ANNUAL DIVING REPORT

2010 Edition

A Report on 2008 Diving Incidents, Injuries and Fatalities

DAN
YOUR DIVE SAFETY ASSOCIATION

Annual Diving Report – 2010 Edition

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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 a common set of protocol standards. Each DAN 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.

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1. INTRODUCTION

Neal W. Pollock

1.1 The Annual Diving Report

The Divers Alert Network (DAN) Annual Diving Report presents information on diving activity and incidents collected by DAN. Electronic portable document format (PDF) copies of all DAN (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."

This report, the 2010 edition, is based on events occurring in 2008. Key sections include reviews of our 2008 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 compressed gas diving injuries (Appendix A), compressed gas diving fatalities (Appendix B), and breath-hold diving incidents (Appendix C).

A list of publications and materials authored or co-authored by DAN Research and medical personnel and affiliated investigators from 2008 through 2013 is found in Appendix D. 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 production rate (mean±standard deviation with range) of 40±12 (26-56) annually.

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.diversalertnetwork.org/training/seminars/index.asp.

A list of presentations delivered by DAN Research personnel and affiliated staff from 2011 through 2013 is found in Appendix E. 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 delivery rate (mean±standard deviation with range) of 57±16 (46-75) annually.

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

1.2 Data Collection at DAN

The data discussed in this report represent a cross-section of events occurring in the recreational diving community, not an exhaustive one. The report includes only data made available to DAN and only cases that could be followed up with a manageable effort. Most sections are limited to residents or citizens of the United States or Canada. The exception to this is the breath-hold incident section, which includes cases without national or geographical restriction.

Figure 1.2-1 depicts the annual record of inquiries to DAN Medical Services since DAN started in 1981. The total count for 2008 was 12,593.

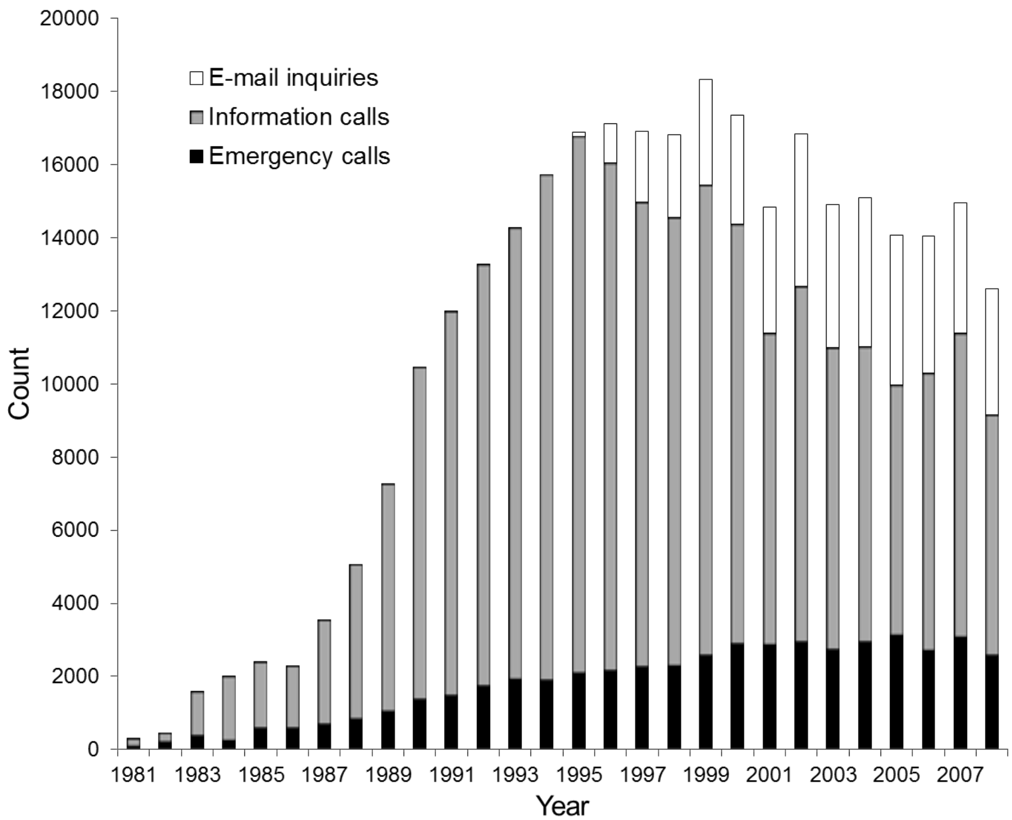

Figure 1.2-1 Emergency calls, information calls and e-mail inquiries for information

Information on dive injuries is captured by DAN through the Medical Services Call Center (MSCC). A total of 9,888 calls or e-mails were logged into the MSCC system by DAN medics during the 2008 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 and Appendix A.

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 1.2-2. The annual case intake (mean±standard deviation) for the 20-year period from 1989 through 2008 was 89±12, with a range of 67-114 cases. The 2008 intake was 83 cases, just below average for the period. The most common disabling injuries were ranked as drowning, heart problems and arterial gas embolism (AGE), respectively. The most common triggers associated with fatal events were running out of gas and rough seas. Information on the medical history of victims was rarely complete. Details are found in Section 3 and Appendix B.

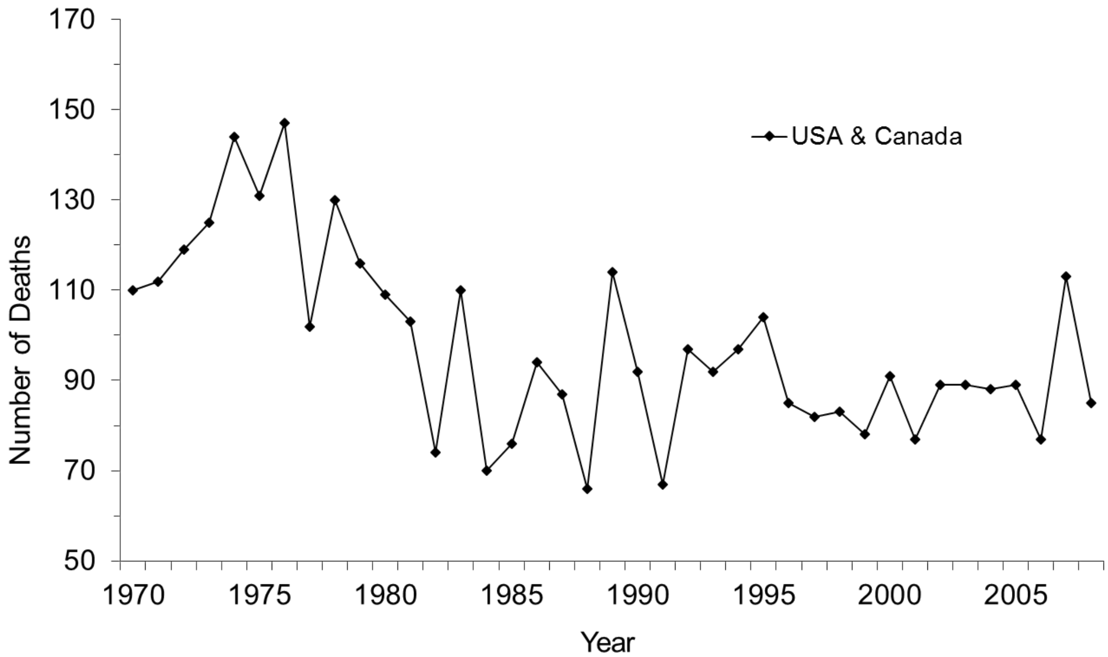

Figure 1.2-2 Annual record of US and Canadian diving fatalities

DAN has collected unsolicited reports of breath-hold incidents since 1993. A dedicated effort to capture breath-hold case data began in 2005, including cases from 2004 forward. Breath-hold sections were added to the annual report in 2005. Figure 1.2-3 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 it is possible that there has 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 cases captured in the five-year period from 2004 through 2008 was 54±19 (mean±standard deviation), with a range of 30-80 cases. A total of 80 breath-hold incidents were collected in 2008, 64 fatal (80%) and 16 non-fatal. This total was up from 58 in the previous year. Interpreting the often scant evidence is challenging, but the most commonly identified disabling agents were hypoxic blackout (likely facilitated by excessive hyperventilation), health issues (primarily cardiac) animal interactions (primarily between shark and spearfishermen), drowning (a categorical assignment usually allowed to stand when limited information precludes further classification), boat strikes (propeller or hull), and entanglement (in kelp), respectively. Details are found in Section 4 and Appendix C.

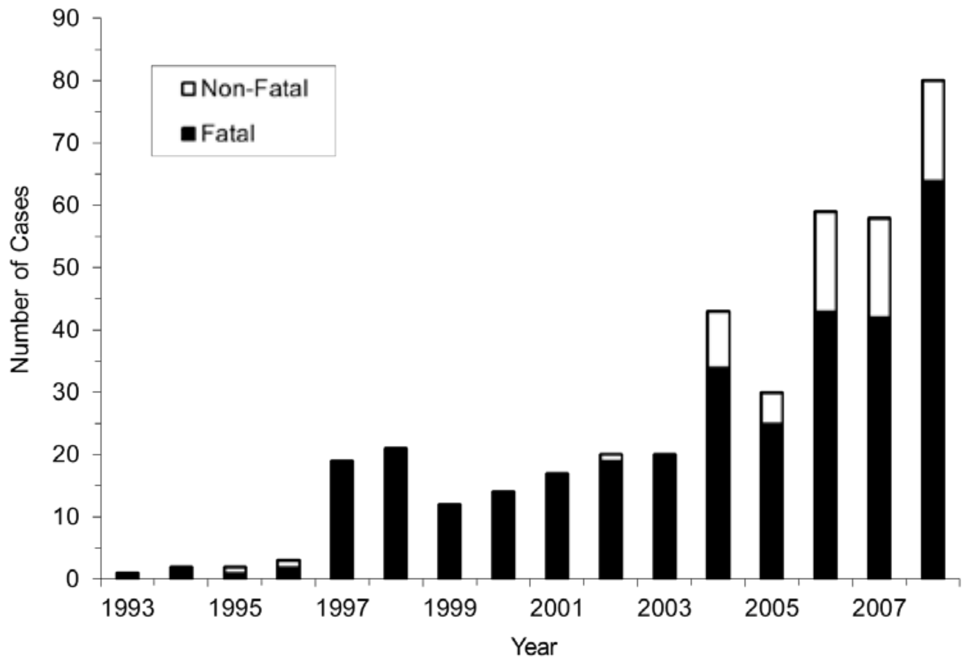

Figure 1.2-3 Annual record of captured breath-hold diving incidents

1.3 The Diver's Responsibility

Diving can provide a flexible foundation for a lifetime of enjoyment. The choice of environment, equipment and purpose create a 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, knowledge and physical competence (Bennett et al. 2006). Since many of these elements can change over time, either acutely or chronically, it is important to re-evaluate readiness before every dive. Periodic medical evaluation and regular physical exercise can preserve or improve physical preparedness; appropriate initial and continuing training and education can 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 where to participate. To help ensure problem-free events, the actual conditions at the time of the dive need to be critically appraised.

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. 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 at numerous points by appropriate action. Being aware of practices and patterns that escalate risk can help ensure that unmanageable conditions do not arise. 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.

1.4 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. The challenge is in defining a required level of physical fitness. The broad range of diving conditions makes arbitrary requirement difficult to justify. This does not mean, though, that physical fitness should be ignored. Immersion alone puts a significant strain on the cardiovascular system, 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. 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 develop that demand significant physical fitness.

The first test of physical fitness is an evaluation of the ability to handle typical tasks associated with diving. Additional fitness reserves must then be considered to meet emergent demands. A general rule of thumb is to maintain a fitness level adequate to meet twice the demand of the most strenuous dive conducted.

The retrospective assessment of physical fitness 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 over time. For reference, the 'normal' (optimal) BMI range is 18.5-24.9 $kg \cdot m^{-2}$. Details on the full scale are found in the glossary (Appendix E). Calculating waist-to-hip ratio (WHR) is a good adjunct to 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.

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).

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.

Really smart divers maintain a solid knowledge base and sound medical and physical fitness to help ensure diving safety.

1.5 References

Bennett PB, Cronje FJ, Campbell E, (with Marroni A, Pollock NW). Assessment of Diving Medical Fitness for Scuba Divers and Instructors. Best Publishing: Flagstaff, AZ. 2006; 241 pp.

Ma AC, Pollock NW. Physical fitness of scientific divers: standards and shortcomings. In: Pollock NW, Godfrey JM, eds. Diving for Science 2007. Proceedings of the American Academy of Underwater Sciences 26th Symposium. Dauphin Isl, AL: AAUS, 2007: 33-43.

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2. DIVE INJURIES

Petar J. Denoble, James M. Chimiak

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 a 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. With the MSCC, we also see a different mix of cases than solely through reports from hyperbaric chambers that are limited to cases most likely needing recompression treatment.

2.2 Data Sources

A total of 9,888 calls or e-mails were logged into the MSCC system by DAN medical services staff between January 01 and December 31, 2008. The frequency distribution of call origin is shown in Table 2.2-1. There were 7,022 information calls and 2,866 calls regarding actual cases. Almost 42% of the information requests came through e-mail and 10% through the emergency line. Not all requests for emergency assistance came through the emergency line. Twenty-eight percent came through the information line, nine percent were transferred from Travel Assist services, and three percent came through e-mail.

Table 2.2-1 Origin of DAN calls entered into the MSCC in 2008

Source	Information requests		Cases		Combined	
	Frequency	%	Frequency	%	Frequency	%
Information Line	3,239	46.1	813	28.4	4,052	41.0
Emergency Line	703	10.0	1,687	58.9	2,390	24.2
E-mail	2,916	41.5	85	3.0	3,001	30.3
Referred from Travel Assist	159	2.3	263	9.2	422	4.3
N/A	5	0.1	18	0.6	23	0.2
Total	**7,022**	**100**	**2,866**	**100**	**9,888**	**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 working diagnoses is shown in Table 2.3-1

Table 2.3-1 Working diagnosis of cases as assigned by case manager (n=2,866)

Working Diagnosis	Frequency	Percent
DCS	651	22.7
Non-diving-related	505	17.6
Barotrauma	328	11.4
Hazardous marine life injuries	186	6.5
Trauma	70	2.4
Other	532	18.6
Not assigned	594	20.7
Total	**2,866**	**100**

The diagnosis may change in the process but the initial working diagnosis is not changed in the record. The diagnoses of treating physicians were available in 352 cases. The final diagnosis is sometimes established long after the emergency phase of case management. DAN tries to do follow-up on each suspected dive injury case and determine the final diagnosis. Non-dive-related calls are not followed up once they have been referred or transferred to the proper health care provider with the exception of life-threatening emergencies.

DCS was the most frequently assigned working diagnosis in cases involving divers with acute symptoms (23% of all assigned working diagnoses; n=651) which is the same as in the previous year. Non-diving-related problems were quite common (18%; n=505). Barotrauma, including all injuries of lung, ear, sinuses and/or mask squeeze caused by pressure changes was suspected in 11% cases (n=328). Barotrauma saw a slight decrease in the total number and in relative number in comparison to the previous year. Other injuries include hazardous marine life injuries (HMLI) 6.5% (n=186), trauma 2.4% (n=70) and a large share of miscellaneous conditions (19%; n=532). As in the previous year, 34% (n=979) of all calls represented the collective of DCS and barotrauma diagnoses. The prevalence of DCS as a working diagnosis probably reflects both a reporting and diagnostic bias. In other words, divers are more likely to call DAN to report suspected DCS than for other concerns, and DAN operators may be more likely to consider it to avoid missing any possible DCS cases. Treating physicians are able to more fully evaluate patients, thus making it a reasonable expectation that the number of treated divers will be less than number of suspected cases.

2.4 Decompression Illness (DCI)

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

2.5 Arterial Gas Embolism (AGE)

AGE occurs when alveolar gas enters into arterial circulation and is brought 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.

AGE is rarely reported. In 2008 MSCC data, we have found 27 cases with explicit concerns about AGE. In addition, we reviewed for possible AGE all cases suspected for DCS/DCI reporting sudden loss of consciousness or other cerebral symptoms and those cases occurring less than 15 min post-dive. Our criteria for the retrospective diagnosis of AGE are listed in the Table 2.5-1.

Table 2.5-1 Certainty levels of AGE diagnosis

Certainty level	Criteria
Certain	Present neurological symptoms indicating brain involvement AND onset <15 min post-dive AND insufficient exposure for DCS
Possible	Present or transient neurological symptoms indicating brain involvement AND onset <15 min post-dive AND possibly sufficient exposure for DCS OR provocative event and only transient loss of consciousness
Unlikely	Provocative event and constitutional symptoms only
Ruled out	Other causes, such as spinal cord DCS

There were 27 calls concerning symptoms that may have been AGE, according to either DAN staff or callers. Retrospectively, after reviewing 199 suspected DCS cases with symptom onset time less than 15 min, three more cases were classified as AGE. This adds to a total of 30 suspected AGE cases.

Table 2.5-2 shows the result of a review of 30 case histories to which the criteria described in Table 2.5-1 were applied. There were no cases that met the criteria for certain diagnosis of AGE and in 15 cases a diagnosis of AGE was ruled out.

Table 2.5-2 Certainty of AGE in suspected cases

Certainty of Diagnosis	Frequency	Percent
Certain	0	0
Possible	11	37
Unlikely	4	13
Ruled out	15	50
Total	**30**	**100**

Case 02-01: One example of suspected AGE that was ruled out involved a rescue diver who was conducting a vehicle recovery. He dived to a depth of 25 ft (8 m) for a total time of approximately 60 min, making at least three trips to the surface for equipment during the exposure. He used a full-face mask with voice communication to the surface. On his third descent he experienced acute pain in his forehead above his left eye. At that moment, he lost all recall of events. His tenders stated that he was communicating with them but his verbal communication was not coherent. They slowly brought him to the surface via his safety line. The caller stated that the next time he became aware, he was already on shore with all his equipment removed and receiving oxygen. Emergency medical services were already on the scene, and the caller was taken to a hospital. He was evaluated and was treated with a US Navy Treatment Table 6 (USN TT6) for a possible AGE. Head computed tomography (CT) scans showed no signs of damage. Chest X-ray and examination showed no sign of pulmonary barotrauma. The caller remembered that as soon as the chamber was pressurized, he had a return of the acute pain in his forehead but at the time of the call he had no symptoms. We ruled out AGE because the onset of symptoms occurred at depth. The return of pain during recompression and the lack of neurological symptoms indicate a probable sinus problem rather than AGE or DCS.

Case 02-02: A call came from a hyperbaric chamber that was just completing the recompression treatment of a female diver in her late thirties for AGE. She did two days of diving with two dives on her last day (81 fsw [25 msw] for 54 min; surface interval (SI) 1:52 h:min; then 74 fsw [23 msw] for 62 min). Upon surfacing from her last dive, she complained immediately of dyspnea. During transportation to a chamber, she experienced nausea and vomiting. Upon examination at the chamber, it was noted that she had mottled skin (cutis marmorata) from the lower abdomen to the chin. She also remembered having a rash on her left hip before the last dive (for which she took one tablet of Benadryl). It had mainly resolved by the time of examination. Neurologic exam revealed loss of motor function in her left leg (3/5), decreased strength of both upper arms, and numbness in the right hand. Reportedly, she lost control of bowel and bladder twice. In this case, skin manifestations supported the diagnosis of DCS as a cause of her central nervous system (CNS) symptoms. There were no associated findings supporting pulmonary barotrauma. We classified this case as skin and cerebral DCS and possible chokes.

Case 02-03: A dive shop owner called DAN for advice regarding one of his clients who walked into his shop but could not remember how he got there. Reportedly, he dived the day before from shore and had to swim hard. He could not recall any events from the conclusion of the dive to presentation. He was referred for neurological evaluation. While this kind of mental problem may be caused both by DCS and AGE, the evolution is usually different. AGE mostly occurs suddenly with severe symptoms that gradually improve with time. DCS usually progresses gradually before it stabilizes or starts to resolve. The sudden onset of symptoms that remained unchanged for 18 hours raised suspicion of other non-diving, medical causes. In the hospital, the diver underwent CT imaging that demonstrated a dissection of the inner carotid artery. This condition represents a separation of the inner lining of artery from its wall, which then obstructs circulation of a blood to the brain and causes neurological symptoms.

Among 11 **possible AGE** cases, presentations and their severity vary.

Case 02-04: A typical case was reported by a physician from a hyperbaric chamber. He evaluated a 43-year-old male who lost consciousness immediately upon surfacing from his single dive to 70 fsw (21 msw) for 23 min. The diver was brought in by friends. He complained about pain in his extremities and tingling on his right side. He was confused and was hard to persuade to accept hyperbaric treatment. Eventually, he was treated twice and his symptoms resolved. AGE often starts with a loss of consciousness which may resolve shortly leaving an array of CNS symptoms. Based on the dive history, DCS was very unlikely in this case and we ruled it as ‘Possible AGE,’ which was very likely.

Loss of consciousness may have many causes, which may not be established even after extensive work up in hospital.

Case 02-05: Such was the case for this 55-year old diver who immediately after surfacing from a second dive (80 fsw [24 msw] for 45 min and 75 fsw [23 msw] for 45 min) complained of dyspnea and lost consciousness as soon as he climbed on the dock. He shortly regained consciousness but lost it temporarily again during boat transportation, and again after two hours of hyperbaric oxygen (HBO) treatment. He remained comatose and apneic for a week and passed away. A review of his medical history revealed that he had recently passed an extensive physical examination. The autopsy revealed that he was suffering from advanced kidney cancer that had spread into his liver. His brain was severely damaged, but it is not an unusual finding after a seven-day coma. The scenario was suggestive of AGE but other causes may not be excluded. There was no direct link to cancer in this case.

2.6 Decompression Sickness (DCS)

The criteria for certainty of the diagnosis of DCS that we have used in our retrospective review are quite vague (Table 2.6-1). The diagnosis of DCS over the phone is even less reliable than in the examination room. Besides an ascending paralysis that occurs immediately post-dive and progresses within minutes or hours, or a characteristic skin blotching, there are few other symptoms that unequivocally indicate DCS. Post hoc classification of DCI depends heavily on diagnosis reported by the treating physician.

Table 2.6-1 Criteria for certainty of diagnosis of DCS

Certainty level	Criteria
Very Likely	Sufficient exposure AND symptom onset <24 hours AND confirmed by physician upon examination OR skin mottling post-dive OR ascending leg weakness post-dive
Likely	Sufficient exposure AND onset <24 hours and typical complains BUT no physical exam OR resolution upon first aid oxygen (FAO2) before examination
Unlikely	Insufficient exposure OR onset >24 hours OR atypical symptoms OR likely that other cause was present
Ruled out	Insufficient exposure OR onset >48 hours OR ruled out by physician upon examination

Sufficient exposure to cause DCS has always been considered by diving medicine experts but its definition varied. Once the decompression tables were established and no-decompression (or, more appropriately, no-stop) curve introduced, many believed that any symptoms occurring after dives to no more than the no-decompression limit are either not DCS or are so called ‘undeserved DCS.’ DCS risk generally follows the dose-response pattern: the more poison an animal receives the more likely it will be affected. Sufficient dose (which is not necessarily decisive dose), however, was formally defined recently with the so-called SANDHOG Criteria (Grover et al. 2007). These criteria may be of help to establish a cut-off point for practical purposes to frame the otherwise probabilistic phenomenon of DCS.

Response to treatment may be used for retrospective classification of DCS, but it is of little help in establishing diagnosis at a patient’s presentation when the physician must decide on the course of treatment. Resolution of symptoms upon recompression treatment does not necessarily become absolute proof of DCS because many conditions may benefit from the actual effects of hyperbaric oxygen or its strong placebo effect. However, prompt relief of major symptoms during compression or soon after reaching treatment depth, strongly supports the diagnosis of DCS. (Vann et al. 2003) That usually happens in quite clear DCS cases and thus does not add much to the diagnosis.

We reviewed all cases labeled as DCS by case managers, and there were a total of 651 cases with concerns of acute DCS. In retrospective review of all data available in each case, we have classified them as shown in the Table 2.6-2.

Table 2.6-2 Number of calls concerning DCS

Leading Symptoms	Incomplete	Likelihood of DCS					
		Confirmed	Possible	Unlikely	Not DCS	Inconclusive	Row Total
Skin	2	36	20	3	5	1	67
Pain		10	37	6	5	6	64
Spinal	2	28	15	1			46
Cerebral		16	10	1		1	28
Vertigo		2	1			1	4
Other	34	30	126	84	148	20	442
Total	38	122	209	95	158	29	651

There were 122 (19%) cases of suspected DCS retrospectively reclassified as Confirmed. This more than doubled in comparison to the previous year's eight percent. This increase may be mainly due to improved follow-up that benefited from the detailed examination of the treating physicians. Most cases concerning suspected DCS were classified as Possible DCS (32%; n=209). This means that they met all criteria for DCS except we did not have the results of professional medical assessment or symptoms resolved with FAO_2 before medical assessment was possible. In some instances, medical assessment was indecisive.

Nearly a quarter of all DCS suspected cases retrospectively were classified as Not DCS (n=158; 24%), Unlikely DCS (n=95, 15%) or Inconclusive (n=29, 4.5%). This does not negate the original working diagnosis of suspected DCS established in the early stage of emergency case management. To classify symptoms reported by divers post-dive as Not DCS without hands-on medical assessment is problematic. Subjective reports by an injured diver or unqualified observer must always be considered incomplete and diagnosis based on such reports tentative. In some cases, diagnosis remained uncertain even after medical examination and treatment.

2.6.1 Other was the largest category with 442 cases (68%). This included mostly mild subjective symptoms or other atypical symptoms that did not fit other categories explicitly listed. The cases fit previously used Perceived Severity Index group 3 (Vann et al. 2003). Diversity of non-specific symptoms, often only subjective and very mild, resulted in the end with this category having the least percentage of cases in combined Confirmed and Possible category (24%) and the highest percentage of cases with DCS ruled out. Many of the mild symptoms resolved in hours or days and the divers were never admitted for evaluation. Divers were concerned about DCS if they were aware of risk factors incurred during the dive, like a rapid ascent, heavy exertion, flying after diving, or even a missed safety stop.

Case 02-06: In this case, a husband called about suspected DCS that he thought his wife was experiencing. Three days before the call, she did two certification air dives to 50 fsw (15 msw) for about 40 min (surface interval not reported). The dives were uneventful and pleasant. Later that evening, she started feeling some shoulder and knee tingling, which worsened next morning. She was taken to a chamber five hours away where she received recompression treatment on USN TT6 that same night and two US Navy Treatment Table 5 (USN TT5) protocols the next day. She was symptom-free after the last treatment and released. After a good night sleep, she was taken by car back to her hotel. On the way back, the road led over an elevation of 1000 ft (305 m). She started feeling dizzy (no vertigo), "a little tingly" on her feet and fingers, nauseated and dry mouthed. The husband was advised that the new symptoms were most likely not due to DCS but they were referred to a hyperbaric chamber for an evaluation. The patient flew home and was admitted for evaluation. She received another USN TT6, although no neurological abnormalities were found. After the treatment, the patient still complained about some symptoms and said she would seek acupuncture treatment. She was lost for further follow up. In retrospect, the initial symptoms of tingling in both shoulders and knees have no feasible medical explanation. The exposure was very low risk for DCS. There were no objective findings on examination before the first treatment. The new symptoms, three days post-dive could not be linked to decompression. Thus, we retrospectively classified this case as Not DCS.

Bilateral tingling in both arms was reported in several cases.

Case 02-07: A 46-year-old female diver called the morning after she did two dives with a complaint of some tingling in both arms. She denied any other symptoms. Her first dive was to 81 fsw (25 msw) for an unspecified time, on 32% nitrox (EAN32), followed by a surface interval of 59 min and a second dive was to 51 fsw (16 msw) for 38 min on 36% nitrox (EAN36). She also complained about discomfort with the mattress she slept on. She was referred to a hospital with a hyperbaric facility for evaluation. Medical evaluation did not reveal any abnormalities and the physician ruled it Not DCS. On a follow-up call the next day, she reported that all her symptoms resolved and that she was completely fine. However, on the third day, she called and complained about the return of tingling. She went to another hyperbaric chamber and received recompression treatment on USN TT6, one day after she presented for evaluation. Reportedly, she had a stiffness of arm muscles and jaws. The doctor gave her a tablet of Valium and ordered her for re-evaluation later that day. When she came back, she complained about the same symptoms and was given another recompression treatment, this time on USN TT5. Symptoms remained unchanged. Eventually, she was lost to follow up. In retrospect, this case was most likely Not DCS. In summary, the dive exposure produced a quite low DCS risk, symptoms were subjective only and went away without any treatment the first time, the return of symptoms could not be linked to decompression and the response to recompression was not decisive, thus we ruled this case Not DCS. Tingling in both arms in this case was more likely caused by some kind of neck strain while sleeping on the uncomfortable mattress. While the tingling may be an early symptom in some DCS cases, it rarely remains the only symptom. A loss of feeling of touch, pain or cold and warm as well as muscle strength must always be checked in case of tingling. If present, decreased skin sensitivity or muscular weakness make a much stronger support for diagnosis of DCS.

Case 02-08: Tingling may be the only subjective symptom, but usually it shows some progression. This was a case of an 18-year-old diver. His mother called because he complained about tingling in his right foot. He had made two dives, one to 102 fsw (31 msw) for 39 min and after a 1:40 h:min surface interval he made another dive to 82 fsw (25 msw) for 41 min. Both dives were on air and involved multi-level profiles. Tingling started approximately 40 min after the last dive. The tingling was not dependent on position or exertion but it may have spread into his lower leg. He was not aware of any recent trauma. The diver was referred for evaluation. The physician who evaluated him recommended recompression treatment. The next call to the DAN emergency line was by the diver's father who questioned the recommendation and was inquiring about the possibility of delaying the treatment until after the commercial flight home. DAN advised him not to fly and supported the recommendation to undergo treatment first. It took another consultation with a senior consulting physician in the DAN system to persuade the family to follow the recommendation of the physician who initially examined the diver. Eventually, the diver received recompression treatment; all symptoms resolved and did not return during the flight home.

Case 02-09: The combination of pain with numbness and tingling should always be taken seriously, but it is not specific for DCS. Here is the case that occurred in the Caribbean. It is described in the words of diver's wife and the diver:

"I am attaching the dive series for my husband. Following the eighth dive in the series (Tuesday), after returning to the boat, he experienced pain in his left buttock, followed by tingling along the outside of his left leg. After approximately 10 minutes, the crew administered oxygen. The pain went from 8 on a 1 to 10 scale to 6. When the symptoms did not subside, the crew called an ambulance. Once off the boat, the pain in the leg and buttock subsided. He was transported to the local hyperbaric chamber attached to a clinic where he was examined by a physician. The doctor found other symptoms and treated him in the chamber on Tuesday afternoon and again on Wednesday afternoon. Some mild symptoms remained on Thursday, although chamber treatment was not required. He was released on Friday and we flew home on Saturday, with no incidents."

Upon request for more details about dive and health history, we received this reply:

"I am 'the husband' and can provide you with the information you requested. The attached file is the medical report. I used a buoyancy compensator with an integrated octopus, and dive computer. On this trip, I would dive air on the first dive, then 32% nitrox the second and third dives of the day. Conditions for diving were excellent. On the last dive I used air, did a normal descent and slow ascent, with safety stop at 15 feet for three minutes. My wife was my dive buddy. Our dive profiles are almost identical.

"Anything unusual: Nothing until I came out of the water and walked to my seat on the boat. I am 54 years old, in very good health. My weight is 185 pounds. I work out at the gym five times a week performing mixed low impact aerobics and weight machines. Prior to that, I have been running for 20+ years until I damaged my knee in the summer of 2006. I had my six-month checkup with my doctor last week, which included blood tests. Everything looked excellent. I am a light drinker, I am not overweight, and don't smoke. My prescription medicines are Altace (ramipril, an ACE [angiotensin-converting-enzyme] inhibitor) for high blood pressure (10 mg) and Lipitor for cholesterol (40 mg). I had been tracking my blood pressure since returning from the dive trip and took this data to the doctor. My blood pressure was nominal with no concerns from him. I did 150+ dives since my open water certification in 1993."

The estimated risk of DCS for the entire series of dives is shown in Table 2.6.1-1. All dives were low risk dives. The last dive had the largest risk but it was still low. The dive profiles for the last two dives are shown in Figure 2.6.1-1.

Table 2.6.1-1 Estimated risk of DCS (P[dcs]) for the dive series

Day	Dive	P(dcs)	95% CI		
1	1	0.173	0.112	-	0.258
1	2	0.026	0.004	-	0.112
1	3	0.111	0.042	-	0.261
2	1	0.174	0.083	-	0.34
2	2	0.08	0.007	-	0.492
2	3	0.149	0.021	-	0.666
2	4	0.29	0.064	-	0.969
3	1	0.725	0.261	-	1.692

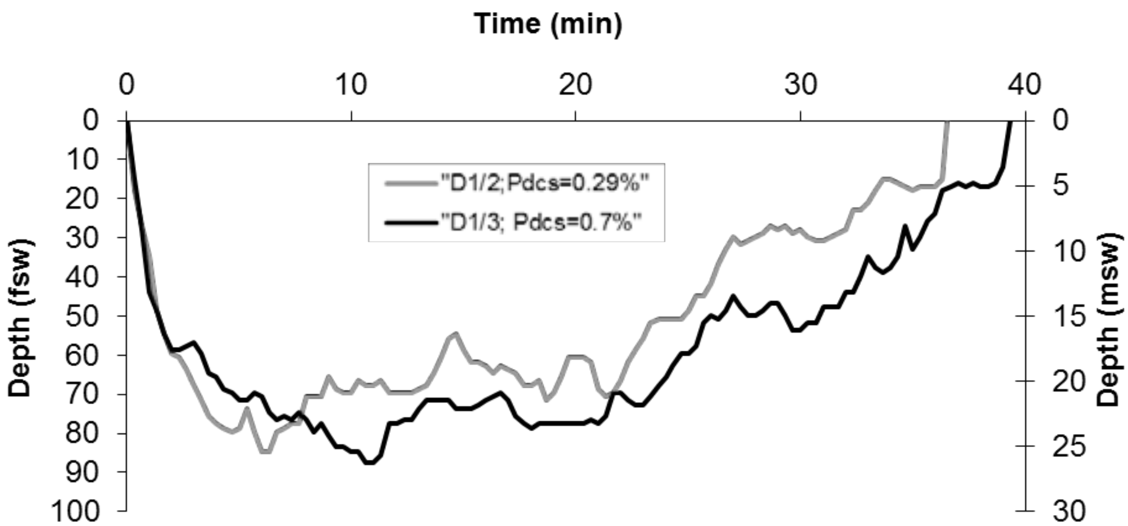

Figure 2.6.1-1 Dive profile of diver with post-dive numbness and tingling

2.6.2 Skin DCS was of concern in 67 (10%) of the DCS Suspected cases. In addition, there were 32 cases with afflictions of skin that were diagnosed as non-diving-related (n=14), other (n=10), envenomation (n=7) or trauma (n=1). Non-diving and other categories included allergic rashes, viral infections, and unspecific rashes that occurred with long delays after dives. In cases of suspected skin DCS, skin mottling and rash were often associated with other symptoms.

Case 02-10: This experienced technical and cave diver in her late twenties developed breast and shoulder pain with skin rash and mottling, 40 min after a dive. Here is her account:

"I made a dive with two friends at a fresh-water sinkhole. We were diving on the downstream side of the siphon. The dive started at 10:42 am. I was side mounting steel 95s with 27% oxygen nitrox with an aluminum 80 as a stage bottle with 31% oxygen. I also had a 40 cubic foot deco bottle with 100% oxygen. I was well hydrated, rested and in good health. I routinely conduct 3-4 long decompression cave dives a week. The first 700 ft (213 m) of the cave is at a depth of about 60-70 ft (18-21 m) and then it drops pretty quickly down to 130-140 ft (40-43 m) for the rest of the dive. It is typically a strong siphon, but on the day of this dive had minimal flow. I was using the stage bottle for the upper 60-70 ft (18-21 m) section. At 12 min into the dive, I switched to my bottom gas of 27%. The dive was uneventful and I did not overexert myself. On the way out, I switched back to my stage bottle with 31% at 58 min into the dive at 82 ft (25 m) [See Figure 2.6.2-1 for dive profile]. Decompression started at 65 min into the dive for a 30 ft (9 m) stop of eight minutes. At 80 min into the dive, I began my 20 ft (6 m) stop on 100% oxygen. The remainder of the deco was conducted at 20 ft (6 m) and above. The entire run time of the dive was 99 min and I surfaced at 12:21 pm. Since I was side mounting, each tank was removed from the water at my convenience. I remained hydrated after the dive. I live about 20 min from the dive site and began having muscle pain in my chest on the way home. This would be about 40 min after the dive. By the time I got home, the chest pain was pronounced and there was a rash [skin bends] over my torso, upper left arm and abdomen. I laid down and breathed 100% oxygen and hydrated, this did not change my symptoms. When I got up to get my dive computer to pull off the exact profile, I became light headed and nauseated. I called DAN half an hour after getting home. After discussing things with a medic at DAN, I went to a local hospital for medical evaluation. I was diagnosed with DCS and was given a [USN] Table 6 recompression treatment that started at 7:30 pm. Symptoms resolved almost completely within minutes of being taken to depth and were completely gone by the end of the first oxygen cycle. The following morning the chest pain was present again along with pain in my left shoulder. I returned for a second Table 6 recompression treatment. Symptoms never went away, but there was some improvement. Now after a week, symptoms are all but gone. The chest pain is completely gone but my shoulder is still tender and slightly sore."

Figure 2.6.2-1 shows dive profiles for the dive which caused symptoms and for the dive done four days prior. The estimated risk for the dive that caused injury was 4.45% and for the prior dive it was 1.67%. Despite the greater maximum depth, the total run time was the same and the decompression shorter on the second dive, raising the risk of DCS, which in this case produced symptoms.

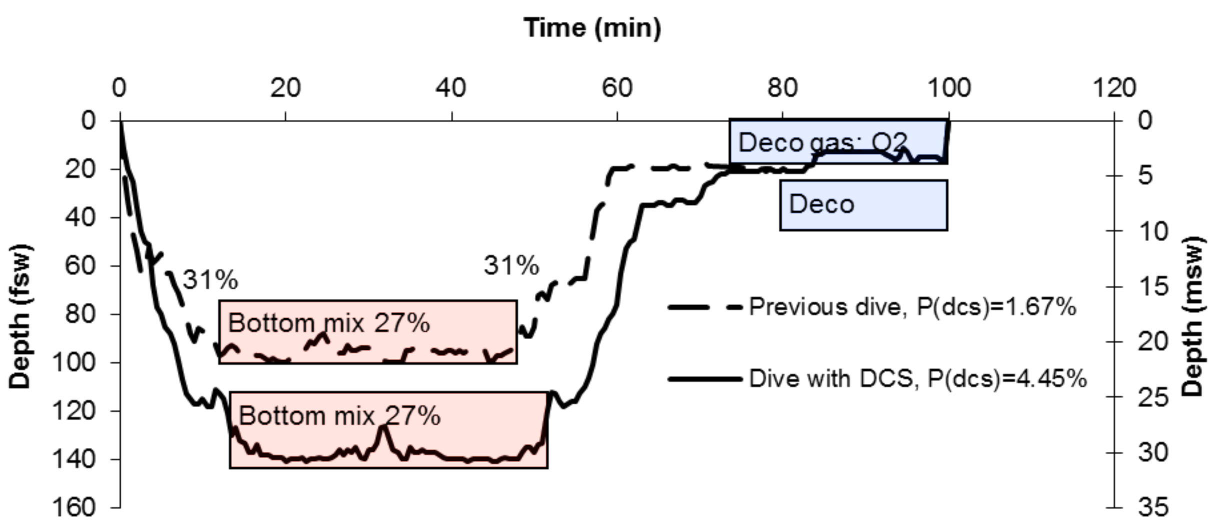

Figure 2.6.2-1 Dive profile of diver with breast and shoulder pain, skin rash, and mottling

Skin changes may be caused by **drysuit squeeze.**

Case 02-11: One recreational diver reported prominent black marks over his upper back and around his left shoulder where the exhaust valve sits over the skin. He did a single drysuit dive to 95 fsw (29 msw) for 15 min. He denied any difficulty equalizing his drysuit and did not feel that the bruising was caused by drysuit squeeze. Another diver woke the next morning after a dive and noted discoloration on both shoulders as if he had a 'hickey' (a reddish mark on the skin typically caused by biting or sucking). The day before, he did one dive to 35 fsw (11 msw) for salvaging attempts but does not recall any unusual problems or complications with his dive. He was diving in a drysuit and he thinks drysuit squeeze was possible. Both of these cases were deemed to be drysuit squeeze. The appearance and location of bruises with a link to a mechanical cause made it easy to exclude skin bends. No action was needed and skin changes resolved shortly.

Case 02-12: The mechanical factors of a drysuit may also trigger DCS-caused change, which is what likely happened in following case. An attending HBO physician called for a consult about a male scientific diver in his thirties who completed a series of two decompression dives using trimix (180 ffw [55 mfw] and 173 ffw [53 mfw]) the previous day. Both dives were without complications, and decompression was completed as scheduled. Immediately after surfacing and removing his drysuit, he noticed a discolored mottling and palpable tenderness throughout the left shoulder but no pain. He slept well and awoke noticing an increased swelling in his left shoulder even though the discoloration and mottling were resolved. The physician found left shoulder discomfort and soft tissue swelling throughout the pectorals and triceps. The patient reported that six years earlier he received USN TT6 for similar symptoms. He was diagnosed with DCS again, and all symptoms resolved with one recompression treatment.

Breast pain associated with skin rash or mottling was reported by four women. Eight males reported pain in the shoulder and breast area associated with skin rash, mottling or swelling in what may be similar to breast pain reported by women. In two cases, the women had breast implants but the symptoms involved a larger area than just the surface above the breast implants; thus, the implants were not necessarily the cause of these changes.

Case 02-13: Breast pain was reported by one spearfisherwoman. She did three dives spearfishing and within 20 min after her last dive she began to experience bilateral breast pain and itching without any change in skin appearance. She denied any other symptoms. She stated that this has happened once before after spearfishing. She is a frequent diver and does not experience breast pain when making multiple dives without spearfishing. She was curious if other women have ever reported this occurrence. We did not know about similar cases. However, it is quite likely that loading the speargun, which requires substantial physical effort, could cause breast muscle soreness and pain.

Case 02-14: Skin changes may be associated with serious symptoms. We have presented in past diving reports cases of skin bends associated with neurological symptoms. Here, we have a case of serious spinal cord injury which started with skin mottling and abdominal pain but soon developed muscular weakness of both legs (paraparesis) followed by numbness and tingling of both arms. Fortunately, the accident happened on an island with good emergency and hyperbaric medicine services, and the diver was treated at an early stage. Full paralysis never developed and recovery was complete. However, it took two recompressions (USN TT6 and TT5, respectively) and several one-hour sessions of hyperbaric oxygen for complete resolution of symptoms.

2.6.3 Pain was discussed in 760 out of 9888 calls/emails (77%) and in 314 out of 651 (48%) suspected DCS cases. In most cases pain was accompanying other symptoms and, in 64 cases, it was the leading symptom.

2.6.4 Spinal cord DCS is assumed when a patient suffers muscular weakness or certain types of sensory loss sometimes associated with loss of bladder control. Typically, muscular weakness is ascending from toes upwards. It may be preceded by tingling and numbness starting in the fingertips and spreading to the entire extremity. In most cases, it affects both sides of the body, but in some cases one side may lose motor and the other side may lose sensory functions.

Spinal-related symptoms were reported in 46 out of 651 (seven percent) DCI cases. When spinal DCS was suspected, it turned out to be confirmed in most cases (confirmed 28, possible 15, unlikely in one, and incomplete data in two).

Symptoms usually occur soon after dive and progress to various degrees of muscular weakness and sometimes to complete paralysis. Recovery is not always complete. It is important to recognize it and react early. Surface first aid oxygen should start immediately while arrangements for evacuation to a hyperbaric chamber are being made.

Case 02-15: In severe cases, DCS may be fatal. In this case, a young female diver did an out-of-air ascent after 10 min at 284 fsw (87 msw) directly to surface from an undetermined depth. She arrived at the surface alert and oriented but complained of immediate onset of difficulty breathing (presumably chokes) and tingling in the hands which quickly progressed to a lower level of consciousness. She was placed on emergency oxygen and transported to shore where she was met by local ambulance and transported to the local emergency department. At admission, the patient appeared alert, oriented and grossly intact but neurologic exam revealed abnormalities that prompted recompression on USN TT6. The patient tolerated treatment well but immediately upon completing it and exiting the chamber, she complained of severe pain in her legs and lost the ability to move her legs except to wiggle her toes. Respiration became depressed, blood pressure dropped and the patient's consciousness deteriorated. The patient was moved to the intensive care unit but could never be stabilized and expired during the night. At the same time, her buddy, who did the same dive and the same emergency ascent, did not have any neurological symptoms but started complaining about knee pain. Both buddies were evacuated at the same time, and both probably received first aid surface oxygen. The dive to 284 fsw (87 msw) on air should never have happened. That depth is far beyond the safe limit for air dives. Besides a risk of nitrogen narcosis, oxygen toxicity and breathing limitations, the consumption of air at that depth is excessive and decompression obligation builds up very quickly. Any adverse event that prevents a diver from completing proper decompression may cause serious consequences. Having one buddy who survived this accident does not justify the feasibility of deep air diving. Indeed, the buddy may have survived due to early administration of surface oxygen or due to sheer luck. Luck should never play an intended role in the dive plan.

2.6.4.1 Bladder dysfunction usually indicates a severe spinal cord injury and fortifies the diagnosis of DCS. In this series, bladder dysfunction was reported in 11 cases. In fact, there was one more case with bladder/bowel dysfunction in a diver who complained of leg paresthesia with normal strength. This raised suspicion since a lesion of the spinal cord area that controls bladder is associated with the region that controls lower extremity motor strength. In this particular case it turned out that the diver complained about an instance of passing a stool after a dive without being aware of it. Both paresthesia and loss of sensory control in the anal area could be explained by injury to the spinal cord. The function of the bladder was unaffected but there was no other way to report the described symptoms other than checking the box bladder/bowel. This checkbox, however, was intended for the cases involving paralysis of muscles controlling the bladder and bowel. In the case of the bladder, the muscle that actively executes voiding is affected and urine cannot be passed. The bladder accumulates urine over time and appears distended above the pubic line. The patient must be catheterized to empty it. In cases when the bowel is affected, the regular movement of bowel stops and no stool is passed. However, since passing the stool occurs usually once a day, patients rarely report bowel problems. In patients with paresis or paralysis, a physician may check bowel movements by listening for sounds with a stethoscope placed on the abdomen as well as evaluating sphincter tone.

Spinal DCS does not always appear dramatic, at least in the beginning.

Case 02-16: The call regarding this case came through Travel Assist from a general practitioner located on an island. They had in their clinic a diver in his sixties who was diagnosed with DCS and needed an air ambulance for evacuation to a hyperbaric chamber on another island. The diver had completed three scuba dives on air in two days. His last dive ended one day before he called for assistance. All dives were multi-level profiles with a short bottom time and slow ascent along a reef slope. On the last day, he completed one dive to a maximum depth of 95 fsw (29 msw) for 36 min of total dive time. Five minutes after surfacing, he felt pain in the upper back and shoulder, weakness in both legs, and he had difficulty removing his dive equipment. In the evening, he took one tablet of Motrin. During the night, the weakness in his legs got worse, and he could not pass urine. Early the next morning, he walked into the clinic. The physician found decreased strength in both legs, but sensation was normal. The patient received a Foley catheter by which 850 mL of urine was voided. At this time, he did not feel any pain. An evacuation to a mainland hospital was advised and organized. Once in the hospital, the patient underwent a physical exam, lab tests and magnetic resonance imaging (MRI). His vital signs were stable. Most symptoms improved by that time, but the patient still had a catheter. He was treated in a hyperbaric chamber with a USN TT6. All symptoms seemed to be relieved after the first recompression, but some minor numbness and tingling in the fingertips remained. He then received a USN TT5 and two standard hyperbaric oxygen treatments in three days. His catheter was removed, and he was able to control his bladder. He flew home 72 hours after the last treatment. DAN followed up with this diver several times during and after the treatment. Four weeks post-treatment, the patient stated that he had returned to work but still experienced mild lower extremity weakness and some shoulder pain and stiffness. He was under the care of his primary care physician. This was not a "typical case" in the sense that muscular weakness was very mild but bladder function was impaired.

Case 02-17: This technical diver did a trimix (21% oxygen/35% helium/balance nitrogen) dive of unspecified depth and duration but omitted 25 min of the mandatory decompression, according to his own account. He reported an equipment malfunction that resulted in a rapid ascent to the surface. He suffered a severe headache immediately after surfacing, tingling in his feet, and numbness of his right leg. Reportedly, he received surface oxygen within 10 min after surfacing and an intravenous infusion of fluids within 15 min. His symptoms first resolved but then came back. He was airlifted to a hyperbaric chamber where he was found unable to walk or urinate; he felt numb from the umbilicus down. The first treatment took about 12 hours. After the first treatment, he was flown to a mainland hyperbaric center where he received further treatments. His recovery was significant but not complete. We did not know of this case until after all treatments were completed and the patient called DAN asking about his prognosis and the likelihood of returning to diving.

2.6.5 Cerebral manifestations of DCS (mental confusion, vision disturbances, disorientation, one-sided muscular weakness, dizziness, other weakness) were reported in 28 (4.3%) of cases.

2.6.6 Inner ear DCS (IEDCS) was reported in four (<1%) of DCS Suspected cases. Vertigo was reported in 77 cases. Nystagmus (involuntary eye movements) without vertigo was reported in seven cases. In 39 cases with vertigo, DCS was suspected at the onset. Retrospective evaluation of diagnosis of inner ear DCS depends on reported symptoms, dive history, findings and diagnosis of treating physician. In cases with reported vertigo but incomplete information, retrospective classification may not be possible.

Case 02-18: In some instances, one can suspect that dizziness was reported as vertigo. In this case, the caller called on behalf of his 41-year-old male dive buddy. They did a single technical dive to 190 fsw (58 msw) using trimix. The total run time was 60 min. The dive was uneventful. Within 15 min of surfacing, the diver experienced acute dizziness, coughing and visual disturbances. The caller placed him on oxygen immediately. The diver reported that the coughing and visual disturbances had resolved but the acute dizziness remained. In this case, more than one cerebral symptom was reported. Nausea and vomiting that typically accompany IEDCS vertigo were not mentioned. By the time the patient arrived at the hospital, he did not have any objective neurological findings except positive Rhomberg sign (inability to stay up with closed eyes and feet next to each other). The remaining symptom, slight dizziness, improved after a USN TT6 and with additional treatment resolved completely. The treating physician's diagnosis in this case was missing and we classified it as cerebral DCS.

Both vertigo and nystagmus were reported in five cases (Table 2.6.6-1)

Table 2.6.6-1 Cases of vertigo and nystagmus

Diver	Dive	Symptom Onset (minutes post dive)	Symptoms	Diagnosis
59-year-old, male	73 fsw (22 msw)/71 min	20	vertigo, nystagmus, nausea, vomiting	Inner ear DCS
32-year-old, female	1st: 60 fsw (18 msw)/30 min; SIT=45 min 2nd: 40 fsw (12 msw)/45 min	>60 (after a nap)	vertigo, nystagmus, nausea, vomiting, ear fullness	Inner ear barotrauma, probable fistula
35-year-old, male	121 fsw (37 msw)/43 min on 31% nitrox. Deco gases: 50% and 80% nitrox.	5	vertigo, nystagmus, nausea, vision disturbances, elbow pain	Inner ear DCS
50+ year-old, male	90 fsw (27 msw)	10-15	vertigo, nystagmus	Inner ear DCS
47-year-old, male	143 fsw (44 msw) at altitude of 8,000 ft (2,438 m), 5 min bottom time, 15 min required deco, 10 min omitted	1	neck pain, shoulder pain, dizziness, weakness, dysarthria, deafness in his left ear	Cerebral DCS

2.6.7 Not DCS was ruled in 158 (24%) of Suspected DCS cases, most in the category Other and a few in the Skin and Pain categories.

Case 02-19: This caller was a 51-year-old woman, a beginner diver and physician by profession. She called to discuss an ache in her knee that occurred after a dive. She had completed two dives as a part of open water training. One dive was to about 50 fsw (15 msw) and the other to about 64 fsw (20 msw). She ran out of air during the second dive and she buddy-breathed with her instructor while ascending at a reasonable rate. Two days later she dived to 54 fsw (16 msw) for 30 min and after a 90 min. surface interval she dived again to 60 fsw (18 msw) for 30 min. She felt an intense prickling sensation on her arm while at depth, but this resolved in a few minutes and was not present at the surface. About one hour after the last dive, she felt an itching and tingling that migrated all over her skin that moved around. This was different from the forearm sensation during the dive. After an unspecified time, these symptoms resolved. But now, she also felt an aching pain in her upper calf and the popliteal area (behind the knee joint), which she ascribed to tripping while getting on the plane. This pain got worse during the flight home but it improved when she walked. She was admitted to a local hyperbaric chamber and received one USN TT6 recompression treatment, but the symptoms remained. Over the next few weeks, the symptoms resolved. She now thinks that pain was related to tripping. Her physician agrees. We classified it as Not DCS since even her early symptoms did not fit DCS patterns.

2.7 Barotrauma (BT)

Barotrauma is an injury caused by change of pressure. In divers, it may occur during ascent or descent. It affects hollow organs and spaces containing gas, most commonly the ears, sinuses and lungs. Less frequently it affects the stomach, intestines and teeth. The spaces between the body surface and the equipment may be exposed to the effects of squeeze: mask squeeze, drysuit squeeze. There were 328 cases with working diagnoses of barotrauma (assigned when initially received as emergency calls). Retrospectively, after follow-up of emergency cases and review of information calls, there were 494 cases of barotrauma. The most common forms of barotrauma reported in 2008 are shown in Table 2.7-1.

Table 2.7-1 Cases suspected of barotrauma

Area Affected	Count	Injury	Frequency	%
Ears	409	Middle ear barotrauma (MEBT)	344	69.6
		Inner ear barotrauma (IEBT)	26	5.3
		Otitis externa	12	2.4
		Alternobaric vertigo	6	1.2
		Facial baroparesis	4	0.8
		Other	17	3.4
Sinuses	21	Sinus barotrauma	21	4.3
Lungs	56	Lung barotrauma, unspecified	34	6.9
		Subcutaneous emphysema	13	2.6
		Mediastinal emphysema	3	0.6
		Pneumothorax	6	1.2
Face	3	Mask squeeze	3	0.6
Teeth	5		5	1.0
Total	494		494	100

Table 2.7-1 includes more cases than were reported through the emergency line. This is because, in some cases, acute symptoms may not be severe enough to prompt the injured diver to seek help immediately. They may call later through the medical information line to obtain advice and referral. Thus, we searched the entire database for cases of barotrauma and included in this table all that appeared to be in need of help and evaluation.

2.7.1 Ear Barotrauma

Middle ear barotrauma is the most common injury in diving. It affects both new and experienced divers. Equalization of pressure in the middle ear is a basic diving skill which can be learned by most divers. Structural auditory (Eustachian) tube dysfunction that permanently prevents equalization of pressure in middle ear is rare. However, temporary dysfunction due to the common cold may be experienced by any diver. Wise divers abstain from diving when congested. Trying to dive despite equalization difficulties may cause serious injury.

Case 02-20: Diving with middle ear equilibration difficulties, typically resulting from a cold or infection may result in a sensation of a blocked or muffled ear after diving. Using a Valsalva maneuver to clear it may cause injury as in the following case. This 37-year-old male recreational spearfisherman was diving three days prior to the call. He had completed a series of four dives in the range of 150 fsw (46 msw). Approximately 10 min after surfacing from his final dive, he was attempting a Valsalva maneuver to clear a “blocked sensation” in his right ear. Instead of relief, he experienced a sudden onset of severe vertigo, nausea and several uncontrolled episodes of vomiting. He was hospitalized overnight in his local emergency department with a diagnosis of inner ear barotrauma. His vertigo improved by the following day and the nausea and vomiting were completely resolved. Follow-up uncovered that he had recently been diagnosed with bilateral middle ear infections, which had not completely resolved before he went diving. He had ear clearing difficulty during his dives, but he was not concerned. He called DAN because he was curious to know if his symptoms could also have been due to DCS. The answer is that although vertigo may be caused by DCS, it was unlikely in this case. The problem was most likely due to barotrauma that could have been prevented by waiting a bit longer for the previous ear infection to heal and regaining the ability to equalize the middle ear space.

Beginner divers are sometimes too eager and try to complete a dive despite difficulties with equalizing. They may even be encouraged by their instructor if the extent of the difficulty is not fully appreciated. The case below seems quite common.

Case 02-21: This case of middle ear barotrauma involved a 26-year-old student. In his own words: *"I think I have a middle ear barotrauma and am not sure what to do. Obviously, the first step should probably be to see a doctor; however, I do not have active medical insurance yet and I am wondering if there is something I may be able to do on my own.*

"This past weekend I did my checkout dives for certification. During each of my pool dives to only 10 ft (3 m) before the checkout dives, I had noticed discomfort in my ears during and after the dives. I have had issues with sinus congestion in the past, including a retention cyst in my right maxillary sinus and a deviated septum. Because of this, my instructor suggested an oral decongestant prior to each subsequent dive alongside constant focus on ear equalization. During one of my dives this past weekend, I noticed discomfort that turned to pain at around a depth of 10-15 ft (3-5 m). I never neglected the Valsalva or other techniques but still couldn't seem to equalize. As I sat at 10-15 ft trying to equalize, I noticed the pain slowly subsiding. We continued the dive which went as deep as 50 ft (15 m). I didn't feel any more pain until our ascent which occurred around 15 ft again at our practiced safety stop. Upon reaching the surface, we found that I had a nosebleed and later found blood in mucus from my sinuses. Since this dive, I have had mild discomfort in my right ear and it sounds like I have a pillow over it, slightly muffling the sound. We did one last dive afterward that didn't require as much focus on my ears particularly that right one as mentioned. Before we left the water, we practiced an emergency ascent from 25 ft (8 m). During this ascent, I noticed some moderate pain and at the surface had another nosebleed and slight vertigo. Now there seems to be only discomfort rather than pain, but it still seems as if there is a pillow on my right ear, or perhaps water inside the ear. It has been 33 hours since my last dive and the symptoms still exist as they did upon the exit from the water."

Divers with a similar medical history should be advised to have medical examination before commencing dive training. Instructors should not encourage diving with equalization difficulties. Divers should know that it is not acceptable to suffer during any dive. If they have pain and discomfort, they should seek an evaluation before continuing diving.

Case 02-22: Another diver with a history of frequent infections of his right ear in childhood caused by swimming did frequent Valsalva maneuvers during dives to have his right ear equalize while his left ear was equalizing easily. He suspected something was wrong with his right Eustachian tube but did not consider seeking medical evaluation of his fitness to dive. It should be a normal step for anybody who has a history of ear disease to seek medical evaluation as specified by the Recreational Scuba Training Council (RSTC) pre-participation assessment form.

Eardrum perforation was reported in 39 cases of middle ear barotrauma. Reported signs and symptoms included visible stream of gas bubbles coming out of ear canal while trying to equalize pressure underwater, a hissing sound coming from the ear while employing a Valsalva maneuver at the surface, sudden ear pain at the moment of perforation and bloody or serous discharge from the ear.

Alternobaric vertigo was suspected in six cases. This is vertigo resulting from unequal rates of equalization in the two middle ears. It is most common on ascent and usually either resolves when ascent stops or when the differential is eliminated. Vertigo may be preceded with equalization difficulties.

Facial baroparesis or drooping of one side of the face associated with equalization difficulties was reported in two cases. This may occur in subjects who have an incomplete bony cover of the facial nerve canal which passes through the wall of the middle ear cavity.

2.7.2 Inner ear barotrauma versus inner ear DCS

Inner ear barotrauma and inner ear DCS have similar symptoms at onset. The diagnosis at the time of admission is helped by a thorough examination. Vertigo that occurs during descent while attempting to equalize middle ear pressure is most likely caused by barotrauma. Vertigo that occurs during or after ascent may be caused by either barotrauma or inner ear DCS. For DCS, a necessary condition is a sufficient exposure but that is usually an arbitrary estimate. Barotrauma-related vertigo is usually of sudden onset in association with the event of changing pressure or forceful Valsalva while DCS-related vertigo may be of gradual onset but still pretty quick progression. Complicating the presentation, when there is a fistula of oval or round window, vertigo can occur some hours after a dive event, reflecting a slow or delayed leak of inner ear fluid.

Usually, severe vertigo will make most divers submit for evaluation. Even mild vertigo that lasts more than 30 min or is getting worse should receive urgent medical attention.

2.7.3 Pulmonary Barotrauma (PBT)

Pulmonary barotrauma was suspected in 56 cases. In 13 cases, there were signs of subcutaneous emphysema such as swelling of the neck or crackling of the skin on contact. Mediastinal emphysema was suspected in cases with retrosternal chest pain and voice change without subcutaneous emphysema. Pneumothorax was explicitly suspected in six cases when chest pain on deep breathing (pleuritic pain) was reported. Hemoptysis (coughing up blood) was reported in several cases, but it was impossible to verify whether it was due to lung injury or sinus mucosa injury. Most complaints followed a provocative event like a rapid ascent or breath-hold during ascent sometimes as short as few feet. Cases were seen with experienced and unexperienced divers. Provocative factors most often included rapid ascent. Triggers included panic, regulator failure, mask flooding, skill exercise with mask and regulator, and strenuous work underwater. In many cases, the diver was not aware of any provocative factor.

Case 02-23: One injury was to an experienced diver using a rebreather. He began to experience vertigo while at depth on a closed-circuit rebreather. He switched to open-circuit scuba 'bailout' and ascended (somewhat) rapidly. On the surface, he coughed bloody phlegm three to four times. He breathed a cylinder of oxygen immediately after ascent and was asymptomatic other than the hemoptysis. He developed some chest tightness over the following week, and called DAN to obtain a referral.

Pneumothorax was a topic of interest for many calls on the information line. Divers called to ask about medical fitness to dive after a traumatic pneumothorax, which is commonly seen after motor vehicle injuries.

Rapid Ascent was reported quite frequently. We identified 53 cases with explicit report of rapid ascent. Causes of rapid ascent included: equipment malfunction (12) [buoyancy compensator in four cases, regulator free flowing in three, one case of a regulator delivering water, one case of a regulator accidentally kicked out of mouth by another diver, mask flooding in two cases, and rebreather failure in one case], out of air (9), panic (9), and equalization problems (3).

Thirty cases of rapid ascent resulted in no injury. Despite that, the divers called DAN and asked for advice because they were concerned and rightly so. In most cases when there are no symptoms, the recommendation is to remain out of the water for one day. When rapid ascent followed a deep or decompression dive, divers are advised to have first aid surface oxygen ready for use and possibly be medically evaluated.

In 11 cases of rapid ascent, divers manifested symptoms of pulmonary barotrauma. Four of them had signs of pneumothorax. In 10 cases rapid ascent resulted in symptoms of pulmonary barotrauma. In nine cases, rapid ascent resulted in symptoms that may have been caused by AGE. In two cases, divers developed DCS. Both cases occurred during deep dives with omitted decompression.

Case 02-24: One case of rapid ascent resulting in injury occurred in the Arctic. The 45-year-old male was diving to 18 fsw (5 msw) on a rebreather which failed suddenly, and he was forced to do a rapid ascent to the surface where he soon lost consciousness. He was transferred to a hospital more than 1,000 mi (1,600 km) away. At the emergency room, he had no signs of air embolism, but still had some hemoptysis. At the time of contact, the chest X-rays were not yet available but, according to the physical exam, there were no signs of pulmonary barotrauma. On follow-up, it was confirmed that the diver had a suspicious pulmonary lesion and was in stable condition before being transferred to a hospital back home.

Case 02-25: A 43-year-old male did a single dive on air to 284 fsw (87 msw) for a bottom time of 10 min. He ran out of air and made a rapid ascent directly to the surface. The total underwater time was 24 min. Immediately upon surfacing, he complained of dyspnea and tingling in the hands which quickly progressed to a lower level of consciousness. He was placed on emergency oxygen and transported to shore where he was met by local ambulance and transported to an emergency department. At this point, DAN was called for consultation and to help organize evacuation and treatment. The patient was evacuated to a hospital with hyperbaric chamber facilities. He received a hyperbaric oxygen recompression treatment (a USN TT6 with two-extensions). He tolerated the treatment well until surfacing when he complained of severe pain and loss of motor functions in lower extremities (but could wiggle his toes). His respirations were weak, he was confused, and his blood pressure was depressed. He received medication to stabilize his blood pressure and required respiratory support in the intensive care unit. Efforts to stabilize the patient failed. He suffered respiratory failure followed by cardiac arrest. Attempts at resuscitation were unsuccessful, and he was pronounced dead shortly thereafter.

This was a sad case of unnecessary death. The diver should never have gone that deep on compressed air in the first place.

Case 02-26: The caller in this case was a physician from the emergency room of a small community hospital. He had in his care a 35-year-old female diver who was brought in after a rapid ascent to the surface. Reportedly, she was diving at 80 fsw (24 msw), and after five minutes she ascended rapidly to 40 fsw (12 msw) and then even faster all the way to the surface. The reason for the rapid ascent was apparently due to equalization problems; an observer reported that she was pointing at her head or ear during ascent. She was found at the surface, unresponsive and without pulse. Cardiopulmonary resuscitation was administered; pulse and spontaneous breathing was established and she was then taken to hospital. At the emergency room, she was found poorly responsive but hemodynamically stable. Chest X-rays showed no sign of pneumothorax. Blood chemistry showed acidosis. She was mechanically ventilated with 100% oxygen. After consultation with a medical information specialist on the DAN emergency line, she was treated with recompression using a USN TT6 with one extension. She experienced severe nausea and vomiting and agitation, which were controlled by medications for the duration of the treatment (eight hours). She was carried into the chamber on a stretcher and exited the chamber under her own power. Upon treatment, she had no visual impairment and her headache was mostly gone. At follow-up, a few months later, she had no residual symptoms and wanted to return to diving.

2.8 Panic

Panic was self-reported in 22 cases. In four cases it was triggered by mask flooding, either accidentally or during skill practice. In three cases, the trigger was running out of air. Regulator difficulties were implicated three times: one regulator failure resulting in the diver inhaling water instead of air, one lost regulator and one mouthpiece coming loose.

Unexpected life-threatening events like loss of gas supply or less threatening, but unpleasant events like mask flood may trigger a panic reaction. Of great concern, there are some individuals who may have a constitutional predisposition for panic reaction.

Case 02-27: One beginner diver panicked and admitted having the same reaction two years previously when he tried diving for the first time. He was advised not to try diving again without first seeing a psychiatrist.

Case 02-28: A diver called DAN about her sister from a remote location and said that she had some heavy feeling in her chest, dyspnea and panicking after a dive. The question was whether this could be dive-related. Later, the diver herself called DAN and said that she had DCS in the previous few days and was having panic attacks every time she gets in the water.

2.9 Envenomation

Rashes, scrapes, stings, cuts and allergic reactions related to hazardous marine life were reported in 186 cases. In most cases, the victims were not aware of what caused their symptoms and the symptoms were not telling either. We classified them as Unspecified as shown in Table 2.9-1:

Table 2.9-1 Injuries due to hazardous marine life (n=186)

Cause	n
Unspecified	101
Sea urchin	24
Coral	22
Jellyfish	18
Stingray	8
Other	13

Sea urchin spine punctures (n=24) were the most frequently identified specific cause of marine life injuries; the moment of injury is marked with pain and the spines usually break off into the diver's tissue. Similarly, coral cuts or fire coral injuries (n=22) and jellyfish stings (n=18) can be easily identified. Stingray stings were reported in eight cases. There were no details about circumstances in which this happens.

The 13 cases classified as Other causes included stings by toadfish, squirrel fish, scorpion fish, weaver fish, and sea stars. There was also one explicit report of a fish bite and two cases of suspected ciguatera poisoning.

The number of HMLI cases reported to the MSCC is likely very small in comparison to the incidence of these injuries in the general population. This may be partly because divers are protected with dive suits and also because they are better educated about HMLI than swimmers and beach goers. On the other hand, most of these injuries can be helped with a first-aid kit or by local medical providers and thus divers do not call DAN for help. Do not be fooled with the small numbers reported here. Instead, be aware of the risks, avoid contact and protect yourself, and be prepared for self-aid in case of injury.

2.10 Other conditions

Atrial fibrillation

There were eight cases of reported atrial fibrillation (AF) during or immediately after dive and in addition, 30 divers inquired about fitness to dive with AF.

Case 02-29: On a liveaboard trip in the middle of the Pacific, a 54-year-old male recreational diver completed a single uneventful dive (profile unknown) on the morning of the first day of the trip. Approximately 1:30 h:min after surfacing, he complained-of rapid, irregular heart rhythm. Another passenger, who was a physician, examined him and, using a portable electrocardiograph, determined that he was experiencing atrial fibrillation. The diver was not diagnosed previously with AF but remembers a similar transient event three to four months earlier at a time when he was not diving.
In some people, AF may cause a loss of consciousness, which is a danger that is compounded if in or around water and can result in drowning. We found two reports of AF while diving; both resulted in near-drowning accidents.

Case 02-30: An emergency room attending physician reported having in his care a 53-year-old male who was awake but disoriented, in AF and hypotensive (systolic pressure 90 mmHg). The patient had surfaced unresponsive after a 10 min dive to 57 fsw (17 msw). Cardiopulmonary resuscitation was initiated immediately upon removal from the water. The patient suffered rib fractures but regained spontaneous pulse and breathing. He was later transferred to another cardiology unit where he recovered completely.

Case 02-31: An emergency physician reported treating a 57-year-old female diver. At a depth of about 50 fsw (15 msw), she experienced dyspnea and lost consciousness. She was diabetic and had a history of AF. Although the AF had not been documented at the time, it was most likely the cause of her problems, although hypoglycemia was not ruled out.

Implanted pacemakers and defibrillators

A number of callers inquired about medical fitness to dive after receiving implanted pacemakers or defibrillators. The subset of divers who are eager to dive despite known cardiac issues is worthy of study on its own right. However, we did not receive any calls from divers who are actually diving with an implanted pacemaker or defibrillator, if it we did, it was not reported.

2.11 Conclusion

Dive specific injuries, DCS and barotrauma, are the most common causes for emergency calls to DAN, but divers call DAN also for other injuries and acute medical conditions. However, the distribution of calls by diagnosis in this statistics does not reflect the true distribution in the field. Divers are more likely to have illness or other emergency while travelling and diving than what these numbers reflect.

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3. DIVE FATALITIES

Petar J. Denoble, Jeanette P. Moore, Brittany M. Trout

3.1 Introduction

The purpose of collecting and studying injury and fatality data is to learn from past accidents and inform efforts to prevent similar accidents in the future. Fatal injuries in recreational scuba diving are rare, but there are more non-fatal injuries and even more incidents without injury (near-misses), all of which may spoil the pleasure of diving, decrease the retention of divers and affect the well-being of divers, dive operators and the entire dive industry. The relationship between participation in diving, mishaps, injuries and fatalities is represented in the pyramid of injuries, commonly used in other fields of human activities. The pyramid of injuries is shown in Figure 3.1-1.

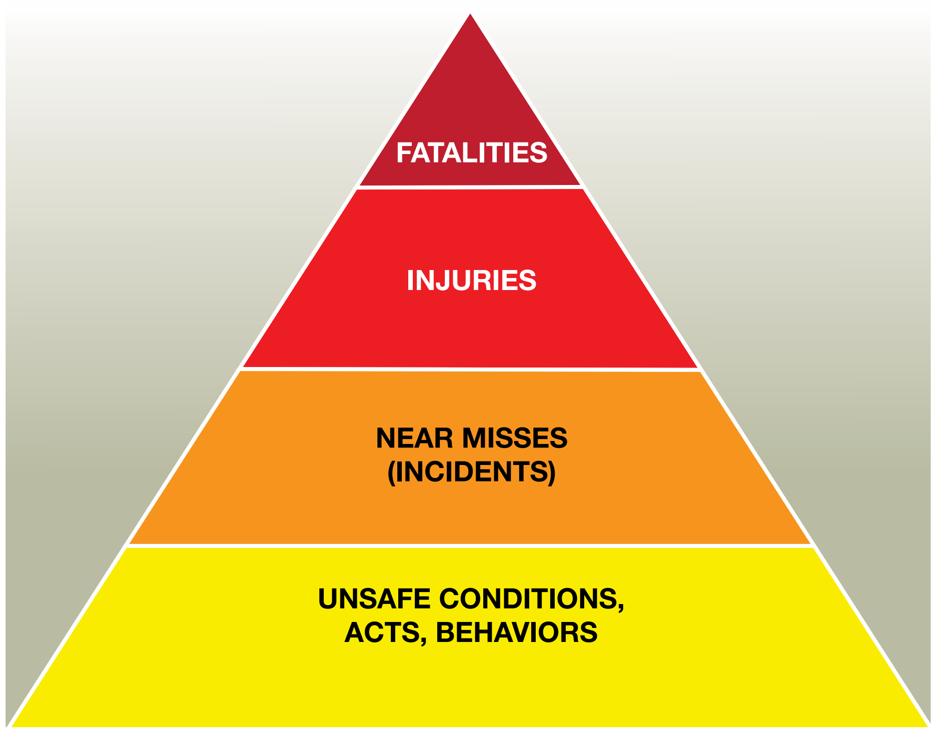

Figure 3.1-1 Pyramid of Injuries

There are many theories that try to explain injuries and preceding factors. Most incidents are built on a series of events. The removal of unsafe acts or hazardous conditions, effectively removing critical dominos, can stop the march leading to an unwanted outcome.

Our analyses of diving accidents seek to establish the relevant elements leading to an injury, with the practical purpose of identifying targets for preventive interventions.

The quality of data depends on the availability of evidence, thoroughness of the investigation and medical examination. Some of the challenges in gathering information are discussed in the data collection process section below. Another purpose of injury and fatality monitoring is to establish trends and possible effects of changing dive practices or introduce interventions into dive safety. With the small number of fatalities, this sometimes appears to be an impossible task. The variation in the rate of fatalities from year to year does not provide much information because of the natural random variation of rare events. However, the tracking of multi-year data may reveal more interesting trends. The number of fatalities by month is shown in Figure 3.2.1.

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 not tagged as follow-up since it is virtually impossible to get additional details aside from that found on news reports.

News reports, mostly online, are monitored constantly for keywords involving diving deaths and scuba. Other sources for 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; the DAN Medical Services Department usually assists in the management of any scuba diving event that is reported.

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 subjected 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 analyses.

Each state in the US has its own set of regulations regarding the release of information. Some states consider these reports to be public information and are readily released while others are governed by more stringent privacy laws. In addition, within each state, sometimes the regulations (ease in procuring reports) can also vary from county to county. Coincidentally, as many diving deaths in the US occur in Florida and California, these two states have straightforward protocols for requesting reports.

Local investigating agencies (sheriff and police departments) follow similar 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 takes longer to close cases so it may take up to two years after the incident before a case is closed and copies released. The USCG follows FOIA protocols and will not release personal information contained in their reports. A redacted copy, removing all personal and identifying information, can be requested.

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 or may be requested from the research and medical services departments. When necessary, the family of the decedent or his or her 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 can also be used by family and witnesses to report a fatality and provide additional details regarding any scuba diving fatality.

Data Entry and Analyses

DAN research maintains the scuba diving fatality data in a secure server. Once all pertinent information has 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 144 deaths involving recreational scuba diving in 2008. This is shown in Table 3.2-1. Only the deaths of 83 US and Canadian recreational divers have been actively investigated by DAN. 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	Aruba	1	0	1
	Bahamas	0	1	1
	Canada	5	0	5
	Cayman Islands	4	1	5
	Netherlands Antilles	3	2	5
	United States	66	1	67
	North America Totals	**79**	**5**	**84**
Central America	Belize	1	0	1
	Mexico	3	0	3
	Central America Totals	**4**	**0**	**4**
South America	Chile	0	2	2
	South America Totals	**0**	**2**	**2**
Europe	Cyprus	0	2	2
	Egypt	0	4	4
	France	0	1	1
	Germany	0	2	2
	Ireland	0	1	1
	Malta	0	3	3
	Netherlands	0	1	1
	Russia	0	1	1
	Scotland	0	6	6
	Spain	0	2	2
	Sweden	0	1	1
	United Kingdom	0	6	6
	Europe Totals	**0**	**30**	**30**
Japan	Japan	0	0	0
	Japan Totals	**0**	**0**	**0**
Asia-Pacific	Australia	0	6	6
	Fiji	0	2	2
	Indonesia	0	3	3
	Malaysia	0	1	1
	Maldives	0	1	1
	Micronesia	0	2	2

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

Region	Country	US & Canada Residents	Non-US & Canada Residents	All Cases
	New Caledonia	0	2	2
	New Zealand	0	2	2
	Palau	0	1	1
	Philippines	0	1	1
	Thailand	0	2	2
	Asia-Pacific Totals	**0**	**11**	**11**
South Africa	South Africa	0	1	1
	South Africa Totals	**0**	**1**	**1**
	Total	**83**	**61**	**144**

The 83 cases involved US (n=76) and Canadian (n=7) residents. Most US residents' scuba fatalities occurred in the US (66 out of 76, 87%).

Table 3.2-2 shows the geographic distribution of domestic US and Canadian fatalities by state or province. Forty-two percent of 71 US domestic scuba fatalities occurred in Florida and 11% in California.

Table 3.2-2 Number of fatalities in US and Canada by state or province in 2008 (n=71)

Accident State	2005	2006	2007	2008
Florida	17	17	32	30
California	9	11	15	8
Hawaii	3	1	5	4
Ontario	4	4	5	2
Washington	5	7	5	5
Ohio	0	0	4	0
Alaska	0	0	3	0
Massachusetts	3	1	3	3
Michigan	0	4	2	1
New Jersey	0	2	2	1
New York	4	2	2	1
North Carolina	3	1	2	1
Pennsylvania	2	0	2	0
Texas	3	0	2	1
Alabama	0	0	1	0
Alberta	0	0	1	0
British Columbia	5	2	1	2
Illinois	2	1	1	0
Indiana	0	0	1	0

Accident State	2005	2006	2007	2008
Manitoba	0	0	1	0
Newfoundland	0	1	1	0
Rhode Island	0	0	1	2
Utah	0	0	1	0
Connecticut	1	0	0	0
Georgia	0	0	0	1
Lousiana	0	1	0	0
Maine	1	2	0	2
Minnesota	0	1	0	0
Nevada	0	0	0	1
New Hampshire	0	0	0	1
Nova Scotia	3	0	0	1
Oregon	1	0	0	0
Quebec	0	1	0	0
South Carolina	1	0	0	1
Vermont	1	0	0	0
Virginia	0	0	0	1
Wisconsin	0	0	0	2
Total	**68**	**59**	**93**	**71**

Figure 3.2-1 shows the months of death for fatalities in 2008 and average number of fatalities in 2004-2007. While the peak was in July, in 2008 the October and November counts reached or exceeded June and August counts.

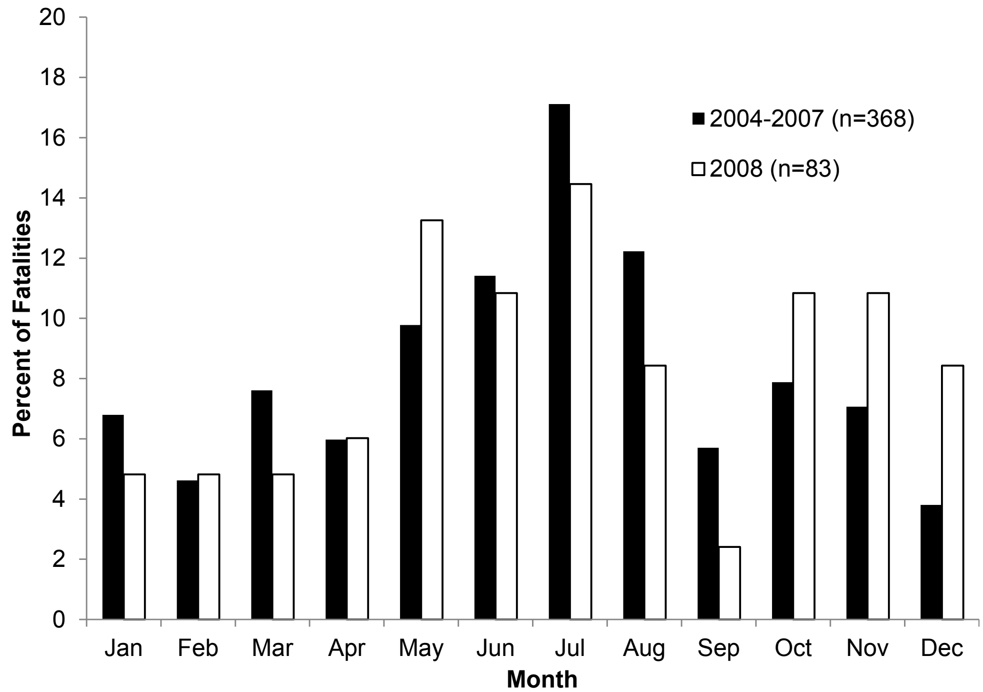

Figure 3.2-1 Monthly distribution of diver deaths

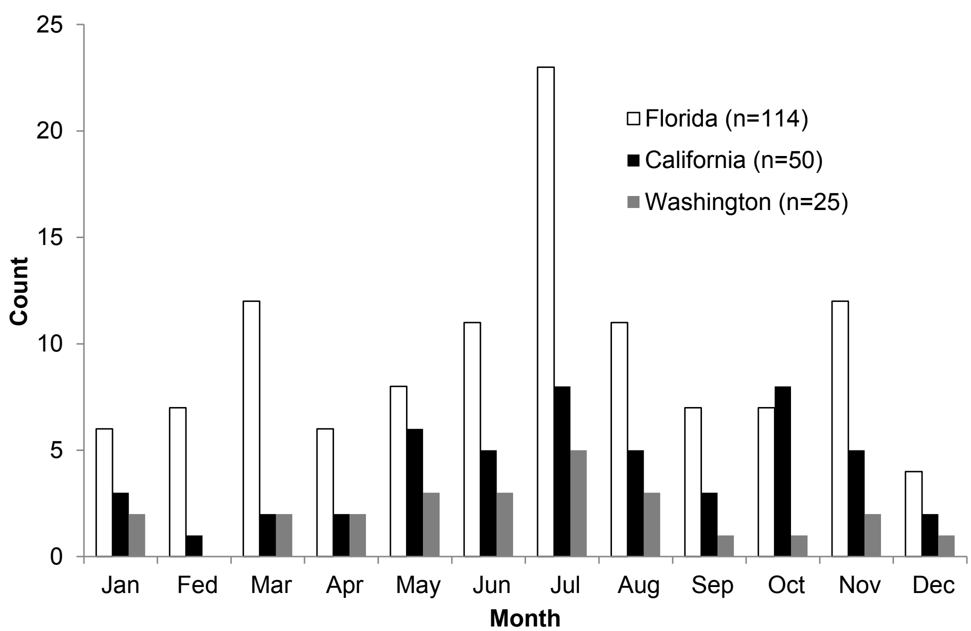

Figure 3.2-2 Month of accident by states with the most diving fatalities in 2004-2008

3.3 Source of information

Eyewitness reports were available for 49 cases. Twenty-five cases were not witnessed and for 11 cases, the witnesses may have been present but did not come forward.

Autopsies were conducted in 53 out of 83 US and Canadian cases, and medical examiner reports were available for 43 cases as shown in Table 3.3.1. Coroner summaries were available for three cases and one case included a death certificate. The body of the decedent was not recovered in two cases. An autopsy was not performed in three cases. It was unknown if an autopsy was performed in 21 cases. Witness reports were obtained in 49 cases (59%), 23 cases (28%) occurred without a witness and for 11 cases (13%) there were no data.

Table 3.3.1 Medical examination data (n=83)

ME reports available	43
Autopsy conducted, report not available	10
Coroner summaries	3
Death certificate	1
Autopsy not performed	3
Body not recovered	2
Unknown/Missing	21

3.4 Age and Health of Decedents

Figure 3.4-1 shows the age distribution for dive fatalities. Eighty-one percent of the victims were male and 19% female. Seventy-five percent of the male victims and 65% of the female victims were 40 years or older. Fifty-one percent of male victims 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.

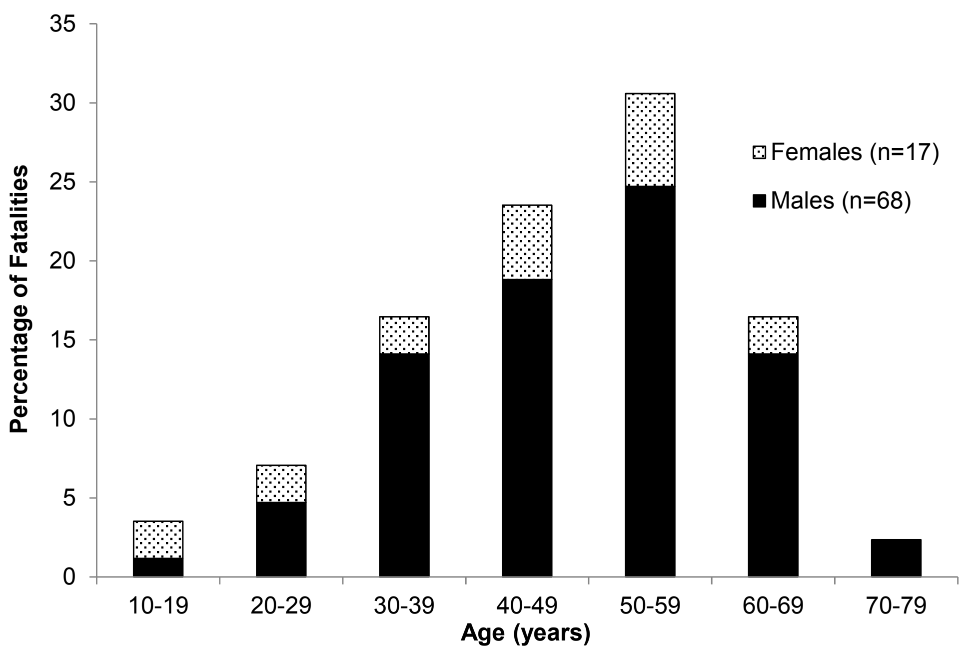

Figure 3.4-1 Distribution of fatalities by age and sex (n=83)

There were two teenagers among the victims. One 19-year-old female had participated in an advanced university biology class. She had dived with a buddy to 60 fsw (18 msw) and upon ascending to a safety stop, she disappeared.

Another teenager was a 16-year-old female participating in an open water class. Her father, a certified diver, was her buddy. They made a single dive to 26 fsw (8 msw) and performed buddy breathing and emergency ascent exercises. When she and her father surfaced, she was heard to have yelled something and then lost consciousness. She was pulled from the water onto the boat and cardiopulmonary resuscitation was started. She was transported to the hospital where she was pronounced dead. The medical examiner established barotrauma (cerebral arterial gas embolism [CAGE]) as the cause of death.

Medical history was in most cases incomplete. The most frequently revealed medical conditions in decedents were hypertension (n=11; 13%), heart disease (n=10; 12%) and diabetes (n=7; 8.4%).

Table 3.4-1 Known medical history of decedents

Current Medical Condition	n	%
Hypertension	11	13.3
Cardiovascular disease	10	12.0
Diabetes	7	8.4
Depression	2	2.4
Nervous System	2	2.4
Asthma	1	1.2
Back Pain	1	1.2
Lung Disease	1	1.2

The true prevalence of hypertension 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 10 cases with known heart disease, only three cases had explicit information about passing a medical exam.

One 58-year-old male, with a history of heart disease and coronary angioplasty four to five years earlier, was reportedly cleared to dive by his physician, but it is not known when. He was diving with his wife in tropical waters. On their third day of diving, he surfaced after an uneventful dive and controlled ascent when he became unresponsive at the surface and died of sudden cardiac death (SCD).

Another victim with a known history of heart disease was a 77-year-old male, an experienced instructor. He had seen his doctor about one year prior for dizzy spells. It is not clear whether he was cleared to dive by the physician. He was going to dive with a buddy from shore, but when they got to the sand bank, they aborted the dive as the sea was too choppy. They started swimming back to shore when the victim lost consciousness. An autopsy revealed a dilated cardiomyopathy, and the family indicated a history of irregular heart rhythm. Dizzy spells are a contraindication for diving and should prompt an extensive medical evaluation for arrhythmias.

The third case with recent medical exam involved a 61-year-old instructor. He had a myocardial infarction at age 42 and a left femoral bypass. He was on medication for high cholesterol. Medical records reveal that he had a narrowing of the coronary artery (left anterior descending branch) for which he underwent balloon angioplasty. Two months prior to the accident, he underwent a stress test which was interpreted by the cardiologist as abnormal. The test was positive for ischemia. However, the absence of symptoms or functional limitations suggested that no change in his therapy was needed. It is not known what advice the diver may have received regarding his fitness to dive. Symptoms did develop soon after the stress test; the diver reported feeling dizzy while teaching a class two to three weeks prior to the accident. He also complained of right side chest pain and of feeling dizzy a week before his death. Regardless of any possible advice from his physician, the newly developed symptoms required self-exclusion from diving and a review of symptoms with his physician. Instead, the diver ignored the symptoms and continued diving.

Observing symptoms could have prevented the premature death of this 55-year-old diver who died of SCD while diving with four other family members. His medical history included coronary heart disease, a heart operation three years before his death, hypertension, smoking up to three packs per day for 30 years, marijuana and alcohol use. He experienced chest pains after he jumped in a lake two years previously. Six months later, he experienced chest pain during a dive to 85 ft (26 m). These two episodes should have prompted him to abstain from diving and to seek medical evaluation

Diabetes was a known medical condition in seven of the fatality victims. The age of decedents ranged from 42 to 67 years. Four had known heart disease and three with no known history of cardiovascular diseases, but the medical examiner found post-mortem signs of advanced heart disease in all three cases. It is not known whether these divers had medical clearance for diving. Subjects with diabetes and known cardiac disease would probably not be medically cleared to dive.

One 67-year-old diver with diabetes, congestive heart disease, an implanted pacemaker and an extensive list of medications drowned after he rapidly exhausted his air supply in an innocuous dive and surfaced out of air.

A 61-year-old victim had a known diagnosis of diabetes and hyperlipidemia. He died of SCD while swimming at surface without submerging. Autopsy revealed a 95% narrowing of his coronary arteries. While he may have been asymptomatic, proper medical examination including the stress test would have revealed pure exercise tolerance.

One victim was a 57-year-old male with a history of Type I diabetes for 40 years, coronary artery disease, hypertension, a myocardial infarction five months before the accident, and amputation of half of both of his feet due to diabetes-associated peripheral vascular disease. He became unresponsive while readying his scuba gear at the surface and drowned.

Diabetes affects 26 million people of all ages or 8.3% of the US population (19 million diagnosed and 7.0 million undiagnosed). Among people 20 years or older, the prevalence of diabetes is 11% and among 65 years and older it is 27%. It is known that diabetes is an independent risk factor for coronary heart disease (CHD). Moreover, myocardial ischemia due to coronary atherosclerosis commonly occurs without symptoms in patients with diabetes. As a result, multi-vessel atherosclerosis is often present before ischemic symptoms occur and before treatment is begun. A delayed recognition of various forms of CHD undoubtedly increases the risk of dying while diving for older divers with diabetes. Among individuals with diabetes, cardiovascular disease (CVD) is the leading cause of morbidity and mortality; adults with diabetes have a two- to four-fold greater risk of CVD compared to those without diabetes. Diabetes is often associated with hypertension. In 2005-2008, of adults ages 20 years or older with self-reported diabetes, 67% had blood pressure greater than or equal to 140/90 mmHg or used prescription medications for hypertension (NIH Publication 2011).

About 60-70% of people with diabetes have mild to severe forms of nervous system damage. The results of such damage include impaired sensation or pain in the feet or hands, slowed digestion of food in the stomach, carpal tunnel syndrome, erectile dysfunction, or other nerve problems. Almost 30% of people with diabetes ages 40 years or older have impaired sensation in the feet, for example, at least one area that lacks feeling. Severe forms of diabetic nerve disease are a major contributing cause of lower-extremity amputations (American Diabetes Association 2009).

Another form of diabetic neuropathy is cardiovascular autonomic neuropathy (CAN), which includes damage to the autonomic nerves that innervate the heart and blood vessels. This causes autonomic dysfunction which impairs exercise tolerance by reducing the increase in heart rate, blood pressure, and cardiac output in response to exercise. Thus, subjects with CAN may reach hazardous levels of exercise and suffer myocardial ischemia before their heart rate achieves the expected maximum for their age. In controlling their exercise, subjects with CAN have to rely on their perceived exertion, not heart rate. Diabetic patients who are likely to have CAN should be tested for cardiac stress before undertaking an exercise program (Vinik and Ziegler 2007).

Divers with diabetes and their physicians must consider these facts when deciding about conditions for their participation (Pollock et al. 2007).

Body mass index (BMI) was available in 49 victims as shown in Figure 3.4-2. Eleven (22%) were classified as normal weight (18.5-24.9 kg·m^{-2}), 23 (47%) as overweight (25.0-29.9 kg·m^{-2}), 12 (24%) as obese (30.0-39.9 kg·m^{-2}) and 2 (4%) as morbidly obese (≥40 kg·m^{-2}). One teenage girl and one 51-year-old woman had BMI values below 18 kg·m^{-2}.

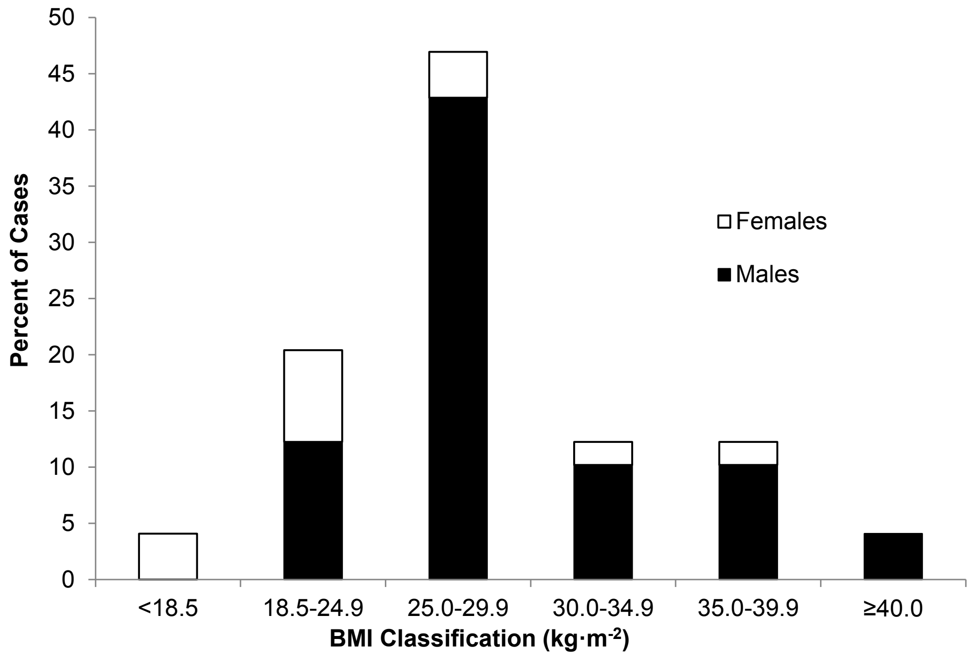

Figure 3.4-2 Classification of fatalities by BMI (n=49)

A history of asthma was known in one victim. It was a 33-year-old male who used an inhaler on an as-needed basis. He smoked about one pack of cigarettes per day and used marijuana. He went spearfishing with equipment that he was not familiar with. He dived solo, apparently ran out of air and drowned. This unnecessary death was a result of risky behavior, which appears to be a personality trait in this case.

3.5 Diving Certification and Experience

Information about certification was available in only 41 cases as shown in Table 3.5-1. Six victims were students on their first open water dive. The youngest victim was a 16-year-old girl. The ages of the other students who died were between 49 and 69 years. Two deaths appear to be related to pulmonary barotrauma and cerebral arterial gas embolism (CAGE). Two cases were likely sudden cardiac deaths. In one case, the female student aspirated saltwater and was later found unconscious. The cause of death was declared as drowning.

Most victims had basic open water diving certification (n=14) but there were also six instructors, four master divers or assistant instructors and four divers with technical certifications.

Table 3.5-1 Diving certifications of fatality cases (n=83)

Certification	Count
Student	6
Basic/Open water	14
Advanced/Specialty	4
Rescue	1
Master Diver /Asst. Instructor	4
Instructor and above	6
Technical	4
Scientific	1
Other	1
Unknown	42

The experience of divers as indicated by the number of years since certification was known in only 23 cases. The details are shown in Figure 3.5-1.

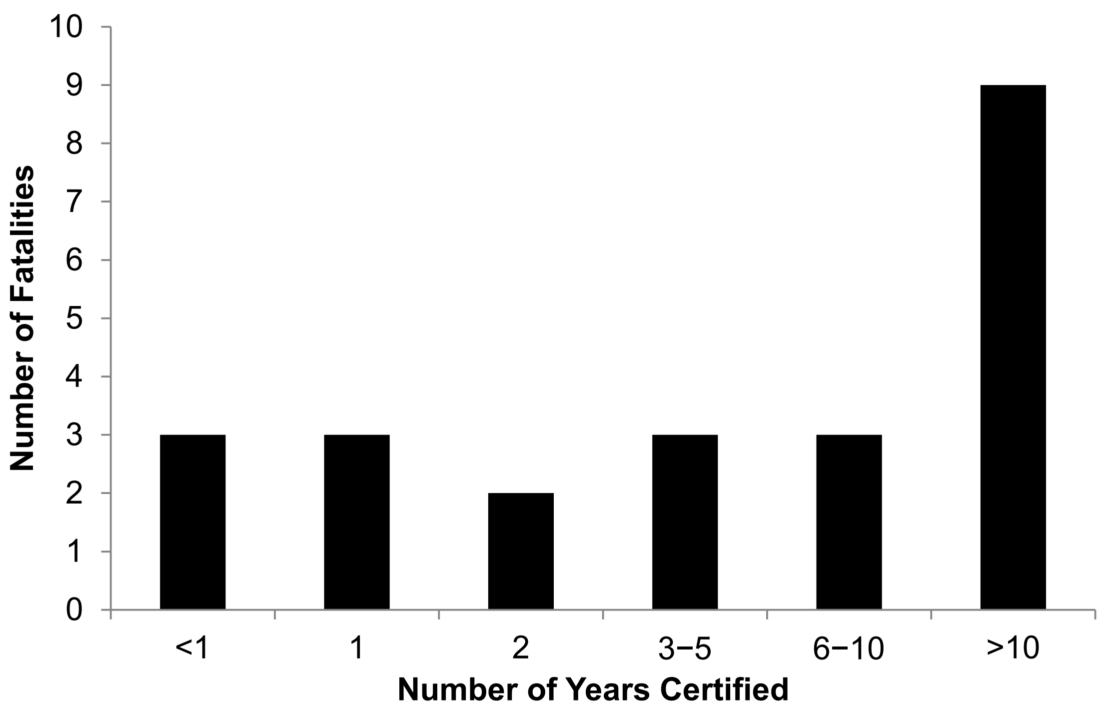

Figure 3.5-1 Number of years since initial certification of divers who died (n=23)

3.6 Characteristics of Dives

Figure 3.6-1 shows the type of diving activity during the accident. Information was available for 81 cases. Fifty-three (65% of known cases) of the fatal dives involved pleasure or sightseeing, 12 cases (15% of known cases) involved spearfishing, hunting or collecting game, 11 (14% of known cases) involved training, and two photography, one personal task, one scientific and one other.

All 12 victims who died while engaged in harvesting or spearfishing were males between 22 and 65 years of age. Four of these deaths occurred during mini-lobster season in Florida. In six cases, victims obviously ran out of air while at depth. One of them suffered fatal DCS after ascending directly to the surface from 165 ft (50 m) depth. Most cases involved solo diving.

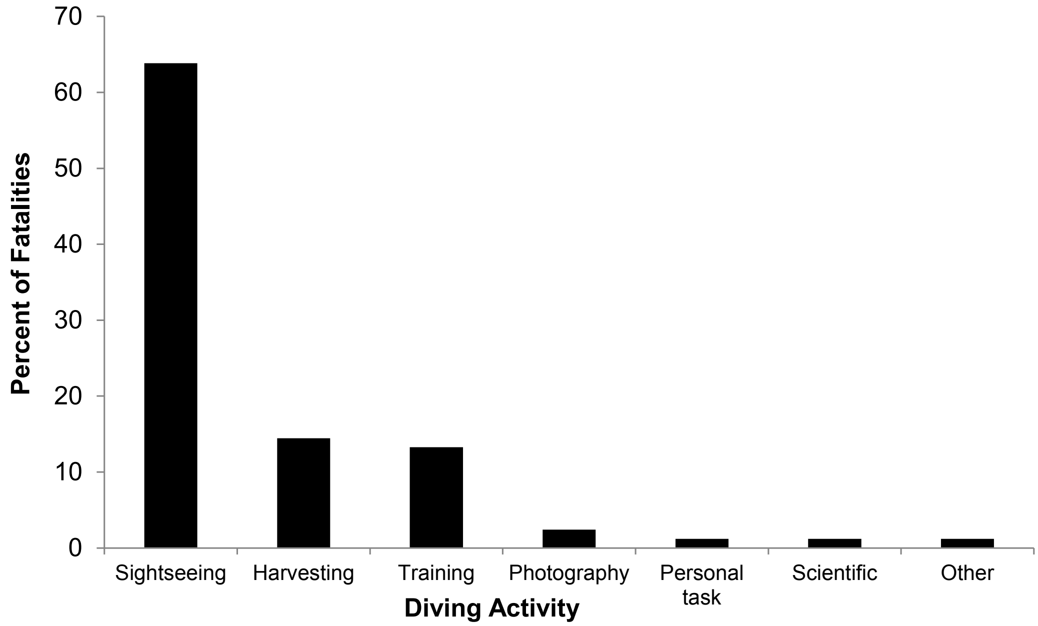

Figure 3.6-1 Primary task associated with fatal dives (n=81)

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=46; 55% of known cases), consistent with previous reports. Dives began from shore in 34 cases (41% of known cases), from a pier in two and a liveaboard in one case.

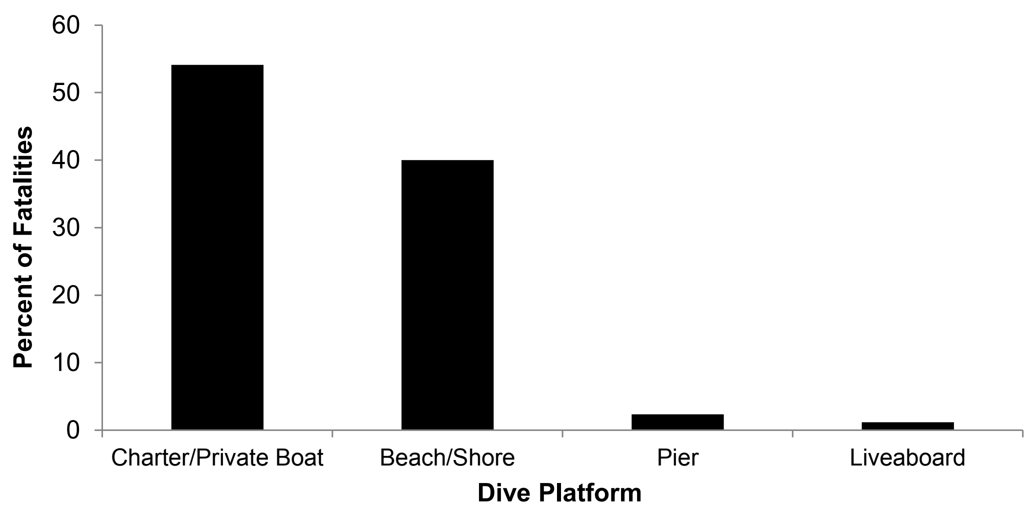

Figure 3.6-2 Point of deployment for fatal dives (n=83)

Most dives occurred in ocean/sea environment (n=66), with a significant numbers occurring in stationary fresh water (n=9) and rivers (n=10). Out of 10 cases that occurred in rivers or springs, eight occurred in Florida (seven in caves), one in New York and one in Ontario, both while wreck diving in the St. Lawrence River. Stationary freshwater cases occurred in various lakes in eight different states.

Visibility was reported in 31 cases. It was excellent in six, moderate (10-50 ft [3-15 m]) in 15 and poor (<10 ft [<3 m]) in 10 cases. Some dive sites have poor visibility most of the time, but inexperienced divers may not appreciate the risks involved. One such case is a fatality involving a father (45 years) and son (19 years). The father was certified one year before the accident but had not dived since. His son had the same experience and certification level. They did not have a particular dive plan. They swam out from shore and submerged to about 150 fsw (46 msw) in poor visibility. The father ran out of air at depth and started sharing air with his son but the son's air also soon ran out. They both started a free, rapid ascent to the surface. At approximately 40 fsw (12 msw), the son saw his father start sinking. He surfaced and called for help. The son was taken for hyperbaric treatment. The victim's body was recovered later that afternoon. In this case two inexperienced divers went diving for no particular purpose, in bad conditions and deeper than would be reasonably safe even for more experienced divers.

Water condition (sea state) was reported in 32 cases (39% of total). Rough seas were reported in 10 cases. Currents were described as strong in 12 cases.

Information about **protective suits** worn by divers was available in 49 cases (59% of total). Thirty-four of the victims wore wetsuits and 12 wore drysuits. Drysuit did not appear to be part of the problem in any of the 12 fatalities. Most of the fatalities involving drysuits occurred in cave, wreck and deep diving.

Figure 3.6-3 shows the **maximum dive depth** reported for known cases (n=59; 71% of total). Seven cases occurred while preparing to dive or swimming at the surface toward the descent point. Twenty fatalities involved diving to 60 fsw (18 msw) and 20 deeper than 60 fsw (18 msw). The maximum dive depth of a reported fatal dive was 270 fsw (82 msw).

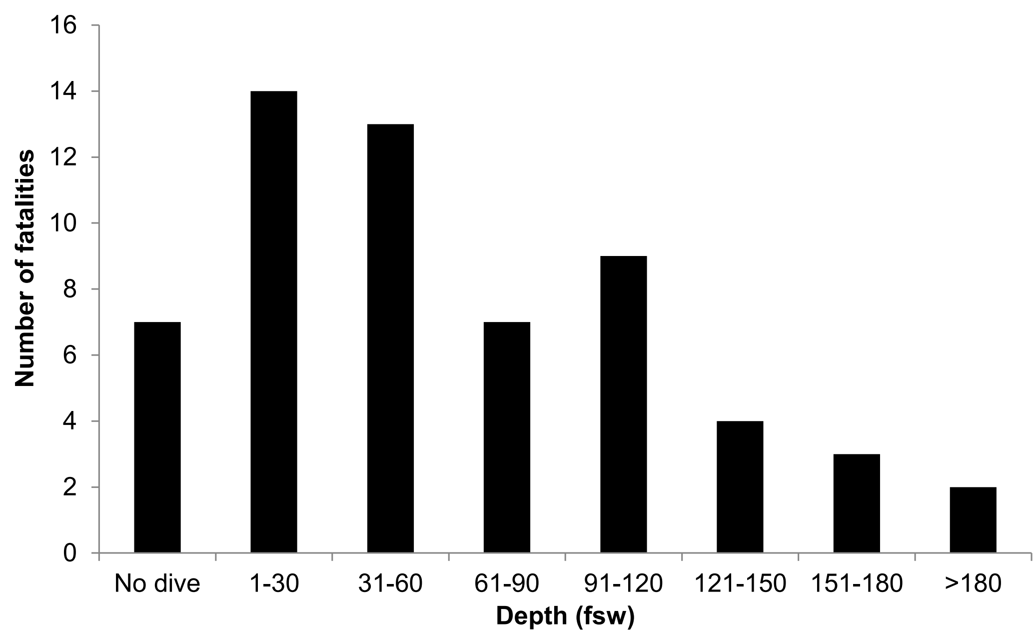

Figure 3.6-3 Maximum depth distribution of fatal dives (n=59)

Fourteen 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.

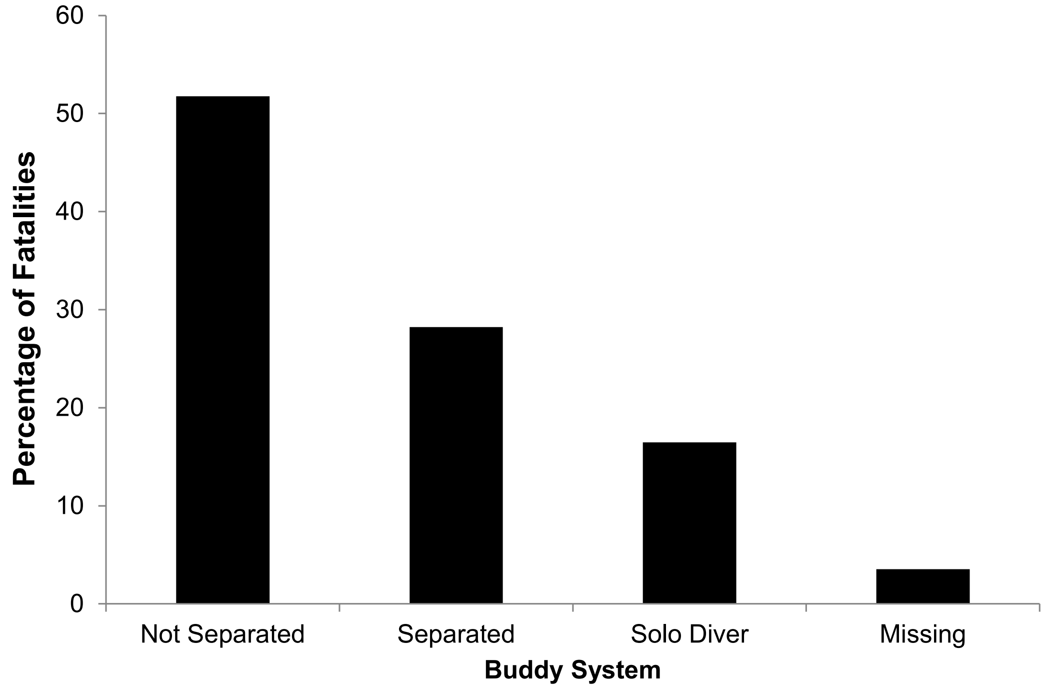

Figure 3.6-4 Support system used in fatal dives (n=83)

Open-circuit scuba was used in 76 cases (92%), rebreathers in six and surface-supply in one case. One rebreather fatality occurred on US territory, but the victim was a Swiss citizen. At least 12 more rebreather fatalities occurred worldwide in 2008.

Breathing gas was compressed air in 46 (55%) cases, enriched air nitrox was used with scuba in 12 (14%) cases, and trimix in one case. Rebreathers used unspecified gas mixes. Information was not available in 23 cases (28%).

3.7 Analyses 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.

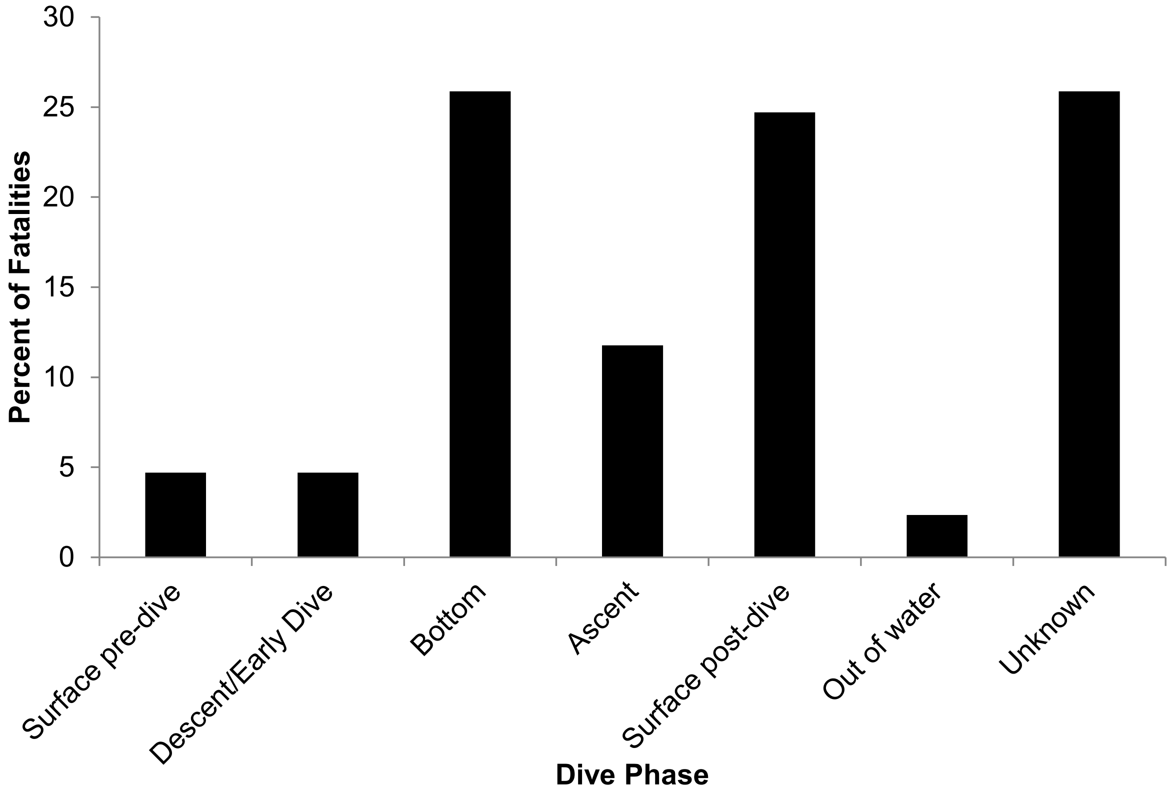

Figure 3.7.1-1 Dive phase when it became obvious that the diver had a problem (n=83)

The accident description was available in 61 cases (73% of total). Problems developed prior to descent in four cases (4.8% of known), during descent in four cases (4.8% of known), on the bottom in 22 cases (27% of known), during ascent in 9 cases (11% of known), at the surface post-dive in 20 cases (24% of known) and after exiting water in two cases.

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

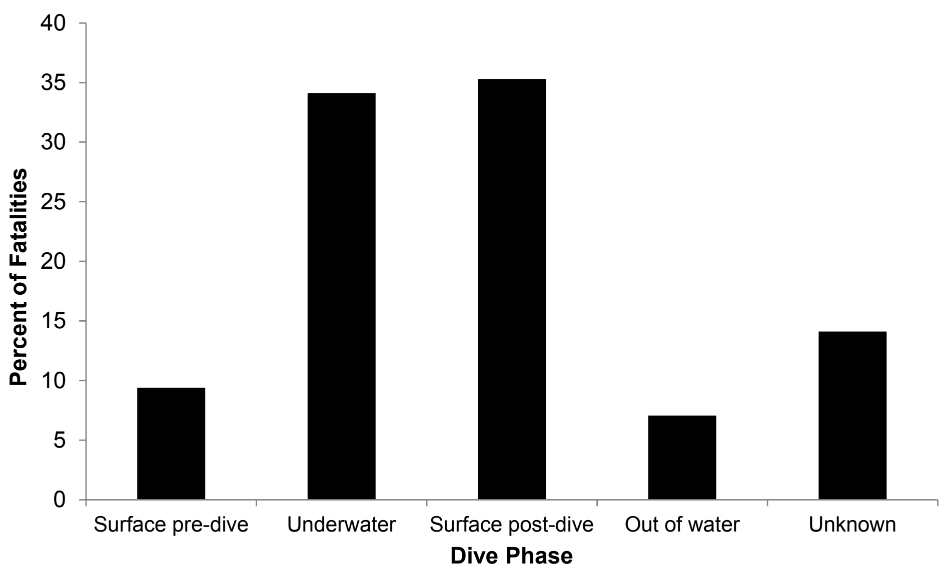

Figure 3.7.1-2 Dive phase when diver lost consciousness (n=83)

The point at which the victim lost consciousness was reported in 71 cases (86% of total). Most victims (n=29; 41% of known 71) lost consciousness upon surfacing. The victims were reported to have lost consciousness underwater in 28 cases (39% of known 71), at the surface before they submerged in eight cases (11% of known 71), and after exiting the water post-dive in six cases (8.4% of known 71).

Out of the eight cases that occurred pre-dive, seven victims were diving from shore and one from a private boat. One victim seemed to have drowned after starting the dive with an empty tank. Seven victims appear to have died from SCD. Of the seven victims who died from SCD, four died while fighting rough waters, two in relatively calm waters, and one was still ashore while preparing for the dive.

Thirty victims lost consciousness at the surface post-dive. CAGE was suspected in 10 cases, cardiac related death in five and in one case, death may have been related to severe decompression from 170 fsw (52 msw) on a 55 min dive.
Six victims lost consciousness upon exiting the water. In three cases, the suspected cause of death was SCD, pulmonary embolism in one and CAGE in another. One lost consciousness shortly after climbing aboard after a dive to 164 fsw (50 msw) for 25 min in which obligatory decompression was omitted due to running out of air.

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 due to missing information and an inconclusive investigation. Based on available data, the most common known triggers were running out of breathing gas (n=13) and rough seas (n=8) (Table 3.7.2-1).

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

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

The most common known harmful events were rapid ascent (n=16) and exertion (n=13) (Table 3.7.2-2).

Table 3.7.2-2 Harmful events (n=83)

Harmful Event	Count
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 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.

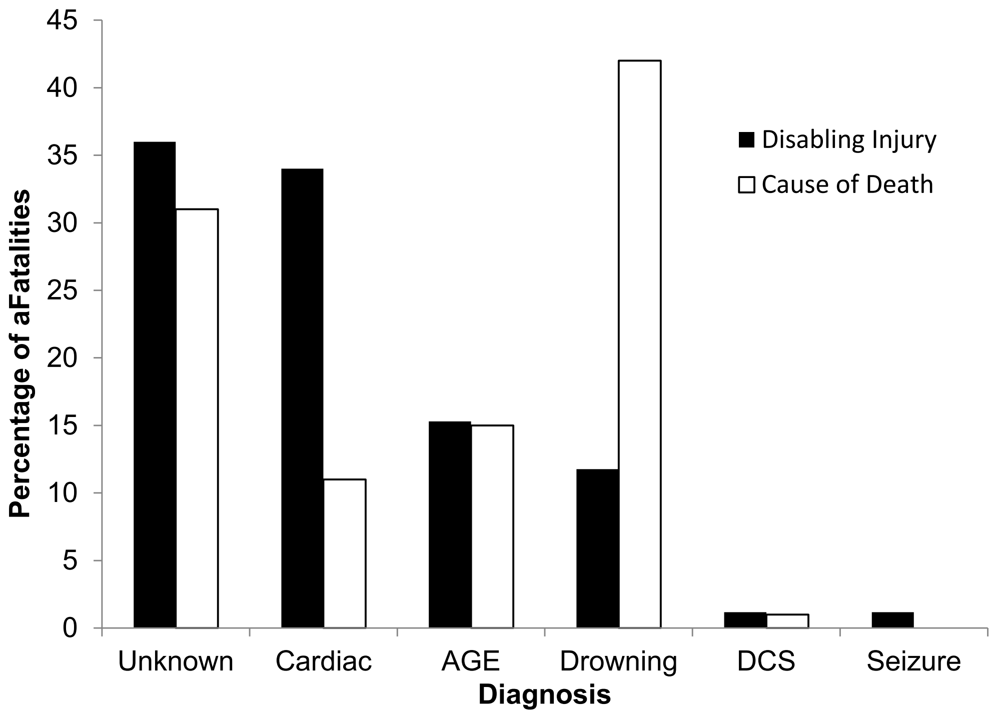

Figure 3.7.2-1. Distribution of disabling injuries (n=83)

3.8 Rebreather Fatalities

In 2008, we learned about 19 fatalities involving rebreathers. The distribution of rebreather fatalities by country is shown on Table 3.8-1. DAN attempted follow-up in six cases occurring in the USA.

Table 3.8-1 Number of rebreather fatalities by country

Country	2006	2007	2008	Country	2006	2007	2008
USA	6	3	6	Greece		1	
Canada		1	2	Spain		1	
UK	5	4	2	Egypt	1	1	1
France		2	2	South Africa		1	
Italy	3	2	1	Israel			1
Croatia	2		1	Micronesia			1
Germany	1		1	Japan		1	
Ireland		2		Thailand	1		
Switzerland		2		Australia	1		
Belgium	1			New Zealand			1
Norway	1			**Total**	**22**	**21**	**19**

08-650 Cause of Death: Myocardial Infarction

Limited information is available for this case since an official investigation was not conducted. The decedent, in his fifties, was a technical diver for more than 20 years and had well over 3,000 dives. He was diving in a lake, participating in a training course using a rebreather he had recently purchased. At 107 fsw (33 msw) he signaled to the instructor to abort the dive. He switched to his bailout bottle at 70 fsw (21 msw) after indicating he did not feel well, and at 30 fsw (9 msw) he lost consciousness. An autopsy was performed; however, the official report was unavailable. According to a statement made by the coroner's office, the cause of death was myocardial infarction and manner of death was natural, therefore no official investigation was conducted. Due to limited information regarding the incident, it is speculated the myocardial infarction began during the dive and then progressed.

08-580 Cause of Death: Suspected Arterial Gas Embolism

The victim was in his forties and an experienced diver. He and his dive buddy dived to 200-240 fsw (61-73 msw) and completed the wreck portion of the planned dive in strong currents. After ascending normally to 100 fsw (30 msw) for the first decompression stop, the victim went into distress of undetermined cause as reported by the dive buddy. The decedent bailed out to open-circuit and ascended directly to the surface. More than 30 min of decompression obligation was omitted. A surface attendant spotted him immediately and the victim was reached within 90 s. He seemed conscious, but was not responsive. The victim appeared to have lost consciousness as he was being towed to the dive boat by fellow divers. He never regained consciousness. Autopsy results were not available; however, a preliminary report described a lung expansion injury due to rapid ascent and a possible cardiac incident. The suspected cause of death includes arterial gas embolism.

08-211 Cause of Death: Asphyxia due to Drowning due to Insufficient Air

An experienced rebreather instructor in his early fifties completed a 140 fsw (43 msw) dive to a wreck earlier in the day. The second dive of the series was a reef dive to 60 fsw (18 msw). The surface interval between the two dives was not reported. While at depth, the decedent signaled to his dive buddy that he was out of breathing gas and lost consciousness. The dive buddy reported that he could hear the alarm on the decedent's rebreather unit as he brought the unconscious diver to the surface. Cardiopulmonary resuscitation was administered at the surface. The medical examiner concluded that the victim died as a result of asphyxia due to drowning. His medical history included obesity (BMI=30.3 $kg \cdot m^{-2}$), minor cardiac arrest, and smoking. Myocardial scarring and atherosclerotic coronary artery were reported as contributory causes. According to an investigator, the decedent did not conduct a pre-dive check to make sure all of his equipment was working properly. The equipment inspection found the oxygen valve was closed. It was concluded that the decedent's oxygen tank valve was not opened fully prior to entering the water for his second dive. The dive profile from the victim's dive computer would be very helpful in establishing additional root causes and their relative contribution to this death, but in this case, it was not available to DAN.

08-587 Cause of Death: Air Embolism Secondary to a Dive Accident

This 60-year-old, experienced diver had a medical history that included kidney and liver disease and a kidney transplant. He was reported to be in his normal state of health before the dive. He went diving with a buddy to a shipwreck located at a depth of 130 fsw (40 msw). Both divers stopped on the descent line at 30 fsw (9 msw) before continuing to a maximum depth of 110 fsw (34 msw). The total dive time was 46 min.

Here is the abbreviated incident account from the rescue diver: *"I grabbed the unconscious diver by his rebreather harness and rotated him onto his back and alerted the personnel on the boat to pull us in. In-water rescue breathing was not attempted because it would delay rescue onto the boat and delay CPR. I grabbed hold of the strap on top of the diver's rebreather and the tag line and assisted pulling the unconscious diver aboard the boat.*

"Medical personnel on board included a physician and two paramedics who offered assistance and assessed the victim. Personnel aboard the dive boat readied the onboard oxygen for use. I entered the water to recover the conscious diver who was not in distress and assisted him aboard. At this time, I heard that the unconscious diver had a thready pulse (a scarcely perceptible and commonly rapid pulse that feels like a fine mobile thread under a palpating finger) and agonal breathing (abnormal breathing characterized by gasping). The victim was monitored for a couple of minutes and reassessed to have no pulse and not breathing, therefore CPR was resumed. The AED [automated external defibrillator] advised no shock. High flow oxygen was administered at 25 $L \cdot min^{-1}$. Several providers rotated through CPR to relieve each other as needed.

"The victim's dive buddy reported they could not find the ascent line but continued to freely ascend up to 50 fsw (15 msw) to complete a safety stop. At 40 fsw (12 msw) the victim became buoyant and began a runaway ascent. The diver recovered at approximately 20-30 fsw (6-9 fsw) and descended to approximately 70 fsw (21 msw). The victim signaled OK and showed no signs of distress. Shortly after signaling, the dive buddy noticed the victim fumbling for his bailout bottle. The victim was able to switch to his bailout bottle and completed a normal controlled ascent to the surface. On the surface, the dive buddy reported the victim was alert, oriented, and indicated no signs of distress. The dive buddy realized they had surfaced far from their boat and turned to advise the victim they should swim to an approaching dive boat when he noticed the victim was unresponsive and face down in the water. The diver inflated the victim's BCD while divers aboard the dive boat assisted in getting both divers aboard. CPR was administered until Coast Guard arrived. The victim's equipment was inspected onboard by dive staff and all valves were found to be fully opened."

The US Navy Experimental Dive Unit (NEDU) inspected the equipment and reported saltwater intrusion into the electronic housing. The reported autopsy findings included cardiomegaly with concentric left ventricular hypertrophy consistent with hypertensive cardiovascular disease, emphysema and chronic pyelonephritis. The significance of cardiomegaly as possible contributing factor in this case is not clear. The cause of death established by the medical examiner was air embolism secondary to the dive accident.

08-643 Cause of Death: Drowning due to Faulty Equipment

This 40-year-old male diver was experienced in both technical and cave diving. He had completed 150 dives in the last year, had more than 400 lifetime dives and had no significant medical history. The dive buddy and the victim had previously completed more than 10 cave dives together. On the dive when the incident occurred, both the victim and the dive buddy used open-circuit equipment. The dive buddy reported witnessing the decedent complete all pre-dive preparations with his equipment, test his breathing gas, and label every tank with the correct breathing gas configurations. The victim reported to the dive buddy prior to the start of the dive that his oxygen sensors were more than 1.5 years old, but still usable. Both divers were using scooters during the dive; the victim recently repaired his scooter and was not comfortable using it past 3,300 ft (1,006 m) into the cave. After entering the cave, the victim signaled his scooter was malfunctioning, and both divers abandoned their scooters and continued the dive.

Approximately 55 min into the dive and more than 1,500 ft (457 m) into the cave, the dive buddy reported the victim swam in place as a significant amount of bubbles surrounded his head. The dive buddy used a light to signal the victim, but the victim appeared to be unable to signal back since his movements seemed uncoordinated. The victim quickly swam toward the entrance and then stopped. When the dive buddy reached him in several seconds, the victim's movements were erratic, his mouthpiece was not in his mouth, and the loop was floating above his head. The dive buddy immediately deployed and placed the bailout regulator in the victim's mouth. The victim did not attempt to breathe from the regulator. The dive buddy held the regulator in the victim's mouth and continuously purged it in an attempt to get the victim to breathe. After 15 min the victim remained unresponsive, and the dive buddy began to ascend to prevent compromising his own safety and breathing gas supply. After performing an eight-minute decompression stop at 88 min into the dive, followed by two minutes of decompression on oxygen, the dive buddy ascended to the surface. He got the attention of divers on a dive boat who then called 911.

The dive profile from the victim's dive computer recorded a descent to 39 fsw (12 msw) for 10 min followed by a descent to 92 fsw (28 msw) and maintained a depth between 89-98 fsw (27-30 msw) for approximately 12 min. The diver began a slow ascent and reached approximately 66 fsw (20 msw) after 35 min. At 60 min after the start of the dive, the depth remained fixed at 66 fsw (20 msw), and the dive computer indicated the consumption of oxygen ceased. After 85 min the depth increased to 95 fsw (29 msw) before it decreased to the surface, as the body was taken back through the cave toward the exit.

According to the autopsy report, the cause of death was drowning and the manner of death was ruled an accident. The diver's equipment was inspected by NEDU. The equipment test findings indicated two primary faults with the rebreather: excessive age of the oxygen sensors with resulting significant nonlinearity and improper assembly of the solenoid-controlled oxygen add-valve. NEDU reported it is unlikely the target partial pressure of oxygen (PO_2) would have been accurately maintained given the oxygen sensor's significant age. Through further inspection, NEDU concluded the oxygen isolation valve was intentionally closed to prevent gas from free flowing through the non-functional solenoid controlled add-valve into the breathing loop. Deep scratch marks on the isolation valve suggest it may have unintentionally switched from closed to open as the victim swam through narrow cave passages. The breathing gas analysis concluded no contamination.

The investigative report suggests that unintentionally closing the isolation valve could have led to a rapid rise in the PO_2. A hyperoxic condition, which can lead to convulsions and unconsciousness, may have existed due to the significantly aged oxygen sensors. Changes in depth and exertion level can also contribute to altered PO_2 levels.
Contributing factors in this case include equipment issues, specifically, significantly aged oxygen sensors.

08-829 Cause of Death: Drowning due to Myocarditis
The decedent was a certified technical and experienced diver in his thirties. He was diving from a commercial dive boat to a shipwreck at a maximum depth of 240 fsw (73 msw). According to court documents, on his second dive of the day he went solo and lost consciousness underwater. The body was recovered on the bottom near the wreck by crew members and other divers from the dive boat. A physician aboard the dive boat reported the victim's equipment was improperly configured. It is suspected that the rebreather unit flooded and the diver did not have a sufficient gas supply to maintain buoyancy. According to the autopsy report, the cause of death was myocarditis and the manner of death was natural.

For more information, visit the Diving Incidents section of the DAN website: http://www.diversalertnetwork.org/incidents/

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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 decade. 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 May 2014)

Discipline	Description	Record Performance Male	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	738 (225)	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)	226 (69)
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 back-ups when pushing their limits. Educational efforts are critical even when little equipment is needed to use breath-hold techniques. The absence of equipment should not be equated to inherent safety.

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 2008 (mean±standard deviation) was 54±19 (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 2008

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 80 cases were captured in 2008, 64 fatal (80%) and 16 non-fatal (20%). The number of fatalities jumped from 58 in the previous year, but it cannot be determined if this reflects an increase in the number of events or improvements in reporting and/or case capture.

Incidents were reported from 28 different countries, up from 22 in the previous year. Half (n=40; 50%) occurred in the US, distributed between nine states or territories. Multiple events occurred in three states: Hawaii (13 cases; 33%), Florida (12 cases; 30%) and California (nine cases; 23%). 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=75; 94%). Two cases occurred in a swimming pool, and one each in a lake and a river.

The primary activity of incident victims was most commonly described as snorkeling (n=39; 49%). Spearfishing and free-diving were tied with 14 cases (18%) each, followed by collecting with 12 cases (15%). 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 2008 cases. The majority of victims were male (n=73; 94% of 78 with known sex). The mean age (±standard deviation) was 43±17 years, ranging from five to 82 years (in cases with known age; n=76). The mean age has increased by one year in each of the last two years.

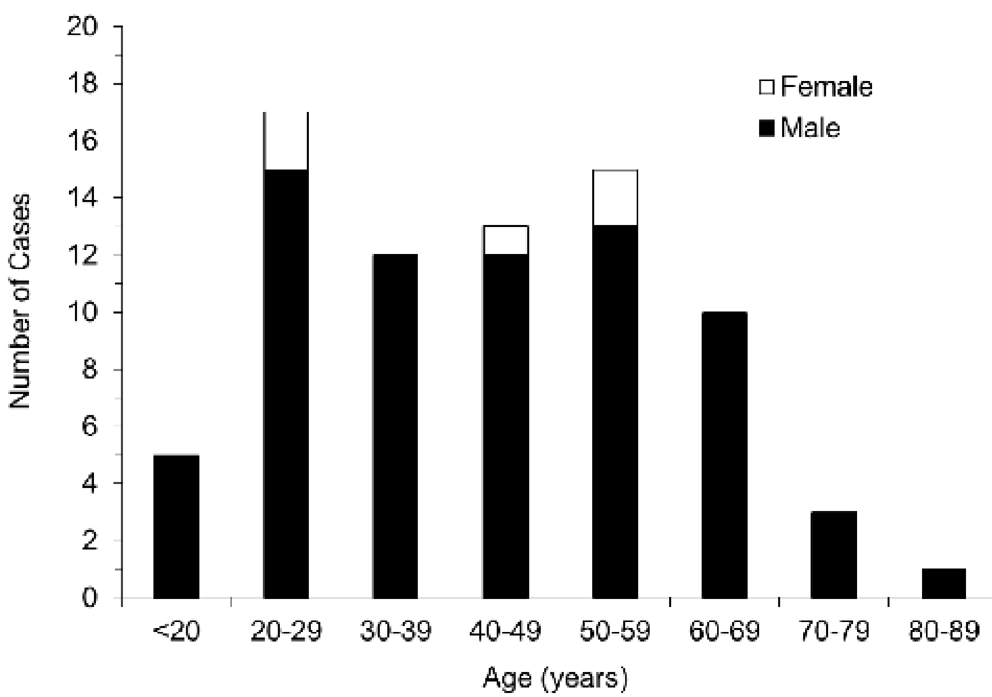

Figure 4.2-1: Age and sex distribution of breath-hold incident victims in 2008 (n=75)

Information regarding the support available to divers was captured in 86% of the cases. The most common patterns were diving with a partner (n=21; 30% of known), diving in a group (n=20; 29% of known), solo or unsupported diving (n=19; 28% of known), and other forms of oversight, typically with less engaged observers on a boat or shore while the activity was underway (n=9; 13% of known). The distribution of group support should not be interpreted as suggesting that there is no difference in safety with different forms of oversight. The delay in recognizing 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 dedicated and able to provide support.

The presence of one or more witnesses to the event was established in almost three quarters of the captured cases, with witnesses present in half of these (n=29; 49% of known cases). Problematically, many of the acts that may contribute directly to accidents are difficult to fully appreciate by observers, particularly casual observers. For example, excessive hyperventilation is a known risk associated with breath-hold diving, but while a witness may report seeing a person hyperventilate prior to a dive, the magnitude of the hyperventilation can be difficult to judge. The specific actions can play a huge role in determining the ultimate risk. There are similar difficulties in quantifying levels of physical exertion, motivation, distraction or fatigue. Since there is generally no physical evidence left concerning any of these factors, the contribution of each is likely to receive insufficient consideration.

While we are incrementally improving the completeness of our data regarding diver support and witness presence, our case information remains wanting. The casualty's level of experience with the breath-hold activity, familiarity with the incident site, pre-dive practices, and health history were rarely confirmed.

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 18 fatal cases (28% of total fatal cases). Drowning was described as the cause of death in 13, but it is the antecedent elements that are more informative. Cardiovascular disease was listed as an agent or contributing factor in six of the cases; blackout, likely hyperventilation-induced, was implicated in five cases; and alcohol, entanglement and shark attacks were deemed pivotal in one case each.

The available data for all 80 cases were reviewed to identify primary disabling agents (Table 4.3-1). Such could not be established in 23 cases (marked as unknown), most often in unwitnessed cases, those in which multiple explanations were possible, or those for which only minimal information was available. The age within this subset was 41±17, ranging from five to 74 years, very close to the distribution of the total sample.

Table 4.3-1 Primary disabling agent ascribed to 2008 breath-hold incidents

Disabling Agent	Count	Percentage
Hypoxic blackout	19	23.7
Medical health	16	20.0
Animal-involved injury	10	12.5
Drowning	7	8.7
Boat strikes	3	3.7
Entanglement	2	2.5
Unknown	23	28.7
Total	**80**	**100**

Hypoxic Blackout

The most commonly identified disabling agent was hypoxic blackout (n=19; 24%). The age within this subset was 28±10, ranging from 16 to 56 years, reflecting a young portion of all victims. Ten of these presented with strong evidence of hypoxia of ascent, and nine involved loss of consciousness in which ascent could not be confirmed, but when behavior appeared to support the conclusion and there were no apparent health or medical problems. 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.

Many breath-hold divers will employ strategies to extend breath-hold time. The risk of blackout during breath-hold is increased by excessive hyperventilation. The following is text extracted from a graphic example of a non-fatal 2008 case involving a 19-year-old spearfisherman.

"After a thorough five- to seven-minute surface breathe up [hyperventilation], I dropped down to somewhere between 75 and 100 ft [23-30 m] (I was not wearing a freediving computer) to look for the fish. After about a minute of searching, I decided to head for the surface as I could not find the fish.

"I was on my way up and passed my buddy at about 30 ft [9 msw]. I was 10 ft [3 m] from the surface, then Bam! I blacked out. One second I was there, the next I was unconscious."

He was completely unresponsive when first brought onto the boat, but slowly regained his senses.

"I can't say that I was aware for much of the time prior to this, but I remember hearing [his dive partner's] voice assuring me that everything would be okay as I drifted in and out of awareness in my own mind. Another five minutes later, after a total of 15-20 min of unresponsiveness, I finally slurred out some words and could lightly squeeze his hand. From this point on, as the boat was speeding towards shore, I slowly regained motor functions and lung capacity (up to about 30%), until the Coast Guard helicopter arrived, 45 min after the original accident, still 55 mi [90 km] offshore. They lifted me in a basket into the copter, and I was at the hospital within 30 min.

"I still had very little lung capacity as they were filled with the sputum from the pulmonary edema, I was throwing up blood that was in my stomach, and my entire body ached. Luckily I dodged two other bullets which were of concern: the blood from my ears and eyes. The blood from my ears was caused by the fact that I had not equalized as I sunk from approximately 25 ft to 80 ft (8-24 m), but somehow I did not burst my eardrums and my hearing was not affected. The blood from my eyes was a result of the massive mask squeeze on my face caused by the fact that I had also not blown air into my mask to compensate for compression as I was sinking, but once again I escaped without injury. I spent a total of one day in the Trauma Center, two days in the Intensive Care Unit, and one day on the hospital floor, with the majority of the time spent concentrating on reducing the amount of fluid in my lungs. There was absolutely no long-term damage to my body or brain, and my lung capacity is back to nearly 100% after only days.

"I cannot stress enough how amazingly fortunate I was. Every little thing worked out perfectly, and if anything was different, I can say with 100% confidence that I would not be here.

"The scariest part is that this could happen to anybody at any time, and those with more experience are even more susceptible to shallow water blackout [hypoxia of ascent]. If my story saves one person then everything that has happened was more than worth it. To everyone, dive safe, always dive with a buddy, and don't push your limits because NO FISH IS WORTH YOUR LIFE!"

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 concentration of carbon dioxide in the blood is much higher than that found in the atmosphere. Delaying the carbon dioxide trigger to breathe can be problematic since the oxygen partial pressure may fall below the level necessary to maintain consciousness before any urge to breathe is felt. Most importantly, the loss of consciousness that can follow hyperventilation-augmented breath-hold can occur with absolutely no warning.

The situation becomes more complicated when breath-hold activities incorporate substantial vertical excursions. The increasing ambient pressure during descent increases the partial pressure of gases in the lungs and bloodstream. Most importantly, this 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 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 positive buoyancy that ultimately caused the victim to fall to the bottom.

Hypoxia-induced blackout is a major life threat to healthy and often extremely capable breath-hold divers. The 19 cases identified in 2008 probably represent 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. Regardless of what some might 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 a lack of understanding and aggressive practice. It is likely that limiting hyperventilation to no more than the equivalent of two or three full ventilatory exchanges will increase breath-hold time but will not remove enough carbon dioxide to inhibit the uncontrollable urge to breathe long enough to threaten consciousness. Hyperventilation in excess of this limit will produce an escalating risk of suppressing the vital drive to breathe long enough for consciousness to be lost.

Medical Health

The second most commonly identified disabling agent was health issues (n=16; 20%). Fourteen of these presented with reasonable to strong evidence of cardiac involvement; two 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±13, ranging from 38 to 82 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).

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 and conditions found in the water. 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 not immediately appreciated by them or event organizers.

Animal-Involved Injury
The third most commonly identified disabling agent was animal-involved injury (n=10; 13%). Nine of the cases involved sharks and one involved a stingray. The vast majority of shark attacks involved spearfishermen, possibly reflecting an influence of being in the vicinity of animal catch. This 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 would not be captured. The age within this subset was 39±10, ranging from 24 to 51 years.

Drowning
The next most common categorization was drowning (n=7; nine percent). This category is one of the least useful, typically reflecting lack of information or multiple explanations were possible. It is likely that additional information would have pointed toward hypoxic blackout, cardiac health and physical fitness issues, but this cannot be confirmed. The age within this subset was 57±9, ranging from 33 to 66 years.

Environmental condition hazards include current and wave conditions that may not pose a challenge to physically fit and/or experienced individuals but can be quite stressful for those with less experience, lower fitness, medical issues, or anxiety. While questions regarding medical status are normally asked before a person participates in scuba diving, they may receive less emphasis for breath-hold activity, particularly for casual snorkeling activities. The physiological demands of such in-water activity, however, can be sufficient to warrant sincere attention to confirm participant readiness.

Boat Strikes
There were three cases put in the category of physical trauma associated with boat strikes. Two involved propeller strikes and one a fast-moving hull strike. It is possible that boat strikes are overrepresented in the database due to the greatest physical evidence and media attention. The victims in these cases were 60, 30 and 25 years of age.

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. The victims were 54 and 57 years of age.

A cross-section of illustrative case studies is found in Appendix C. 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, notably those classified under a category of diving health that is not otherwise included in this report.

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 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 s of the post-dive period can address most 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 can return 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 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 related 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 80 breath-hold diving incidents occurring in 2008 were collected by DAN; 64 fatal (80%) and 16 non-fatal (20%). The victims were overwhelmingly male (94%). The most commonly identified disabling agents were hypoxic blackout (likely facilitated by excessive hyperventilation), health issues (primarily cardiac) animal interactions (primarily between shark and spearfishermen), drowning (with inadequate detail or clarity for further categorization), boat strikes, and entanglement (in kelp), 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 INJURY CASE REPORTS

Medical Services Staff

Weakness and rash develops after multiple dives

This was a 45-year-old male diver with no medical history available. He completed a series of six dives over three days with varying gas mixes. It is unknown if the diver was using a computer to control his dives. His initial day of diving included two square profile dives to a maximum of 90 fsw (27 msw), each for an unknown total dive time. On day two, his profiles were: dive #1 - 120 fsw (37 msw) for 30 min on air followed by a 90 min surface interval, then dive #2 - 120 fsw (37 msw) for 30 min on air. On his third day of diving the profiles were: dive #1 - 120 fsw (37 msw) for 30 min on unknown gas mix followed by a 90-min surface interval, then dive #2 - 120 fsw (37 msw) for 30 min on 28% enriched-air (EAN/nitrox), decompressing on a 68% oxygen (O_2) EAN. After the second dive he became lethargic, weak, and developed a rash on his trunk, abdomen, and back. The diver then breathed 100% O_2 via scuba regulator for 45 min until emergency medical services (EMS) arrived. The diver denied any other symptoms. His dive buddy stated that the diver had two or three similar cases previously.

EMS reported that the diver was conscious, oriented, and hypotensive. He was transported to the hospital on O_2 and intravenous fluids. The patient received two hyperbaric oxygen treatments over a period of two days. No persistent symptoms were noted over the next eight-month period, during which time he tested positive for a patent foramen ovale (PFO). Eight months post-accident, he had not returned to diving.

Vertigo, nausea and vomiting caused by perilymph fistula

This was a 60-year-old male diver on a tropical dive vacation with his wife. No medical history was available. It is unknown if the diver was using a dive computer to control his dives. No information is available about prior dives. DAN was initially contacted by the diver's wife to discuss symptoms that developed after diving the day before. The profile for the day prior was to a maximum depth of 80 fsw (24 msw) for 30 min on air. After surfacing, he developed sudden onset of vertigo, nausea and vomiting. He was placed on a high concentration of O_2 by the boat crew and transported to the local hospital for evaluation.

The patient was treated with antiemetics and observed overnight. He later developed persistent dizziness, fullness in his right ear, and tinnitus. The following day, the patient was transferred by boat from the local hospital to an adjacent island hospital with hyperbaric facilities. The treating hyperbaric physician had a working diagnosis of perilymph fistula when he contacted DAN for consult. Subsequent exploratory surgery confirmed the presence of and allowed for repair of a perilymph fistula. He was discharged and was recommended to follow up with a local ear, nose and throat (ENT) specialist. It is unknown if he returned to diving.

Diver with numbness after dive

This was a 34-year-old male diver with no medical history available. It is unknown if he was using a dive computer to control his dives. No information is available regarding whether he completed any previous dives that day or on previous days. The profile for the reported dive was 120 fsw (37 msw) for 12 min. It is also unknown whether the diver was breathing air or nitrox. The diver stated that the dive was uneventful, but that five minutes after completing it, he developed numbness in his feet that rapidly ascended up to his chest with no other symptoms.

Oxygen was being used to assist another diver who surfaced unconscious, so this diver was placed on nitrox and little attention was given to him. Shortly after, the numbness evolved into a 5 out of 10 pain in his lower back and he stated he could not move his legs. Once on shore, 30 min after surfacing, he began breathing O_2 while being transported by ambulance to a medical center.

The diver originally contacted DAN from the emergency department of a local hospital where he was told by a physician to wait two hours to see how his case evolved. DAN told him to ask for the diving physician by name. The patient began a series of six hyperbaric treatments eight hours after surfacing. His delay in care was due to another (unknown) injured diver being treated. Two days after the initial insult, he was improving but still had some residual symptoms including numbness in the lower extremities. The treating physician had agreed to continue treatments. Five days after the initial insult, residual symptoms included some numbness in his toes and on one thigh. His gait was almost, but not quite, back to normal. Bladder dysfunction was still improving but also not fully resolved. Over the course of five days, the diver received six hyperbaric treatments: two US Treatment Table 6 (USN TT6), one USN TT9, and three wound care protocols (30 fsw [9 msw] for 120 min). Twelve days after the initial insult, he had an 80% recovery. It is unknown if he returned to diving.

Loss of vision and chest pain post rapid ascent

The initial call was from a pediatric emergency department physician. He had in his care a 14-year-old male diver who had lost his regulator from his mouth while at a depth of 20 fsw (6 msw). As a result he made a rapid, uncontrolled ascent to the surface. Almost immediately, he reported that he could not see. He also complained of a headache and mid-sternal chest pain. Local EMS was called and transported the patient to the closest emergency department. The attending physician contacted DAN for assistance with evaluating the patient and to discuss possible treatment.

Based on the presenting symptoms, there was a high suspicion for arterial gas embolism (AGE) secondary to pulmonary barotrauma, and the definitive treatment for AGE is hyperbaric oxygen therapy. It was essential to ensure that there was no pneumothorax (collapsed lung) before initiating treatment because pneumothorax is a contraindication to hyperbaric oxygen therapy. A subsequent computed tomography (CT) of the chest did not find a pneumothorax but detected the presence of pneumomediastinum (air around the heart). The pneumomediastinum did not require intervention prior to hyperbaric treatment. There was CT evidence that the patient had aspirated water although he did not present with clinical signs of aspiration syndrome. The patient was transferred to the closest appropriate hospital with an available chamber.

Upon arrival at the treating facility, the patient was evaluated by the attending hyperbaric physician who confirmed the earlier diagnosis. The patient was treated with a USN TT6 with some improvement. He still had residual headache and partial blindness. He was treated the next day with a USN TT9 and again showed improvement. He was treated on the third day with another USN TT6, at which point he experienced complete resolution of all complaints.

Difficulty breathing during and after diving

A call was received from a 51-year-old female diver. She stated that the previous day she participated in an advanced open water certification program. She completed two dives on air with the following profiles: #1, 25 ffw (8 mfw) for 28 min, #2, 70 ffw (21 mfw) for 37 min. On the second dive she experienced an increase in her breathing rate and effort. She attributed this to 'hard kicking' during long swims both while submerged and on the surface. Her difficulty breathing was sufficient enough for her to require assistance in returning to shore. Speaking proved to be difficult and her pulse rate was elevated. High-flow O_2 was provided by her instructor. She improved with the O_2 which prompted her to decline transport to a hospital for evaluation. She returned home without incident.

The next morning she contacted DAN because she was still experiencing difficulty breathing and her cough was producing blood-tinged sputum. It was strongly recommended that she go to the closest hospital for immediate evaluation.

Upon arrival at the emergency department, her signs and symptoms prompted a timely evaluation. An initial electrocardiogram did not show any acute cardiac findings. A subsequent chest CT scan revealed fluid in both lungs. The patient received diuretics to resolve the fluid and was admitted for a full cardiac evaluation. Despite the lack of any acute cardiac findings, further evaluation was essential. The working diagnosis was immersion pulmonary edema. We were unable to obtain the final outcome and diagnosis.

Inner ear decompression sickness

The attending physician from an emergency department contacted DAN regarding a 54-year-old male diver. The diver had participated in a series of dives over the previous three days. His profiles were as follows: Day 1 - dive #1, 67 fsw (20 msw) for 42 min with a surface interval time of 58 min; dive #2, 58 fsw (18 msw) for 46 min. Day 2 - dive #1, 137 fsw (42 msw) for 29 min with a surface interval of 80 min; dive #2, 82 fsw (25 msw) for 41 min with a surface interval of 73 min; dive #3, 54 fsw (16 msw) for 50 min. Day 3 - dive #1, 132 fsw (40 msw) for 25 min with a surface interval of 122 min; dive #2, 109 fsw (33 msw) for 36 min. After the second dive on day three, he did not feel well and declined the third dive. Approximately 60 min after the last dive, he began to experience vertigo with nausea and vomiting whenever he moved his head. He was unable to walk without significant assistance. The dive staff provided O_2 for 45 min with no appreciable improvement. He was taken to the emergency department of the local hospital.

During the evaluation the attending physician did not find any nystagmus, tinnitus or cognitive problems. The diver denied any difficulty with equalization and visualizing the tympanic membranes (eardrums) did not reveal any evidence of barotrauma. The patient had to remain in a partially reclined position and completely still. Any head movement induced acute nausea and vomiting. The physician spoke with one of the DAN consulting physicians and it was agreed that, given the absence of clinical findings suggesting barotrauma and a significant dive exposure, the likely cause of the signs and symptoms was inner ear decompression sickness. The hospital was capable of treating this diver in its chamber, so immediate treatment was planned.

The diver was treated with a USN TT6. After the first treatment, the diver was able to stand without assistance. He was unable to walk 'heel to toe.' While he still experienced nausea with head movement, it was not acute enough to provoke vomiting. The diver was admitted overnight to the hospital. A second USN TT6 was given the next morning, with greater improvement. The diver was now able to walk 'heel to toe' but did display some unsteadiness. The nausea had completely resolved. The third morning the diver was treated with a USN TT5 and experienced complete resolution of all signs and symptoms. He was discharged from the hospital and was able to return home by commercial flight 72 hours later. There was no return of any signs or symptoms during the flights and the diver remained asymptomatic.

APPENDIX B. DIVE FATALITY CASE REPORTS

James L. Caruso

Proximate Cause: Air Embolism

08-11 Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

This 45-year-old male was spearfishing in a group of divers. He was a certified diver with an unknown amount of experience. After a descent to 95 fsw (29 msw), the diver initially seemed okay but then asked his buddy to check the regulator connections. Visibility was less than 10 ft (3 m). The diver then became separated from his buddy and a rapid ascent possibly occurred. He was seen to surface and then descend back toward the bottom. The diver was brought to the surface by a rescue diver, but resuscitation attempts were unsuccessful. The diver's pony tank was empty, but his primary tank was full. An autopsy was performed, but the report was not made available. The cause of death was listed as an air embolism due to a rapid ascent while scuba diving with limited breathing gas contributing to the death as the diver apparently was using the wrong regulator.
BMI = na

08-16 Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

This 54-year-old male was a certified but inexperienced diver with only 12 lifetime dives. His medical problems included hypertension, diabetes, and obesity. The diver was in a group, and one other diver surfaced early due to running out of air. This diver then signaled that he was out of air and was assisted to the surface. The surface swim back to the boat was difficult, and the diver lost consciousness once back on the boat. Resuscitation efforts continued during transit to shore and then the hospital, but the diver was pronounced dead on arrival at the hospital. An autopsy was performed and the cause of death was determined to be air embolism. The diver also had evidence of hypertensive and atherosclerotic cardiovascular disease, a renal cell carcinoma, and fatty metamorphosis of the liver. Toxicology was positive for diphenhydramine and a blood pressure medication.
BMI = 38.5 kg·m^{-2}

08-29 Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

This 54-year-old male was a certified diver with an unknown amount of experience; he was collecting lobster with four other divers. The diver was making his first dive in two years and descended to 30 fsw (9 msw) for 45 min. He lost consciousness during the surface swim back to the boat. Resuscitation efforts were unsuccessful. The autopsy disclosed subcutaneous gas in the neck but no other corroborative findings for air embolism. Other findings included moderate coronary artery disease, morbid obesity, cardiomegaly, and cholelithiasis (gallstones). The cause of death was determined to be an air embolism, but a cardiac event cannot be excluded. One report notes that the decedent was low on air and made a rapid ascent.
BMI = 41.2 kg·m^{-2}

08-33 Cause of Death: Air Embolism due to Rapid Ascent

This 16-year-old female was a student in an initial open water certification class. She was practicing emergency ascent skills to a maximum depth of 26 fsw (8 msw) with a buddy when she surfaced, called out in distress and lost consciousness. The diver was brought into the boat and resuscitation was attempted but without success. An autopsy was performed, and the cause of death was determined to be air embolism due to rapid ascent. No evidence of significant natural disease processes was present and toxicology was negative.
BMI = na

08-37 Cause of Death: Air Embolism due to Rapid Ascent

This 61-year-old male was a certified dive instructor who was conducting a class with four students. He made a rapid ascent from approximately 100 fsw (30 msw) during the course of the lesson, and on the surface he told the students he was having difficulties. The diver was assisted to shore and lost consciousness; resuscitation efforts were unsuccessful. The diver's past medical history was significant for severe coronary artery disease and a prior myocardial

infarction. The diver had undergone coronary angioplasty in the past. An autopsy was performed, and the cause of death was determined to be air embolism due to a rapid ascent. A contributing factor would have to be ischemic heart disease and, in fact, a cardiac event for a trigger cannot be entirely excluded, though the diver did lose consciousness immediately following a rapid ascent. An evaluation of the diver's equipment found it to be in poor condition, and he also was wearing too much weight, particularly for an experienced diver.
BMI = na

08-38 Cause of Death: Air Embolism due to Rapid Ascent

This 53-year-old female had achieved open water certification just two months earlier and was very inexperienced. In fact, this was her first boat/ocean dive. Her medical history was significant for hypertension controlled with medication and apparently depression based on the toxicology results. The diver descended to 10 fsw (3 msw) for a bottom time of 10 min in a group with an instructor. She experienced some unknown problem at depth and panicked. The diver surfaced rapidly and complained of difficulty breathing. She struggled as the instructor tried to put her regulator back into her mouth; she would quickly spit it out. The instructor also attempted to inflate the diver's buoyancy compensator, but the diver deflated it. The diver lost consciousness and resuscitation efforts were unsuccessful. The death was attributed to an air embolism due to rapid ascent. Toxicology was positive for benzodiazepines (tranquilizers) and antidepressant medications.
BMI = na

08-39 Cause of Death: Air Embolism due to Rapid Ascent

This 34-year-old male was making his first dive of the season with a designated buddy down to 165 fsw (50 msw) to explore a wreck. The diver experienced some sort of mask issue, so he was the last to descend and his buddy had descended ahead of him. The diver surfaced alone and was found unconscious on the surface. According to a Coast Guard investigation, the diver had made a rapid ascent. It is unclear if an autopsy was performed as no results were made available. With the investigational information provided, this most likely represents an air embolism.
BMI = na

08-42 Cause of Death: Air Embolism due to Rapid Ascent

This 50-year-old male was making one of his check-out dives in an initial open water certification class. He was taken to 10 fsw (3 msw) by his instructor and gave an "OK" sign. The instructor then went to the surface to get another student who had delayed his descent. When the second student and instructor descended, they found that the decedent had ascended to the surface where he lost consciousness and could not be resuscitated. The deceased diver had a medical history that was significant for hypertension and obesity. The autopsy disclosed left ventricular hypertrophy and moderate coronary artery disease. The diver's equipment checked out fine, though it was apparent that he had consumed air quickly. The cause of death was determined to have been an air embolism due to a rapid ascent.
BMI = 32.6 kg·m^{-2}

08-46 Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

The exact certification status and experience level of this 44-year-old male is unclear. It appears that he was recently certified to become a commercial fisherman by spearfishing. He was on a commercial vessel and had made his third dive of the day, which was to 64 fsw (20 msw) for 24 min. The diver ran out of air and skipped obligated decompression time. He and his buddy became separated during the dive. The diver's buddy surfaced first, then saw the diver surface with a safety sausage inflated. Back on the boat, the diver was getting ready to go back down and complete his decompression when he collapsed and could not be resuscitated. An autopsy was performed, and the cause of death was determined to be an air embolism. It is likely that a component of decompression sickness contributed to the death.
BMI = na

08-48 Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

This 60-year-old male was making a rebreather dive with a buddy to a shipwreck at 130 fsw (40 msw) for a bottom time of 46 min. During ascent the diver went out of control and rapidly went up to approximately 20-30 fsw (6-9 msw). He then sank back down to 70 fsw (21 msw) and switched to his bailout rig and ascended to the surface. The diver made a normal ascent, surfaced away from the boat, and lost consciousness on the surface, according to the investigative information available. The autopsy disclosed natural disease processes that included chronic hepatitis with fibrosis, hypertrophy of the left ventricle of the heart, pulmonary emphysema, and liver and kidney cysts. The decedent had a history of receiving a kidney transplant. The death was determined to be due to an air embolism as a consequence of a rapid ascent due to insufficient breathing gas. An evaluation of the rebreather found that the electronics had flooded.
BMI = na

08-49 Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

This 45-year-old male obtained open water certification one year earlier but had not made a dive since certification. His

dive buddy possessed the same lack of experience. The divers went to 150 fsw (46 msw) and sequentially ran out of air. The divers rapidly ascended toward the surface. The diver's buddy made it to the surface and eventually was treated with hyperbaric oxygen. The diver's body was not recovered until the next day. The autopsy disclosed mild atherosclerotic cardiovascular disease. Nitrogen narcosis should be suspected as having contributed.
BMI = na

08-56 Cause of Death: Air Embolism due to Rapid Ascent

The certification status and experience level of this 32-year-old male is unknown. He was using surface-supplied air to hunt for lobster at 25 fsw (8 msw). The diver surfaced in distress, vomited, and lost consciousness. An autopsy was performed and the cause of death was determined to be drowning; however, this most likely was an air embolism. Organ and tissue procurement prior to the autopsy would have limited anatomic findings, but the pathologist does not appear to have paid attention to the dive profile and history. The equipment was inspected and determined to be in good working condition.
BMI = na

08-61 Cause of Death: Air Embolism due to Rapid Ascent

This 45-year-old male was using a rebreather to dive on a wreck to a depth of 200-230 ft (61-70 m). His medical history was significant for obstructive sleep apnea. The diver ran into distress during a decompression stop at 100 ft (30 m). He switched to open-circuit and surfaced, omitting approximately 30 min of obligatory decompression time. On the surface, the diver reportedly was talking before abruptly losing consciousness. An autopsy was performed, but the report was not made available. A witness stated that the diver made a rapid ascent and partially "popped out of the water" as he broke the surface. This most likely represents an air embolism, but there is a component of decompression sickness as well since he obviously had omitted significant decompression time.
BMI = na

Proximate Cause: Drowning/Air Embolism

08-17 Cause of Death: Drowning due to Air Embolism due to Rapid Ascent

This 54-year-old female was a certified diver with eight years of experience. She was a student in a technical diver class conducted in fresh water. The diver made a dive with a group of other divers to 165 ffw (50 mfw) using nitrox. The diver and her buddy began a rapid ascent, and the instructor stopped her and put her at a decompression stop, which was 70 ffw (21 mfw). The instructor then went after the dive buddy. The diver was found unconscious and on the bottom at 165 ffw (50 mfw). The autopsy disclosed gas in the coronary arteries and cerebral vessels, subcutaneous emphysema, bilateral pneumothoraces, and changes consistent with drowning. She also had ruptured tympanic membranes, indicative of an uncontrolled descent. This was likely a drowning, secondary to air embolism.
BMI = na

08-30 Cause of Death: Drowning due to Air Embolism due to Rapid Ascent

This 52-year-old male was a certified and experienced diver who had not made a dive in the previous three years. He made a shore entry, solo dive and was found floating unconscious approximately 100 yd (91 m) from shore. An autopsy disclosed changes associated with drowning as well as evidence of pulmonary barotrauma, mild cardiomegaly, and moderate coronary atherosclerosis. The diver was also a smoker. The death was determined to be due to drowning, secondary to air embolism as a consequence of a rapid ascent.
BMI = na

Proximate Cause: Cardiac

08-05 Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 40-year-old diver was certified with an unknown amount of diving experience. The diver was preparing for a drysuit dive and made a shore entry to swim out to the descent site. He lost consciousness on the surface and could not be resuscitated. The autopsy report was not made available for review, but this death was likely due to a cardiac event.
BMI = na

08-08 Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 70-year-old male was a certified diver with an unknown amount of diving experience. He was making a series of dives down to a wreck with a large group of divers. After completing the second dive of the day, the diver lost consciousness on the surface and could not be resuscitated. There is no history of rapid ascent or other problems during the dive. The cause of death was determined to be a myocardial infarction, secondary to hypertensive and atherosclerotic cardiovascular disease. It is unknown if an autopsy was performed as no report was made available.
BMI = na

08-09 Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 48-year-old male was a certified diver with an unknown amount of diving experience. He appears to have been a frequent diver in the past, but it is not certain that he had

made a dive within the past two years. The diver carried his gear in his car and likely filled his own tanks. He also appears to prefer to dive solo. The diver made a shore entry, solo dive and was found floating unconscious 45 min later. It was noted that the diver's tank was nearly full. The diver's medical history included diabetes and hypertension, for which he took medications. He was also obese. The autopsy demonstrated severe coronary artery disease, which was determined to be the cause of death. The diver also had a bicuspid aortic valve which is present in a small percentage of the population and may require valve replacement surgery, typically as one ages.
BMI = 36.2 $kg \cdot m^{-2}$

08-12 Cause of Death: Cardiac Dysrhythmia due to Dilated Cardiomyopathy

This 77-year-old male was a certified, experienced diver who planned to make a shore entry dive with a buddy. Apparently, the divers made the surface swim out, but the water was too rough for them to descend. The diver's buddy called out for help and witnesses swam out to assist the divers. Upon reaching the two divers, the rescuing diver found the decedent unconscious and floating on the surface. After he was helped ashore, resuscitation efforts were unsuccessful. The autopsy disclosed dilated cardiomyopathy, pulmonary emphysema, a benign liver cyst and benign prostatic hypertrophy. The death was ruled to be due to a cardiac event.
BMI = na

08-26 Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 61-year-old male obtained his initial open water certification one year earlier. He made a solo, shore entry dive while his girlfriend waited on shore. He never submerged and started to slowly head back to shore. The diver lost consciousness during the surface swim to shore. He was brought to shore where resuscitation efforts were unsuccessful. The diver's medical history included diabetes and hyperlipidemia. The autopsy demonstrated severe coronary artery disease and an incidental diagnosis of cholelithiasis (gallstones). Toxicology was positive for antidepressant medication. The cause of death was determined to be a cardiac event.
BMI = na

08-32 Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 65-year-old male was a certified diver with an unknown amount of diving experience. He was spearfishing with a buddy and became low on air during the safety stop. The diver surfaced alone and struggled on the surface. Witnesses tried to throw the diver a line, and then he was brought into the boat. The diver lost consciousness in the boat, and resuscitation efforts were unsuccessful. The autopsy demonstrated severe coronary artery disease and chronic hepatitis. Toxicology was positive for cannabinoids (chemical compound in marijuana). The death was determined to be due to a cardiac event.
BMI = na

08-67 Cause of Death: Cardiac Dysrhythmia due to Hypertensive Cardiovascular Disease

This 52-year-old male was open water certified but had no formal rescue certification. He was a member of the local fire department dive team. The decedent arrived on the scene where a missing person had possibly drowned at a local quarry pond. The diver was advised to wait for other personnel to arrive at the scene, but he did not and he entered the water without fins and without a buddy. The diver was noted to be floating unconscious by witnesses, and resuscitation efforts were unsuccessful. The deceased diver's medical history included hypertension, for which he took medication. The cause of death was determined to be a cardiac event due to hypertensive cardiovascular disease. The autopsy disclosed cardiomegaly and mild coronary atherosclerosis. The decedent also had a blood ethanol concentration of 0.25 $mg \cdot dL^{-1}$, which is more than triple the limit allowed for operation of a motor vehicle. An examination of his equipment found an elevated level of carbon dioxide in the breathing gas and equipment that was poorly maintained and unsafe.
BMI = na

08-68 Cause of Death: Cardiac Dysrhythmia

This 55-year-old male was diving with a group from a boat in warm water with reasonable visibility. His certification and experience levels are unknown. After completing the dive, the decedent immediately clutched his chest and lost consciousness. Resuscitation efforts were unsuccessful. An autopsy was performed, but the report was not made available. This death was most likely due to a cardiac event.
BMI = na

08-70 Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 58-year-old male had a medical history that was significant for coronary artery disease with angioplasty performed four to five years earlier. After the procedure, the diver's physician cleared him for diving. His certification status and experience level are unknown. On the third consecutive day of diving, the diver surfaced from an apparently uneventful dive and became unresponsive. Resuscitation efforts were begun on the boat, but they were unsuccessful. An autopsy was performed, according to the investigation report. The exact findings were not made available, but one report stated that this was a cardiac event.
BMI = na

08-71 Cause of Death: Myocardial Infarction

This 61-year-old male was a student in an initial open water certification class making his first training dive in open water. He performed the typical required skills, which included ascent training; the dive was only down to 15 fsw (5 msw). The diver complained of feeling poorly and then lost consciousness on the surface. He died later that same day in a hospital. The diver reportedly had no significant health issues. Given the information provided, this would likely represent a cardiac event or an air embolus. If an autopsy was performed, the report was not made available. According to the investigative information available, the diver had sustained an acute myocardial infarction.
BMI = na

08-72 Cause of Death: Cardiac Dysrhythmia

This 62-year-old male was using a surface-supplied helmet rig made for tourists. The activity requires no formal certification or training and the dive is generally to a shallow depth. The decedent apparently lost consciousness on the bottom, and he was pulled to the surface. If an autopsy was performed, the report was not made available. The death was most likely due to a cardiac event.
BMI = na

08-75 Cause of Death: Acute Myocardial Infarction due to Coronary Artery Disease

This 54-year-old male was a certified technical diver who was a student in a rebreather training course. He reportedly complained about feeling poorly and bailed out of the class. According to the limited investigative information available, the diver had an acute myocardial infarction due to an acute blockage of the right coronary artery.
BMI = na

08-76 Cause of Death: Cardiac Dysrhythmia

There is little known about the circumstances surrounding the death of this 50-year-old male dive instructor. It was reported to have been a cardiac event.
BMI = na

Proximate Cause: Drowning/Cardiac

08-06 Cause of Death: Near-drowning due to Cardiac Dysrhythmia

This 57-year-old male was an experienced, certified diver with a medical history that was significant for insulin-dependent diabetes mellitus. He had undergone several amputations of his toes and portions of his feet due to diabetic complications. While preparing to begin a dive the diver lost consciousness and became submerged. He was pulled from the water and resuscitated, but after two days in a hospital, the diver succumbed to his injuries. The autopsy revealed severe atherosclerosis of the coronary arteries, cardiomegaly and atherosclerosis of the aorta. The medical examiner determined the cause of death to be complications of near-drowning due to a cardiac event.
BMI = na

08-07 Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 61-year-old female was a certified diver with an unknown amount of diving experience. She was making a shore entry dive with a group in a rough sea state but first swam with a snorkel to determine if she wanted to make the dive. She subsequently did decide to dive and went to join the group. The diver was found floating unconscious on the surface. An autopsy was performed, and the medical examiner determined the cause of death to be drowning secondary to a cardiac event. The autopsy disclosed moderate coronary atherosclerosis as well as atherosclerotic changes involving the aorta and a thyroid cyst.
BMI = na

08-10 Cause of Death: Drowning due to Cardiac Dysrhythmia due to Hypertensive Cardiovascular Disease

This 58-year-old male was using scuba to gather oysters with another diver. The two divers entered the water together but quickly went off on their own. The decedent was a certified diver, but his experience level is not known. After approximately 30-45 min one diver surfaced and found the other diver floating unconscious and with the regulator out of his mouth. Resuscitation efforts were unsuccessful. The deceased diver's tank was full and his catch bag was empty. The coroner signed the death out as a drowning due to hypertensive cardiovascular disease, but it does not appear that an autopsy was conducted.
BMI = na

08-22 Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 78-year-old male was a certified and experienced basic open water diver who was with a group consisting of an instructor and students. The dive was only to 6 fsw (2 msw) for 13 min but the diver separated from his buddy and was found floating unconscious on the surface approximately 50 ft (15 m) from the entry point. The diver was transferred to a recompression chamber, but he could not be resuscitated. An autopsy revealed focally severe coronary artery disease, with a coronary stent present. The diver also had a history of hypertension and obesity. Additional findings included benign tumors of the liver and pituitary gland, hepatic steatosis and arterionephrosclerosis. The death was ruled a drowning though there were not many changes that suggested this to be a drowning. Certainly the trigger was most likely a cardiac event.
BMI = 31.7 $kg \cdot m^{-2}$

08-41 Cause of Death: Near-Drowning due to Cardiac Dysrhythmia due to Cardiomegaly

This 46-year-old male was on a boat with a group of people but entered the water alone for a solo dive. He was an experienced, certified diver. The diver's medical history was significant for obesity and depression. He descended to 58 fsw (18 msw), and when he had not surfaced an hour later, others in the boat descended and found him unconscious on the bottom. The diver had used nitrox as a breathing gas and borrowed a buoyancy compensator. An autopsy disclosed cardiomegaly and mild atherosclerosis of the coronary arteries. Antidepressant medication was detected in the diver's blood. The diver was also obese. The cause of death was determined to be drowning due to a cardiac event.
BMI = 36.5 $kg{\cdot}m^{-2}$

08-45 Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

The certification status and diving experience of this 42-year-old male are unknown. He made a shore entry dive alone into a partially ice-covered pond to perform maintenance on an aerator. The diver retrieved a part that needed replacing then re-entered the water to replace it. He did not return to the surface, and his lifeless body was pulled from the bottom two hours later. In addition to changes associated with drowning, the autopsy disclosed cardiomegaly and coronary artery disease. The diver also had diabetes and was obese. This likely represents a drowning secondary to a cardiac event.
BMI = 37.3 $kg{\cdot}m^{-2}$

Proximate Cause: Drowning/Insufficient Air

08-01 Cause of Death: Air Embolism Due To Rapid Ascent due to Insufficient Air

This 40-year-old male was a technical diver making a wreck dive with three other divers to 170 ft (52 m) in a lake. The diver ran out of air and had to buddy breathe. The diver's buddy stopped for decompression time, but the diver continued to the surface where he lost consciousness. Resuscitation efforts were unsuccessful. The medical examiner concluded that death was due to air embolism after a rapid ascent associated with an out-of-air event. The investigation revealed that the deceased diver had used the same tank for repetitive dives.
BMI = na

08-02 Cause of Death: Drowning due to Insufficient Air

This 22-year-old male was making a dive with two other divers to a wreck at 105 fsw (32 msw) to spearfish. The diver's certification status and diving experience are not known. The diver became separated from his buddies, and they searched for him for more than 40 min. He was found unconscious and on the bottom with his regulator in his mouth, and he had an empty tank. The medical examiner ruled the death a drowning due to running out of air while scuba diving.
BMI = na

08-13 Cause of Death: Drowning due to Insufficient Air

This 33-year-old male was a certified, experienced diver. He was using twin tanks with nitrox (36%) and was not experienced with the equipment. The diver was spearfishing with a group, but he went off on his own. The diver's medical history was significant for asthma with inhaler use, cocaine and ethanol abuse, and cigarette smoking. He was also obese. The dive platform was a boat, and the depth of the dive was 75 fsw (23 msw). According to the investigative report, the diver surfaced and then descended back down. He was found unconscious on the bottom, and he could not be resuscitated. The cause of death was determined to be drowning. An evaluation of the equipment found that the tanks were configured improperly, and the diver did not have sufficient breathing gas. His buoyancy compensator also did not have gas for auto-inflation. In addition to changes consistent with drowning, the autopsy disclosed cardiomegaly and toxicology was positive for cannabinoids.
BMI = 32.9 $kg{\cdot}m^{-2}$

08-14 Cause of Death: Drowning due to Insufficient Air

This 33-year-old male was a certified technical and cave diver; he was using a rebreather to survey a cave system. The diver entered the cave alone on the rebreather, switched it off, then tried to switch back to using the rebreather, but it was flooded. He also likely experienced a silt out. The diver was not missed until later that evening, and his body was found late that night and recovered the next day. An evaluation of the rebreather showed corrosion of the electronics and flooding of the scrubber. The diver made the dive on nitrox and the maximum depth was 35 ft (11 m). The autopsy disclosed gas in the right side of the heart and cerebral circulation, especially the meningeal arteries. The medical examiner called this an air embolism death, but the diver never ascended alive, so an AGE is essentially impossible. The medical examiner was fooled by postmortem artifact. Toxicology was negative.
BMI = na

08-19 Cause of Death: Drowning due to Insufficient Air due to Entrapment (cave)

This 52-year-old male was a certified and experienced advanced open water diver, but he was not a cave diver. He and another diver misrepresented their intentions and gained access to a complex underwater cave system. Both divers' bodies were recovered by a recovery team the next day at a depth of 54 ft (16 m) and 120 ft (37 m) into the cave.

The bodies were located next to a guideline, but there was no attachment to the line. An autopsy was performed, and the cause of death was determined to be drowning. The diver also had cardiomegaly, moderate coronary artery disease, and he was a smoker. A small amount of ethanol was noted in the blood, which likely was due to decomposition. Toxicology was positive for benzodiazepines (tranquilizers) and antidepressant medication.
BMI = na

08-20 Cause of Death: Drowning due to Insufficient Air due to Entrapment (cave) and Entanglement (lines)

This 42-year-old male was a certified and experienced dive instructor, but he was not a cave diver. He and another diver misrepresented their intentions and gained access to a complex underwater cave system. Both divers' bodies were recovered by a recovery team the next day at a depth of 54 ft (16 m) and 120 ft (37 m) into the cave. The bodies were located next to a guideline, but there was no attachment to the line. This diver's body may have been entangled in a line. He had twin tanks, one full and the other emptied, with no open manifold between them so the diver would have essentially been out of air. An autopsy was performed, and the cause of death was determined to be drowning. No significant natural disease processes were noted on autopsy. The diver was a smoker. A small amount of ethanol was noted in the blood, which likely was due to decomposition. Toxicology was otherwise negative.
BMI = na

08-24 Cause of Death: Drowning due to Insufficient Air

This 38-year-old male was a certified and experienced diver making a shore-entry dive with a buddy. Both divers ran low on air, and this diver went on his back-up air supply but then panicked and would not accept assistance from his buddy. The diver reportedly lost consciousness at a depth of 70-80 fsw (21-24 msw) and approximately 1000 ft (305 m) from shore. The diver's buddy was pulled to shore and treated at a local recompression chamber for tingling in his extremities. It is unknown if an autopsy was performed, but the cause of death was reported to be drowning due to running out of air. Panic would also be a contributing factor.
BMI = na

08-31 Cause of Death: Drowning due to Insufficient Air

This 54-year-old male was a certified technical diver who also was a professional scientific diver. He was making a dive with a buddy to survey the ocean floor, using nitrox. The divers ran low on air and ascended to the decompression stop at 15 fsw (5 msw). The buddy grabbed the regulator at the decompression stop and turned to see the diver sinking toward the bottom. The diver's buddy surfaced and other divers descended to pull the stricken diver up. Resuscitation efforts were unsuccessful. The diver's medications included hydrocodone and diazepam. Based on postmortem toxicology he also used the antidepressant medication citalopram. The autopsy disclosed cardiomegaly, hepatic steatosis, chronic gastritis, diverticulosis, and changes associated with drowning. He was also morbidly obese and a smoker. Toxicology was positive for the antidepressant citalopram and a metabolite of cocaine was present in the urine.
BMI = 41.6 kg·m^{-2}

08-43 Cause of Death: Drowning due to Insufficient Air

This 52-year-old male was an experienced technical diver using a rebreather to make a series of dives. The first dive was reported to have been uneventful. The second dive of the day was to 140 fsw (43 msw), then the diver ascended to 60 fsw (18 msw). He signaled to his buddy that he was out of breathing gas. The diver then lost consciousness as his buddy tried to render assistance. The diver was brought to the surface where resuscitation efforts were unsuccessful. An autopsy disclosed a left ventricular hypertrophy and arterionephrosclerosis. The diver was also a smoker and was obese. An evaluation of the equipment revealed that the oxygen valve was closed and the diluent used may have been a hypoxic mix. The cause of death was determined to be drowning, with the cardiovascular findings as significant diagnoses.
BMI = 30.2 kg·m^{-2}

08-44 Cause of Death: Drowning due to Insufficient Air

The certification status and diving experience of this 23-year-old male is unknown. He planned a shore entry night dive with a buddy, but while the buddy went to get his dive gear, the decedent went into the water alone. His unconscious body was found on the surface when the buddy arrived with his equipment. Resuscitation efforts were unsuccessful. One investigation report stated that the diver's tank was empty, but that could not be confirmed. The diver was a smoker but had no other reported health problems. The autopsy demonstrated changes consistent with drowning.
BMI = na

08-50 Cause of Death: Drowning due to Insufficient Air due to Entrapment (cave)

This 25-year-old male was an experienced, certified diver who made a cave dive with three other divers. It is uncertain if the diver had any formal cave diving certification or training. The dive was a night dive with a start time of 0030. They went to 104 ft (32 m) as a maximum depth for a bottom time of 20 min. Buddy separation occurred and the three other divers ascended, but this diver wanted to continue. When the buddies returned to the point of separation, the diver was not there. His body was found in a cavern area one day later. The death was determined to be due to drowning

as a consequence of running out of air in a cave. The diver had been drinking alcohol prior to the dive. The postmortem toxicology report showed the deceased diver had a blood ethanol concentration of 0.141 or 141 $mg \cdot dL^{-1}$, which is nearly twice the limit legally allowed for driving (80 $mg \cdot dL^{-1}$).
BMI = na

08-53 Cause of Death: Drowning due to Insufficient Air due to Entanglement (netting)

This 51-year-old male was an experienced, certified diver performing maintenance in a 12 ft (4 m) deep pool. He was found unconscious on the bottom by a coworker. The diver's tank was empty, and he was entangled in submerged webbing on the bottom. The autopsy disclosed cardiomegaly with left ventricular hypertrophy and moderate coronary artery disease. The death was determined to be a drowning due to insufficient air as a consequence of entanglement.
BMI = na

08-54 Cause of Death: Drowning due to Insufficient Air

This 67-year-old male was diving with a buddy when he signaled that he was low on air. It is unknown if this diver was certified and what amount of diving experience he possessed. The diver had initial problems descending and returned to the boat for more weight. When he ascended, he needed to buddy breathe and panicked. At the surface he lost consciousness and sank below the surface. The diver's buddy was recovered three hours later on the bottom approximately one mile from the boat. The autopsy disclosed a heart that weighed more than twice what it should have. He also had severe coronary artery disease and evidence of previous myocardial infarctions. The diver's medical history included diabetes, hypertension, chronic anticoagulation, a cardiac pacemaker, and obesity. The death was determined to be drowning due to insufficient air, but the diver's significant natural disease processes could have played a role.
BMI = 31.2 $kg \cdot m^{-2}$

08-62 Cause of Death: Drowning due to Insufficient Air

This 38-year-old male was an experienced technical diver making a solo dive with a rebreather on a very deep wreck. During the second dive of the day to 250 fsw (76 msw), the diver failed to surface and other divers found him several hours later on the bottom next to the wreck. The autopsy disclosed myocarditis, which the pathologist determined was the cause of death. Changes consistent with drowning as well as postmortem decompression artifact were also present. An evaluation of the rebreather showed that it was improperly configured and had flooded. This would supersede the medical examiner's findings as you can have myocarditis and still safely complete a dive. A flooded rig would be an emergency and was likely fatal in this setting.
BMI = na

08-69 Cause of Death: Drowning due to Insufficient Air due to Entrapment (cave)

This 32-year-old male was diving with four buddies in a complex cave system. According to the investigative information, the diver was advised prior to the dive that his equipment might be too bulky to make it through some of the tight areas in the cave. There was buddy separation, and it appears that the diver did remove his equipment and attempted to surface using his pony bottle. When the diver did not exit the cave within a reasonable amount of time, other divers went in to search for him. He was found unresponsive approximately 30 yd (27 m) from the cave's exit. The decedent had a history of back problems, and it is unclear if that limited him in any way. The death was most likely due to an out-of-air scenario with cave entrapment.
BMI = na

Proximate Cause: Drowning/Various Causes

Cause of Death: Drowning Due to Pulmonary Fibrosis

This 48-year-old male was an experienced, certified diver; he was collecting lobster with a dive buddy. The diver's medical history was significant for hypertension, gout, acid reflux disease, and pulmonary fibrosis. He had complained of recent chest pain and night sweats prior to going diving. For an unknown reason, the diver became distressed at 55 fsw (17 msw) and because his buddy was low on air, the buddy went to the surface to summon assistance. Two other divers went into the water to render aid. They pulled the diver to the surface, but resuscitation efforts were unsuccessful. The medical examiner determined the cause of death to be drowning due to pulmonary fibrosis. The autopsy also revealed a left pneumothorax, an enlarged heart, and mild atherosclerosis of the coronary arteries.
BMI = na

08-15 Cause of Death: Drowning

This 54-year-old male was a student in an open water certification class; he was making his first open water dives. He had some blood in his mask after the first dive and also pain in his right eye, but he made a second dive anyway. The diver paired up with his instructor for the second dive, but they became separated; he was found on the bottom, unconscious with his regulator out of his mouth. Resuscitation efforts were unsuccessful. The diver had a history of hypertension and anxiety, for which he took prescription medications. He was also wearing 51 lb (23 kg) of ballast weight. An autopsy was performed, but the report was not made available. The cause of death was determined to be drowning. An evaluation of the equipment noted that the air had an unusual odor, but there were no documented contaminants present.
BMI = na

08-18 Cause of Death: Drowning
This 31-year-old male was a certified but infrequent diver with an unknown amount of experience. He was making his first dive in more than a year into a lake with a dive buddy. They descended to 25 ft (8 m) but became separated during the ascent. The buddy called for assistance on the surface, and a rescue team found the deceased diver on the bottom at 8-10 ft (2-3 m). An autopsy was performed, and the cause of death was determined to be drowning. Toxicology was positive for cannabinoids. An evaluation of the equipment disclosed a broken hose.
BMI = na

08-21 Cause of Death: Drowning
This 53-year-old male was a certified and experienced technical diver; with a buddy, he was making a shore entry into cold water and rough surf. The diver's buddy was approximately 80 yd (73 m) ahead of him, and they had not descended yet when the diver signaled that he was having trouble. The diver sank below the surface and was found floating unconscious. The diver had dropped his weights. Resuscitation efforts were unsuccessful. An autopsy was performed, and the cause of death was determined to be drowning. Cardiomegaly was also present and this most likely represents a cardiac problem as a trigger. Toxicology was negative.
BMI = na

08-23 Cause of Death: Drowning
This 48-year-old female was a student in an initial open water certification class. According to the diver's medications, she suffered from significant mental illness and perhaps was schizophrenic. During the morning dive, she swallowed some water and became fatigued. During the second dive, the diver completed the standard required tasks for a student. She appeared nervous to the instructor, so he advised her to just hover. The diver gave an "OK" signal, but when she was next seen, the diver had her regulator out of her mouth and was unconscious. The diver was brought to the surface where resuscitation efforts were unsuccessful. The autopsy revealed mild myocardial fibrosis and severe hepatic steatosis. Toxicology was positive for olanzapine and topiramate, the former used to treat schizophrenia and the latter typically for migraine headaches. The pathologist called the cause of death "cardiac arrest," which is not typical terminology used by forensic pathologists. It was also called an accident which does not go along with "cardiac arrest." This more likely was a drowning due to panic, with several natural disease processes that may have been contributory.
BMI= 30.1 kg·m^{-2}

08-25 Cause of Death: Drowning due to Rapid Ascent
The certification status and experience level of this 47-year-old male is unknown. He completed a dive to a maximum depth of approximately 25 fsw (8 msw) and lost consciousness during the swim back to the boat. The seas were rough. The stricken diver was brought into the boat where resuscitation efforts were unsuccessful. An autopsy was performed, and the cause of death was determined to be air embolism secondary to a rapid ascent. Gas was present in the heart and numerous blood vessels. Focal severe coronary atherosclerosis in the form of one tight lesion in a branch of a major coronary artery was noted. Toxicology was positive only for aspirin. Given this information, a cardiac event cannot be completely excluded.
BMI = na

08-28 Cause of Death: Drowning
This 33-year-old male was a certified and experienced diver making a shore-entry, solo dive to 25 fsw (8 msw). Upon surfacing, the diver appeared to be fine, according to the investigative report, but he then descended again and resurfaced, calling for help. The diver apparently lost consciousness and sank below the surface. The unconscious diver was pulled from the bottom. The autopsy report was not made available, and the cause of death was reported to be drowning as determined by the medical examiner. With the limited information made available, an air embolism cannot be excluded, particularly taking into account the dive history.
BMI = na

08-35 Cause of Death: Drowning due to Entrapment (kelp)
This 38-year-old female was a certified diver but had not been diving in the previous three years. She was diving in a group and performing underwater photography when she became separated from the other divers. Her body was recovered two hours later from a kelp bed, in which she had become entangled at 30 fsw (9 msw). The autopsy found obesity as the only significant natural disease process present, and toxicology was positive for an antidepressant medication.
BMI = 38.7 kg·m^{-2}

08-36 Cause of Death: Drowning due to Seizure due to Oxygen Toxicity (rebreather)
This 38-year-old male was a certified technical and cave diver using a rebreather with nitrox in a freshwater cave system. He and a buddy were using scooters to get around the cave, but the diver's scooter malfunctioned, and they both decided to leave their scooters and swim for the remaining bottom time. The dive was to a maximum depth of 98 ft (30

m), and bottom time was approximately 50 min. The diver suddenly began to behave erratically and, according to the buddy, exhibited seizure-like activity. The buddy first tried to hold the diver's regulator in his mouth during this time and then tried to get the diver to take an open-circuit regulator but was unsuccessful. The buddy had to surface and the diver's body was not recovered until two days later. An evaluation of the equipment revealed that the rebreather was old, poorly serviced, and possibly delivered higher partial pressures of oxygen than it should have. This appears to be a drowning secondary to an oxygen-induced seizure. The autopsy only revealed scattered intravascular gas, the presence of which would be expected in any long, deep dive.
BMI = na

08-47 Cause of Death: Drowning

This 51-year-old female was diving with a group to gather lobster and take photographs. The dive was to 110 fsw (34 msw), and there was poor visibility at shallow depths. The diver became separated from her buddies and surfaced ahead of them. Her body was found on the bottom one day later. Five years earlier, the diver had suffered a minor stroke, which resulted in temporary paralysis of her left hand. The autopsy demonstrated changes associated with drowning as well as mild cardiovascular disease involving the arteries of the brain and heart. A cardiac event resulting in drowning is certainly possible.
BMI = na

08-51 Cause of Death: Drowning

This 63-year-old male had an unknown dive training or certification status. He was diving for lobster either as a solo diver or at least with early buddy separation. The dive was planned to be to 75 fsw (23 msw) for 50 min. When he did not ascend after one hour, others were concerned and started a search, but the body was not recovered until four days later. At the time of recovery, the diver's tank and buoyancy compensator were not on his body. The death was ruled to be a drowning, but the autopsy disclosed moderate atherosclerotic cardiovascular disease and arterionephrosclerosis. A cardiac event cannot be excluded. Toxicology was positive for benzodiazepines (tranquilizers) and diphenhydramine (antihistamine).
BMI = na

08-55 Cause of Death: Drowning

This 41-year-old male was a certified, experienced diver making a cave dive with a buddy and using scooters. The diver had a history of panic attacks, anxiety, and depression. During the dive, the diver became unresponsive and sank to the bottom. The cause of death was determined to be drowning after an autopsy was performed. The pathologist concluded that the diver had hypertrophy of the right ventricle of his heart, but the measurements in the report do not support that conclusion. The pathologist also concluded that the decedent was obese, but BMI calculations based on the height and weight contained in the autopsy report do not support that either. Toxicology was positive for antidepressant medication and benzodiazepines (tranquilizers) in the blood.
BMI = na

08-57 Cause of Death: Drowning

This 67-year-old male was a certified diver with an unknown amount of experience. He surfaced from a dive and was holding onto a platform and a line when he lost consciousness, and his face went into the water. The diver then sank toward the bottom, and his body was not recovered until 11 days later. An autopsy was performed, and the cause of death was determined to be drowning. Slight myocardial fibrosis was found at autopsy. Toxicology was positive for the presence of a decongestant in the blood. An evaluation of the equipment disclosed that the tank was empty, but with a delay of 11 days until recovery of the equipment, it is unclear if the diver truly ran out of air.
BMI = na

08-64 Cause of Death: Drowning

This 41-year-old female was a recently certified diver with minimal diving experience. She was practicing diving skills with her buddy in a local quarry. According to the investigation, the buddy surfaced and called for help. Other nearby divers, including a group of public safety divers, came to render assistance. She was pulled from the bottom at 28 ft (9 m), and resuscitation efforts were unsuccessful. If an autopsy was performed, the report was not available. The official investigative report was also not available. This likely represents a drowning death, though no trigger can be identified with the limited information available.
BMI = na

08-65 Cause of Death: Drowning due to Panic

This 43-year-old female, reportedly a certified diver, was diving as part of an excursion from a cruise ship. Her level of experience is unknown. She was diving in a group with a designated buddy. According to the investigation, immediately upon reaching the bottom, the diver panicked and wanted to ascend. She was brought to the surface by her buddy and the divemaster. The diver reportedly lost consciousness on the boat and had foam emanating from her mouth. This likely represents a drowning with panic as a trigger. An air embolism cannot completely be excluded. One newspaper report stated that the death was due to natural causes, but that is highly unlikely. An autopsy was performed but the results were not made available.
BMI = na

Proximate Cause: Unspecified or Body Not Recovered

08-03 Cause of Death: Unknown Cause, Body Not Recovered.

This 19-year-old female was a student in an initial open water certification course. The group included nine students and one instructor, and the dive platform was a boat. The dive was made to 60 fsw (18 msw) in cold water with limited visibility and a strong current. The diver became separated from the group at the 15 fsw (5 msw) safety stop, and her body was never recovered.
BMI = na

08-39 Cause of Death: Unknown

This 51-year-old female recently completed initial open water certification and had minimal diving experience. She was making her second dive of the day off a charter boat to a maximum depth of 42 fsw (13 msw). The diver surfaced with her buddy in rough seas, far from the boat. She had a difficult time on the surface, and the buddy saw her floating on her back with her regulator out of her mouth. The diver lost consciousness, and, by the time the divers were pulled into the boat, the stricken diver could not be resuscitated. An autopsy was performed, documenting changes associated with drowning and also some blunt force trauma to neck structures. The medical examiner could not find a reasonable source for the neck injuries, and the cause of death was left undetermined.
BMI = na

08-58 Cause of Death: Unknown

This 38-year-old female was an experienced, certified diver making a deep dive using a rebreather. The dive profile was to 170 fsw (52 msw) for 43 min and, according to the investigation, it was uneventful. The diver and her buddy ascended to a decompression stop, then surfaced. On the boat, the diver complained of weakness and then lost her vision. She was taken to a recompression chamber for treatment, but several hours later she went into cardiac arrest and died. It is unclear if an autopsy was performed, but one report stated that the cause of death was “hypoxia,” which is absolutely inaccurate. This death most likely was due to an air embolism, paradoxical embolus, or decompression sickness.
BMI = na

08-59 Cause of Death: Unknown

There is not much information available on the death of this 54-year-old female. Her dive certification status and experience level are unknown. She and her dive buddy made a dive from a boat, but the profile is unknown. The day prior to the dive she was coughing quite a bit but said that she was fine. During the dive, she signaled to her buddy that she wanted to surface. As her buddy preceded the diver into the boat, she lost consciousness. If an autopsy was performed, the findings were not made available. This death was likely due to a medical problem, though the cough may have been related to an air trapping issue, and an air embolism is certainly a possibility.
BMI = na

08-60 Cause of Death: Unknown

This 53-year-old male was an experienced diver with rescue diver certification. He made a dive from a boat, with a buddy, to 55 fsw (17 msw) for 20 min and included a safety stop. The diver surfaced ahead of his buddy and then called for help. He went into cardiac arrest on the boat and died. If an autopsy was performed, the findings were not made available. The diver had a history of diabetes and, according to the investigative information, he was diaphoretic while walking through the airport, stating that he missed an insulin injection. This death was very likely due to a medical problem and most likely due to a cardiac event.
BMI = na

08-63 Cause of Death: Unknown

There is very little information about the diving-related death of this 45-year-old female. Her certification status and level of experience are uncertain, but it appears to be that she was a certified diver. She and a buddy made a shore-entry dive, and witnesses saw the buddy waving for assistance with the unconscious diver next to him. Resuscitation efforts were unsuccessful, and the diver was pronounced dead at a local hospital. An autopsy was conducted, but the findings were not disclosed.
BMI = na

08-73 Cause of Death: Unknown

There is very little information about the circumstances surrounding the death of this 28-year-old female who was a certified dive instructor. She planned two dives for the day. The first was shallow and reported to have been uneventful. The diver surfaced, and it was reported that her regulator fell from her mouth but she put it back in. She then lost consciousness, and resuscitation efforts were unsuccessful. An autopsy was performed, but the findings were not made available.
BMI = na

08-74 Cause of Death: Unknown

This 58-year-old male made a shore entry for his second dive of the day into a lake. His certification and experience level are unknown. He was diving with a buddy, completed the dive and was swimming back to shore, when he apparently lost consciousness on the surface. This likely was a cardiac event or possibly an air embolism.
BMI = na

08-77 Cause of Death: Unknown, Body Not Recovered
This 69-year-old male made a dive to 120 fsw (37 msw) and was last seen at a decompression stop at 60 fsw (18 msw). According to the investigative information available, the diver may have been a black coral diver. The body was never recovered.
BMI = na

08-79 Cause of Death: Unknown
This 40-year-old male was performing his second dive of the day on a wreck in 40 ft (12 m) of water when he lost consciousness at depth. There had only been five minutes of bottom time at that point. The buddy helped the stricken diver to the surface where resuscitation efforts were unsuccessful. If an autopsy was performed, the report was not made available. Loss of consciousness at depth is typically a medical problem, though tainted breathing gas could also cause this.
BMI = na

08-80 Cause of Death: Unknown
There is not much known about the circumstances surrounding the death of this 64-year-old male. His certification and experience status is unknown. He made a shore entry into cold water and was later found floating unconscious. One report called this a "skin diving accident," but it appears that the diver used scuba. This most likely represents a cardiac-related death, but there is too little information available to be conclusive.
BMI = na

08-81 Cause of Death: Unknown
This 53-year-old male had been a certified diver for five years and went diving regularly. He made a dive with a group of divers from a boat into a lake, but while the rest of the group followed the divemaster, the decedent went off on his own. The dive profile is unknown, but the investigation report states the dive was in "shallow water." The diver surfaced in distress then lost consciousness. Resuscitation efforts were unsuccessful. An autopsy was performed, but the findings were not made available. This most likely was a cardiac event, though an air embolism cannot be excluded. Air embolism is less likely to occur in experienced divers.
BMI = na

08-82 Cause of Death: Unknown
This 64-year-old male made a shore entry dive with five other divers in relatively clear and calm water. He experienced some buoyancy problems and separated from the other divers to head back to shore. The other divers completed the dive and returned to shore, but the decedent was not there. An extensive search followed, but the diver could not be found. Two days later, two fishermen found his body floating on the surface. If an autopsy was conducted, the report was not made available. With the information available this most likely represents an air embolism or cardiac event.
BMI = na

Proximate Cause: Other

08-27 Cause of Death: Anoxic Brain Injury due to Near Drowning Incident due to Entrapment (submerged tree)
This 20-year-old female was a certified diver and a student in an introduction to cave diving course. The dive was made on nitrox, and the diver was paired up with the instructor one-on-one. The diver may have had equalization problems, and the instructor brought her back to the cave entrance assuming she would go to the surface from there. According to the investigative report, the diver was found unconscious and "trapped" under a submerged tree. She was brought to the surface and resuscitated. The diver spent 16 days on life support and eventually succumbed to anoxic brain injury.
BMI = na

08-34 Cause of Death: Decompression Sickness
This 55-year-old male had been certified in basic open water diving for approximately one year and had logged nearly 90 dives. He completed his second dive of the day; the dive was to 78 fsw (24 msw) for 53 min and included a safety stop. Once back in the boat, the diver began to feel poorly and complained of tingling in his fingers and shortness of breath. He was taken to a medical treatment facility and treated with hyperbaric oxygen, but the diver's condition continued to deteriorate and he spent six days in a coma prior to death. The diver's medical history is unknown, but he was morbidly obese. The autopsy revealed marked cardiomegaly, mild coronary artery disease, and an incidental renal cell carcinoma. The autopsy also demonstrated the presence of an acute myocardial infarction and pulmonary emboli, but these would have occurred during the hospitalization. The cause of death in this case was determined to be decompression sickness with complications. The investigation revealed that the diver may have even been symptomatic during the second dive.
BMI = 42.0 $kg \cdot m^{-2}$

08-52 Cause of Death: Pulmonary Insufficiency due to Pulmonary Sarcoidosis
This 57-year-old male was making a dive organized through the cruise ship he was on. He had an unknown dive training or certification status. The diver passed on making the first dive, stating that he had regulator problems. On the next dive, the decedent went to 35-40 fsw (11-12 msw) and ran low on air. On the surface, the diver complained of trouble breathing and he lost consciousness as he was being towed to the boat. Resuscitation efforts were unsuccessful.

The diver's past medical history included a biopsy-proven diagnosis of pulmonary sarcoidosis. He also had asthma and was obese. The cause of death was determined to be immersion pulmonary edema, but the investigation report states that the diver complained of trouble breathing prior to immersion.
BMI = 35.4 $kg \cdot m^{-2}$

08-66 Cause of Death: Anoxic Brain Injury due to Near-Drowning Incident

This 69-year-old female was a student in an open water certification class. There is little information on the circumstances surrounding her death, but she had completed her first training dive to a maximum depth of 20 fsw (6 msw), had difficulty upon surfacing and was pulled to shore by an instructor. Resuscitation efforts were temporarily successful, but she died in a local hospital one week later. The initiating event is unknown, as she may have had a cardiac event, an air embolism, or simply panicked and aspirated water. She apparently sustained an anoxic brain injury during the event. If an autopsy was performed, the report was not made available.
BMI = na

08-78 Cause of Death: Anoxic Brain Injury due to Near-Drowning Incident

This 30-year-old male was a student in a rescue diver certification class. He separated from the group and was found on the bottom with his regulator out of his mouth. The diver was brought to the surface and resuscitated but died five days later of anoxic brain injury.
BMI = na

APPENDIX C. BREATH-HOLD INCIDENT CASE REPORTS

Neal W. Pollock and Niles W. Clarke

Hypoxic Blackout

08-0218

This 21-year-old male was spearfishing from an anchored boat when his speargun became lodged in coral. He dived down again to retrieve the speargun. He was observed to ascend to within approximately three feet (one meter) of the surface when he began to sink. The other occupant of the boat dived into the water but was unable to reach the victim. A later search by divers found some equipment belonging to the victim in the vicinity of the dive, but the body was not found.

The diver apparently exhibited no difficulties until quietly losing conscious and beginning to sink. Overweighting can cause a diver to sink; especially if gas is expelled from the airway during ascent. Defensive weighting establishes neutral buoyancy with an empty lung at a depth around 30 ft (9 m) or deeper. Momentum established during ascent can carry the diver to the surface even if consciousness is lost. A victim remaining at the surface is much more easily rescued.

In this case the disabling injury was almost certainly hypoxic loss of consciousness, exacerbated by ascent and overweighting, possibly triggered by excessive hyperventilation.

08-0227

This 29-year-old male was putting down lobster pots wearing a wetsuit, mask, snorkel, fins and 35-40 lb (16-18 kg) of weight on two belts. He was initially wearing only one belt when he swam out a small distance to where he dropped the first lobster pot in 15 ft (5 m) of water. He felt he needed more weight and asked for a second belt from a companion who remained on shore. He completed three dives without incident, but then his companion observed him stop ascending and sink just before breaking the surface. The companion entered the water but was unable to see victim so he left the water to get help. The victim's body was recovered by divers exactly where he was seen to descend. A post-mortem examination was completed, concluding that death was due to asphyxia by drowning.

This diver was clearly overweighted. It was not determined whether he hyperventilated before diving, but it is possible that he did so with the intention of increasing his breath-hold time to meet his working goals. If he was physically active on the bottom with a delayed urge to breathe, and then had to work hard to lift the excess ballast weight through the ascent, the drop in oxygen partial pressure as he neared the surface could have been the final link in the chain leading to a loss of consciousness. Defensive weighting would have had him remain at the surface where he might have been more easily rescued by his companion.

In this case the disabling injury appeared to be hypoxic loss of consciousness, exacerbated by overweighting and feasibly exercise, possibly triggered by excessive hyperventilation.

08-0230/0231

Two males, one 20-year-old and one 16-year-old, freedived together to 90 fsw (27 msw), a depth within the capabilities of the lead diver, but pushing the limits of the junior diver. Near the end of the ascent, the senior diver noticed that his partner was no longer ascending, apparently having lost consciousness at a depth around 30 fsw (9 msw). The senior diver immediately turned to provide assistance, and in the final stage of carrying the stricken diver to the surface, he too lost consciousness. Both were positively buoyant, so they remained at the surface. Companions on their anchored boat quickly saw them as unresponsive, dived in to remove them from the water, and began cardiopulmonary resuscitation. Emergency services were contacted and both victims were transported to hospital where they made a complete recovery.

These divers were extremely fortunate to have survived. The fact that they were weighted defensively (weighted to be positively buoyant with empty lungs around 30 fsw [9 msw] or deeper) was likely critical to their survival. The fact that they remained on the surface after losing consciousness made recognition and rescue by those on the boat much quicker and easier. Pushing his limits probably led to the loss of consciousness of the junior diver. It is not clear if anticipation may have encouraged him to do more hyperventilation than was safe or if he simply delayed surfacing for too long. Limiting increases in breath-hold time and/or depth to very small increments is the best way to expand a diving range safely. The lead diver was completing what would almost certainly have been a successful surfacing when he turned to offer assistance. The additional breath-hold time and effort involved in the rescue resulted in his loss of consciousness, with the pressure change of ascent a contributing factor.

In this case the disabling injury was hypoxia of ascent, loss of consciousness due to hypoxia, exacerbated by ascent, possibly triggered by excessive hyperventilation in the case of the junior diver, exacerbated by unexpected exertion and prolonged breath-hold time in the case of the senior diver.

08-0247

This 19-year-old male was spearfishing with a partner from a boat anchored approximately 70 mi (110 km) offshore. The last dive of the day was conducted over a bottom at 180 fsw (55 msw). After a "thorough five to-seven-minute surface breathe-up," the diver dropped to the 75-100 fsw (23-30 msw) depth range to look for big fish. After one minute of fruitless searching, he decided to head for the surface. His partner watched most of the ascent and then dropped down to look for fish. The victim diver recalled seeing surface ripples from approximately 25 fsw (8 msw) and then his memory ended as he lost consciousness with no warning. The partner, lining up to shoot a fish around 75 fsw, noticed out of the corner of his eye the white handle of the victim's speargun dropping past him. He then saw the victim sinking headfirst, unconscious and convulsing, approximately 60 ft (18 m) away from him at approximately his own depth. The partner immediately dropped his weight belt and swam for the victim. As he swam, he shot his speargun, successfully spearing one of the victim's longblade fins. The partner then surfaced, told others on the boat to cut the anchor line and reel in his shaft to recover the victim. The victim was brought to the surface after three to four minutes underwater. He was bleeding through eyes, ears, nose and mouth and oozed a small amount of frothy sputum from the mouth. He was turned on his side to drain the fluid. He was not initially breathing but still had a weak pulse. Before artificial resuscitation was started, he made the small first of a slow progressive series of sputtering efforts. After a total of 15-20 min of unresponsiveness, he slurred some words. The boat at this point was speeding toward shore. The victim described slowly regaining motor functions and lung capacity (up to about 30% of normal) by the time a Coast Guard helicopter arrived 45 min after the original accident to transfer him to a land-based hospital. He was released after four days in the hospital with no sequelae.

In this case the disabling injury was hypoxia of ascent, loss of consciousness due to hypoxia, exacerbated by ascent, triggered by excessive hyperventilation that delayed the urge to breathe.

08-0252

This 56-year-old female was freediving off a vessel anchored in 62 fsw (19 msw) at a remote site. The underwater visibility was estimated at 50 ft (15 m) and current at 0.3 kt (0.6 $km \cdot h^{-1}$). She entered the water alone for late-day swimming and freediving. She did not wear a wetsuit, but wore the weightbelt she normally wore with one. She was attached to a buoy and a 75 ft (23 m) floatline that was to be watched by persons remaining on the boat. After a series of shallow dives, she initiated what was thought by one observer to be a dive to the bottom. She was seen to ascend along the anchor line and then let go of it approximately three feet (one meter) beneath the surface. The observer assumed that the victim intended to swim under the boat. When she did not surface as expected a deckhand was notified to assist. The diver could not immediately be found, but the buoy was seen to be caught on a stabilizer fin of the boat. One observer donned a mask and looked into the water to see the victim held in place by the line at a depth of approximately 30 ft (9 m). The victim was then hauled by the line to the surface and removed from the water onto the deck. She was found to have no breathing or pulse. There was blood and foam coming out of her nose and mouth, and her eyes were open but vacant of consciousness. Cardiopulmonary resuscitation was initiated and a pulse found within one minute. An oxygen system was then deployed, initially with manual ventilation, then with continuous flow at 15 $L \cdot min^{-1}$ from an ample high pressure supply. Transport to medical aid was initiated, involving the incident boat and transfers to a faster boat with ultimate delivery to a shore-based ambulance and hospital approximately four hours later. The victim was reported to have gone into cardiac arrest three times during the transport, but was stabilized in the hospital. She woke in the hospital, more than 10 hours after the accident, with more than two days of memory loss and a good prognosis.

The excess weight worn by this diver kept her from being positively buoyant near the surface, creating a clear safety issue. Diving without a partner or partners who may have more rapidly identified the problem and rendered assistance increased the hazard. Her recovery and survival followed an almost incredible string of fortuitous events. She was saved by the buoy being caught on the boat, then by fairly prompt action by surface observers, then by capable first aid support upon removal from the water, and then by assistance to speed her transport to definitive medical aid.

In this case the disabling injury was hypoxia of ascent, loss of consciousness due to hypoxia, exacerbated by ascent, possibly triggered by excessive hyperventilation. Contributing factors were overweighting and solo diving.

Medical Health

08-0220

This 57-year-old male was found unresponsive while in the water snorkeling alone. Efforts at resuscitation were unsuccessful. An autopsy confirmed multiple significant risk factors for cardiac arrhythmia, including heart enlargement, hypertension, and extensive cardiac scarring consistent with a previous heart attack. All toxicological studies were negative. This appeared to be a case of fatal cardiac dysrhythmia triggered by the physical effort of snorkeling activity.

Snorkelers can experience significant physiological strain from water immersion, breathing resistance and physical effort. The presence of a partner or group can provide necessary support to avoid the worsening of a situation.

In this case the disabling agent appeared to be cardiac dysrhythmia, triggered by the physical effort of snorkeling.

08-0221

This 65-year-old male was snorkeling with a group of cruise ship passengers. After about 30 min of snorkeling, he reported feeling tired so they decided to return to the beach. While at the water's edge, the victim developed difficulties breathing and reported feeling chest pains. He was assisted by other persons from the group, and transported to a local clinic by ambulance. He went into full cardiopulmonary arrest during transport and could not be revived at the clinic.

Snorkelers can experience significant physiological strain through the combination of immersion, breathing through a snorkel, moving through a dense medium wearing unfamiliar equipment, sea state conditions, and general excitation. Snorkeling is not a completely benign activity that should be open to all not able to scuba dive. Individuals with health or physical compromise are well advised to discuss suitable activity options with their medical monitors.

In this case the disabling agent appeared to be cardiac dysrhythmia, triggered by the physical effort of snorkeling.

08-0223

This 82-year-old was snorkeling with a group from a cruise ship in tropical waters. Staff members noticed the man experiencing breathing difficulties, but when questioned, he was fine and wanted to continue. He was found unconscious in the water a short time later. Attempts at resuscitation were unsuccessful.

Snorkelers can experience significant physiological strain. Early recognition of problems and decisive action to reduce the stress can be important in the final outcome.

In this case the disabling agent appeared to be cardiac dysrhythmia, triggered by the physical effort of snorkeling.

08-0254

This 66-year-old male was participating in routine snorkeling activity with a group of boys when he complained of not feeling well. He was pulled onboard a boat, at which time he collapsed and lost consciousness. Emergency services transported him to the local medical clinic. Efforts at resuscitation were unsuccessful.

Snorkelers can experience significant physiological strain. Early recognition of problems and decisive action to reduce the stress can be important in the final outcome.

In this case the disabling agent appeared to be cardiac dysrhythmia, triggered by the physical effort of snorkeling.

08-6001

This 67-year-old male was spearfishing on breath-hold 40-50 mi (64-80 km) offshore with a group from a boat. He completed three dives; the first to 25 fsw (8 msw); the second to 56 fsw (17 msw) for 59 s, and the third to 54 fsw (16 msw) for 59 s. He surfaced with a fish after the first dive. After surfacing from the third dive, he began a repetitive pattern of asking who had shot the fish (the one he had shot). He was taken to a local clinic and was evaluated by a paramedic. The diver was alert and knew his name, but did not know where he was or what had happened. He had normal blood pressure, was slightly tachycardic, and his pupils were constricted and not reactive to light. He was evacuated to a major medical center for a higher level of care. The working diagnosis was cerebrovascular accident (stroke). No follow-up information was available.

Although this individual was diving, diving was not necessarily the cause of his problem. Both diving-related and non-diving issues can develop during periods of diving activity and may present in a similar fashion. For example, stroke, hypoglycemia (low blood sugar), and head trauma may have overlap in symptoms presented. Medical evaluation is warranted for any altered level of consciousness.

In this case the disabling agent was most likely stroke, possibly triggered by the stressors associated with breath-hold spearfishing.

08-5835

This 44-year-old male diving instructor took Sudafed® prophylactically (with no congestion) and freedived to a depth of 35 fsw (11 msw) with no equalization issues. He experienced a ringing tone in his ear in the afternoon and into the evening. He woke the next morning with a near total hearing loss. The examining physician found no injury the day after the event, but a hearing test indicated partial compromise. Antibiotics were prescribed. Normal hearing was incrementally restored over the next three to four days. His hearing was determined to be normal during third- or fourth-day follow-up testing.

Although this individual was diving, diving was not necessarily the cause of his problem. Both diving-related and non-diving issues can develop during periods of diving activity. Sudden hearing loss (SHL) can occur at any time and for many reasons. In some cases, early medical evaluation is critical to ensure resolution.

In this case the disabling agent appeared to be sudden hearing loss, cause, trigger, and contributing factors unknown.

Diving Health

08-5936

This 49-year-old male was freediving repeatedly to depths of 30-40 fsw (9-12 msw) when he experienced vertigo during one of his dives with nausea and vomiting that took two hours to resolve post-dive. He had completed 10 scuba dives in the days prior to this vertigo incident. Following all dives, he subsequently began developing some dizziness at the surface, but not reaching the severity of vertigo. He reported a history of slow equalization and chronic congestion, often managed with decongestant sprays prescribed by his physician. The Medical Services staff advised the diver to stop diving until evaluated by an ear, nose and throat physician specialist (ENT). No follow-up information was available.

The middle ear must be equalized to match changes in ambient pressure. Middle ear barotrauma is a common diving injury resulting from improper equalization. Symptoms can include pain, change in hearing acuity, bleeding from ear or into the throat, dizziness and vertigo. Inner ear barotrauma can also occur. Neither compressed gas diving nor freediving is recommended for individuals unable to equalize middle ear pressure effectively without pain or other symptoms of disorder.

In this case the disabling agent may have been inner ear disorder, triggered by the equalization efforts associated with diving.

08-5595

This 25-year-old male was freediving with a partner down to depths of 330 fsw (100 msw). He reported experiencing symptoms consistent with severe narcosis at depth. After surfacing, he felt a “strange sensation” in his left leg. He proceeded to breathe 100% oxygen at 13 fsw (4 msw) for five minutes, swam into shore and continued to breathe oxygen for another two minutes. His symptoms persisted, so he repeated the oxygen breathing at 13 fsw. At this point his partner contacted DAN on his behalf. The Medical Services staff member recommended that the diver stay out of the water, continue breathing oxygen, and be taken to the nearest emergency department to be medically evaluated. No follow-up information was available.

Anecdotal symptoms consistent with decompression sickness (DCS) have long been reported from the freediving community. While some are likely not DCS, it is possible that repeated deep exposures could result in sufficient loading of fast tissues so that the fast ascent rate could result in transient problems. To ensure full recovery, freedivers should maintain adequate surface intervals between dives, at least twice the duration of the breath-hold, but progressively longer as depth increases, and avoid repetitive deep diving. No symptoms, sustained or transient, should be ignored. Medical evaluation is warranted.

In this case the disabling agent was possibly acute decompression stress, possibly triggered by the very fast vertical travel rates, particularly during ascent, associated with freediving.

08-6213

This 16-year-old male reported chest pain following freediving spearfishing. Medical evaluation determined pneumomediastinum that resolved along with the chest pain after 48 hours. The physician called DAN for a consult. The patient was advised to avoid diving for about five weeks.

Lung packing is sometimes used by breath-hold divers to increase the volume of gas in the lungs above normal total lung capacity. This practice increases the likelihood of overexpansion injury. Lung packing should be strictly limited for safety. Any symptoms of chest pain or breathing difficulty should be evaluated by qualified medical personnel.

In this case the disabling agent was pulmonary barotrauma, likely triggered by excessive pulmonary pressures during freediving.

Boat Strikes

08-0421

This 60-year-old male was snorkeling with two others in an area marked as designated for diving. A twin engine speed boat crossed the area at high speed, missing the other two but striking this diver. One propeller hit him in the head, and the other hit his leg just above the ankle. A boat was flagged down to help that coincidentally had medically trained persons onboard. They managed to stabilize the victim through transport to the local medical clinic. He was then airlifted to a regional hospital where the first of several surgeries was successfully conducted.

Swimmers or snorkelers present a low profile in the water that is difficult to see, particularly if they are motionless on the surface and not displaying highly visible colors that can be seen in all directions. Swimming or snorkeling in areas of frequent or high speed boat traffic increases the risk of interactions. Protection is increased by diving in areas in which boat traffic is restricted, employing appropriate flags and buoy markers, wearing high visibility equipment, and maintaining vigilance.

In this case, the disabling injury was a propeller strike. Factors contributing to the accident included the overlap of snorkeling and boating activity, a lack of situational awareness on the part of the boat crew, and low visibility and suboptimal awareness on the part of the snorkelers.

08-1230

This 25-year-old male was snorkeling with a partner in shallow water (8 fsw [2.5 msw]) approximately 200 ft (60 m) from shore when a fast and highly maneuverable tourist boat struck him. Passengers in the boat alerted the skipper of the incident. The snorkelers were not using a dive flag (which was not required by law).

Swimmers or snorkelers present a low profile in the water that is difficult to see, particularly if they are motionless on the surface and not displaying high visibility colors that can be seen in all directions. A fast boat can reach a surface swimmer before there is time to react. High maneuverability does not protect against difficult-to-see objects.

In this case, the disabling injury was a boat strike. Factors contributing to the accident included the overlap of snorkeling and boating activity, lack of awareness on the part of the boat crew, and low visibility of the snorkelers.

APPENDIX D. PUBLICATIONS (2013-2008)

2013

Refereed Articles (primary literature)

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APPENDIX E. PRESENTATIONS BY RESEARCH AND MEDICINE PERSONNEL (2013-2011)

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

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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).

2012

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).

Denoble PJ. Delay to recompression and the outcome of DCI. How it may affect your dive plan. UHMS Northeast Chapter Meeting. Springfield, MA (Sep 2012).

Denoble PJ. Prevalence of sudden cardiac death risk factors in scuba divers – an online survey. UJNR. Tokyo, Japan (Oct 2012).

Denoble PJ. PFO online chat. DAN (Oct 2012). Transcript of Live Chat with Dr. Petar Denoble from DAN on the topic of PFO. Accessible: http://www.scubaboard.com/forums/content/506-dr-petar-denoble-log.html

Denoble PJ. Delay to recompression and the outcome of DCI. How it may affect your dive plan. Eurotek. Birmingham, UK (14 Oct 2012).

Bird N. Management of DCS in remote locations. UHMS Pacific Coast Chapter Meeting. Portland, OR (20 Oct 2012).

Denoble PJ. Delay to recompression and the outcome of DCI. How it may affect your dive plan. DEMA. Las Vegas, NV (14-18 Nov 2012).

Denoble PJ. Chronic diseases and the safety of diving. Results from DAN Membership Health Survey. DEMA. Las Vegas, NV (14-18 Nov 2012).

Denoble PJ. Oxygen toxicity. Drugs that can modify it. DEMA. Las Vegas, NV (14-18 Nov 2012).

Pollock NW. Thermal stress and diving. DEMA. Las Vegas, NV (14-18 Nov 2012).

Pollock NW. Managing the aging diver. DEMA. Las Vegas, NV (14-18 Nov 2012).

Pollock NW. The deep end of diving research. DEMA. Las Vegas, NV (14-18 Nov 2012).

Pollock NW. Antarctica and polar diving. Durham Academy. Durham, NC (28 Nov 2012).

Pollock NW. Breath-hold physiology. DAN DMT course. Durham, NC. (28 Nov 2012).

Pollock NW. Thermal stress and protection. Aquasport International. Birmingham, England (29 Nov 2012).

Denoble PJ. Medical research at DAN. School of Medicine, São Paulo University. São Paulo, Brasil (30 Nov 2012).

Denoble PJ. Diving injuries and fatalities. Brasilian data in DAN database. Workshop DAN Brasil sobre Acidentes Fatais. Itupeva, SP (01 Dec 2012).

Denoble PJ. New on-line incident report system. Workshop DAN Brasil sobre Acidentes Fatais. Itupeva, SP (01 Dec 2012).

Denoble PJ. Consensus discussion - Prevention initiatives (moderator). Workshop DAN Brasil sobre Acidentes Fatais. Itupeva, SP (01 Dec 2012).

Pollock NW. The lore of diving - unfounded beliefs in diving physiology. UK Diving Trade Show. Warwickshire, England (02 Dec 2012).

Pollock NW. Concerns of the aging diver. UK Diving Trade Show. Warwickshire, England (03 Dec 2012).

Denoble PJ. Delay to recompression and the outcome of DCI. How it may affect your dive plan. DAN Public Lecture Series. Durham, NC (15 Dec 2012).

2011

Pollock NW. Tricks and traps in presentation development and delivery. DAN. Durham, NC (13 Jan 2011).

Pollock NW. Antarctica and polar diving. Durham Academy. Durham, NC (26 Jan 2011).

Bird N. Dive safety tips. Scuba Radio. Orlando, FL (22 Jan 2011).

Bird N. Medications and diving and mechanisms of dive accidents. Hyperbaric Medicine Winter Symposium. Breckenridge, CO (29 Jan 2011).

Denoble PJ. PFO and DCS. Why divers test for PFO or choose the closure? Our World Underwater. Chicago, IL (Feb 2011).

Denoble PJ. When, why and how to start treatment for DCI. Our World Underwater. Chicago, IL (Feb 2011).

Pollock NW. Cardiorespiratory and exercise physiology I. CBI 206 Duke University. Durham, NC (02 Feb 2011).

Pollock NW. Long-term effects of diving. DAN Public Lecture Series. Durham, NC (02 Feb 2011).

Pollock NW. How physically fit is fit to dive? Down Under Dive Club. Cary, NC (08 Feb 2011).

Pollock NW. Cardiorespiratory and exercise physiology II. CBI 206. Duke University. Durham, NC (09 Feb 2011).

Pollock NW. Diving and diver protection. Wilderness Medical Society Student Elective. Townsend, TN (15 Feb 2011).

Pollock NW. Research diving in Antarctica. Wilderness Medical Society Student Elective. Townsend, TN (15 Feb 2011).

Denoble PJ. Applied physiology of decompression. AAUS Scientific Diving conference. Pine Knoll Shores, NC (Mar 2011).

Denoble PJ. Summary of fatality workshop. AAUS Scientific Diving conference. Pine Knoll Shores, NC (Mar 2011).

Denoble PJ. PFO and DCS. Why divers test for PFO or choose the closure? Beneath the Sea. Secaucus, NJ (Mar 2011).

Denoble PJ. When, why and how to start treatment for DCI. Beneath the Sea. Secaucus, NJ (Mar 2011).

Pollock NW. Thermal physiology. CBI 206. Duke University. Durham, NC (07 Mar 2011).

Pollock NW. Assessment of decompression exposure. International Congress on Hyperbaric Medicine. Cape Town, South Africa (18 Mar 2011).

Pollock NW. Ultrasonography in aerospace, diving and hyperbaric medicine. International Congress on Hyperbaric Medicine. Cape Town, South Africa (18 Mar 2011).

Bird N. Medications and diving. Day of DAN at Beneath the Sea. Secaucus, NJ (25 Mar 2011).

Bird N. How good is your emergency accident plan? Day of DAN at Beneath the Sea. Secaucus, NJ (25 Mar 2011).

Bird N. Mechanisms of dive accidents. Day of DAN at Beneath the Sea. Secaucus, NJ (25 Mar 2011).

Denoble PJ. Electronic dive profile. Hyperbaric Medicine Fellows. Duke. Durham, NC (Apr 2011).

Bird N. Mechanisms of dive accidents. Danbury Hospital. Danbury, CT (02 Apr 2011).

Pollock NW. Thermal physiology. DAN DMT course. Durham, NC (05 Apr 2011).

Pollock NW. Aviation physiology. CBI 206. Duke University. Durham, NC (06 Apr 2011).

Pollock NW. Diving safety fundamentals. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (10 Apr 2011).

Pollock NW. Physical fitness and diving safety. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (11 Apr 2011).

Pollock NW. Research diving in Antarctica. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (11 Apr 2011).

Pollock NW. Thermal physiology. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (12 Apr 2011).

Pollock NW. Nutrition and diving. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (13 Apr 2011).

Pollock NW. Flying after diving and high altitude depression. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (14 Apr 2011).

Pollock NW. Breath-hold diving. 69th DAN Dive Medicine CME program. Little Cayman, Cayman Islands (15 Apr 2011).

Bird N. Mechanisms of dive accidents. Blue Dolphin Dive Club. Winston-Salem, NC (29 Apr 2011).

Pollock NW. Research diving in Antarctica. Dive Club. Split, Croatia (04 May 2011).

Bird N. Diving medical concerns for trainers and aquarium staff. Sea World. Orlando, FL (11 May 2011).

Bird N. Stacking the deck - dive safety. Tobago Dive Carnival. Tobago, West Indies (17 May 2011).

Pollock NW. Decompression stress and outcomes in extreme diving. Inner Space. Grand Cayman (23 May 2011).

Bird N. Diving medicine and mixed gas diving (panel member). ER Residency. UNC Medical Center. Chapel Hill, NC (08 Jun 2011).

Pollock NW. Transthoracic echocardiography: research techniques. DAN. Durham, NC (23 Jun 2011).

Pollock NW. Diving physiology and safety research (Introduction to STEM careers). Labs for Learning. NC School of Science and Mathematics. Durham, NC (13 Jul 2011).

Bird N. Mechanisms of dive accidents. Triangle Diving. Bermuda (19 Jul 2011).

Denoble PJ. Fatalities in recreational open- and closed-circuit diving. IDAN Divers' Day. Gdansk, Poland (Aug 2011).

Denoble PJ. Medical issues in CCR diving. Hyperbaric Medicine conference. Malawan, FL (Aug 2011).

Denoble PJ. In-water recompression debate. Surface oxygen and evacuation better than in-water recompression. EUBS. Gdansk, Poland (Aug 2011).

Bird N. Medications and diving. Oxygen Research Foundation. Palm Beach, FL (04 Aug 2011).

Pollock NW. Flying after diving and high altitude decompression. NOAA Dive Medicine Course for Physicians. Seattle, WA (15 Aug 2011).

Pollock NW. Thermal considerations for diving. NOAA Dive Medicine Course for Physicians. Seattle, WA (16 Aug 2011).

Pollock NW. Special population divers. NOAA Dive Medicine Course for Physicians. Seattle, WA (16 Aug 2011).

Denoble PJ. Medical issues in rebreather diving. DAN DMT Course. Durham, NC (Sep 2011).

Denoble PJ. PFO and DCS. Why divers test for PFO or choose the closure? DAN DMT Course. Durham, NC (Sep 2011).

Pollock NW. Breath-hold safety. DAN World Seminars. Cozumel, Mexico (04 Oct 2011).

Pollock NW. Diving safety fundamentals. 70th DAN Dive Medicine CME program. Roatan, Honduras (23 Oct 2011).

Pollock NW. Physical fitness and diving safety. 70th DAN Dive Medicine CME program. Roatan, Honduras (24 Oct 2011).

Pollock NW. Research diving in Antarctica. 70th DAN Dive Medicine CME program. Roatan, Honduras (24 Oct 2011).

Pollock NW. Thermal physiology. 70th DAN Dive Medicine CME program. Roatan, Honduras (25 Oct 2011).

Pollock NW. Special population divers. 70th DAN Dive Medicine CME program. Roatan, Honduras (26 Oct 2011).

Pollock NW. Flying after diving and high altitude decompression. 70th DAN Dive Medicine CME program. Roatan, Honduras (27 Oct 2011).

Pollock NW. Breath-hold diving. 70th DAN Dive Medicine CME program. Roatan, Honduras (28 Oct 2011).

Pollock NW. Emergency oxygen: equipment and performance. DEMA. Orlando, FL (02 Nov 2011).

Pollock NW. How fit is fit to dive? DEMA. Orlando, FL (02 Nov 2011).

Pollock NW. Breath-hold diving. DEMA. Orlando, FL (03 Nov 2011).

Pollock NW. Concerns of the aging diver. DEMA. Orlando, FL (03 Nov 2011).

Pollock NW. How fit is fit to dive? DEMA. Orlando, FL (04 Nov 2011).

Pollock NW. Emergency oxygen: equipment and performance. DEMA. Orlando, FL (04 Nov 2011).

Pollock NW. Concerns of the aging diver. DEMA. Orlando, FL (05 Nov 2011).

Pollock NW. Breath-hold diving. DEMA. Orlando, FL (05 Nov 2011).

Pollock NW. What does physically fit to dive mean? UK Diving Medical Committee Meeting. Bristol, England (18 Nov 2011).

Pollock NW. Scientific diving. UK Diving Medical Committee Meeting. Bristol, England (18 Nov 2011).

Pollock NW. Diving with diabetes in the US. UK Diving Medical Committee Meeting. Bristol, England (19 Nov 2011).

Pollock NW. American Academy of Underwater Sciences history and initiatives. Society for Underwater Technology: Diving and Manned Submersibles Meeting. London, England (24 Nov 2011).

Pollock NW. Divers Alert Network research overview. Society for Underwater Technology: Diving and Manned Submersibles Meeting. London, England (24 Nov 2011).

Pollock NW. Thermal stress and diving. UK Diving Trade Show. Warwickshire, England (27 Nov 2011).

Pollock NW. How physically fit is fit to dive? UK Diving Trade Show. Warwickshire, England (28 Nov 2011).

Pollock NW. Antarctica and polar diving. Durham Academy. Durham, NC (30 Nov 2011).

APPENDIX F. 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.

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.

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·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.

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.

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.

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.

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·min^{-1} (2 ft·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.

Incidence
Count of new injuries in a defined population during a specified time period.

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).

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 (parametric). 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.

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.

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.

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 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.

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.

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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