as a hearing loss of at least 30 dB over three or more contiguous frequencies, occurring over a period of 72 hours or less. The cause is variable and often cannot be confirmed. It is frequently accompanied by tinnitus and may or may not resolve spontaneously.

Surface Interval Time (SIT)
Time spent on surface between sequential dives.

Surface Oxygen Treatment (SOT)
Oxygen delivered at the surface with a therapeutic intent. Gas may flow from the supply system in a continuous mode or through a demand valve upon inspiration of the conscious, spontaneously breathing injured person. The breathing circuit may be open (releasing exhaled gas to the environment) or closed (reusing exhaled gas after carbon dioxide is removed). The delivery interface may be some form of simple non-rebreathing facemask, a partial rebreathing facemask or a nasal cannula. The fraction of oxygen delivered to the injured person and the oxygen flow rate required will vary dramatically depending on system configuration and use.

Tachycardia
Abnormally rapid heart rate.

t-test (statistics)
A statistical test used to determine if there is a significant difference between the means of two different groups.

Thrombocythemia
A blood disorder of excess cell proliferation. It is characterized by the production of too many platelets in the bone marrow.

Tinnitus
The perception of sound within the ear in the absence of corresponding external sound. Frequently described as a ringing noise, but a variety of presentations are reported. May be unilateral or bilateral and intermittent or continuous.

Travel Assist
Travel assistance plan available from DAN that covers necessary medical evacuation.

Triggering Event
A tangible or intangible barrier or occurrence that, once breached or met, causes another event to occur. In other words, the pivotal event leading to the ultimate outcome.

Trimix
See "Mixed-Gas."

Type I DCS (DCS I, Musculoskeletal DCS)
Decompression sickness where the symptoms are felt to be non-neurological in origin such as itching, rash, joint or muscle pain.

Type II DCS (DCS II, Neurological or Cardiopulmonary DCS)
Decompression sickness where there is any symptom referable to the nervous or cardiovascular system.

Type III DCS (DCS III)
A serious form of DCS sometimes seen after long deep dives with a rapid ascent. Type III DCS is thought to be caused by arterial gas embolization after a dive where a large quantity of inert gas has been absorbed by the tissues. Presumably the arterial bubbles continue to take up inert gas and grow, causing a rapidly deteriorating clinical picture.

United States Navy Treatment Table 5 (USN TT5)
A 2:15 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks to treat decompression sickness. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw). Extensions can increase the duration at 30 fsw (9 msw).

United States Navy Treatment Table 6 (USN TT6)
A 4:45 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks to treat decompression sickness. Commonly used. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw), with a second step at 30 fsw (9 msw). Extensions can increase the duration at either 60 fsw or 30 fsw (9 msw). Extremely similar to Royal Navy Treatment Table 62.

United States Navy Treatment Table 9 (USN TT9)
A 1:02 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks. The protocol employs a maximum pressure equivalent to a depth of 45 fsw (14 msw).

Upper Respiratory Infection (URI; 'cold')
The most frequently reported acute health problem from the DAN sample of injured divers.

Vasovagal Syncope
Transient loss of consciousness (fainting) resulting from a sudden drop in heart rate and blood pressure and subsequent reduction in brain blood flow. It may be triggered by a variety of stressful conditions.

Venous Gas Emboli (VGE)
Gas phase, also known as bubbles, located in the veins returning blood to the right side of the heart or in the pulmonary artery, delivering blood from the right heart to the lungs where bubbles are filtered out of circulation. See "Patent Foramen Ovale."

Vertigo
Sensation of irregular or whirling motion, either of oneself (subjective) or of external objectives (objective).

Waist-to-Hip Ratio (WHR)
Used to assess for disproportionate accumulation of tissue in the abdominal region, such accumulation being associated with increased health risk. WHR is computed by dividing the circumferences of the waist at the narrowest point by the circumference of the hips at the widest point. Optimal scores are ≤0.8 for men and ≤0.7 for women.

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