DAN
YOUR DIVE SAFETY ASSOCIATION

ANNUAL DIVING REPORT
2009 Edition

A Report on 2007 Diving Incidents, Injuries and Fatalities

Annual Diving Report – 2009 Edition

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Pollock NW, Dunford RG, Denoble PJ, Caruso JL. Annual Diving Report - 2009 Edition (Based on 2007 Data). Durham, NC: Divers Alert Network, 2013; 153pp.

ACKNOWLEDGEMENTS

Data for the 2009 Annual Diving Report have been collected and assembled by DAN employees and associated professionals. DAN wishes to recognize the following for their important contributions:

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DAN America thanks all of the individuals involved in the worldwide diving safety network. This network includes many hyperbaric physicians, DAN on-call staff, nurses and technicians from the network of chambers who complete DAN reporting forms. DAN also thanks local sheriff, police, emergency medical personnel, Coast Guard, medical examiners, coroners and members of the public who have submitted incident data.

International DAN Offices

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

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INTRODUCTION

Neal W. Pollock, PhD

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 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."

Key sections of the report review our case capture for Project Dive Exploration (PDE), dive injuries, dive fatalities, and breath-hold incidents. The data described in the 2009 annual report is based on events occurring in 2007.

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 incidents (Appendix C).

A list of publications and materials authored or co-authored by DAN staff and affiliated investigators from 2007 through 2012 appear 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.

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 glossary of terms used in this report is located in Appendix E.

1.2 Data Collection at DAN

The data discussed in this report provides a cross-section of events occurring in the recreational diving community, not an exhaustive one. The report includes only data made available to DAN America and, only cases that could be followed up with a manageable effort. The majority of sections are limited to residents or citizens of the United States or Canada. The exception to this is the breath-hold incident section, which includes cases without 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 2007 was 14,962.

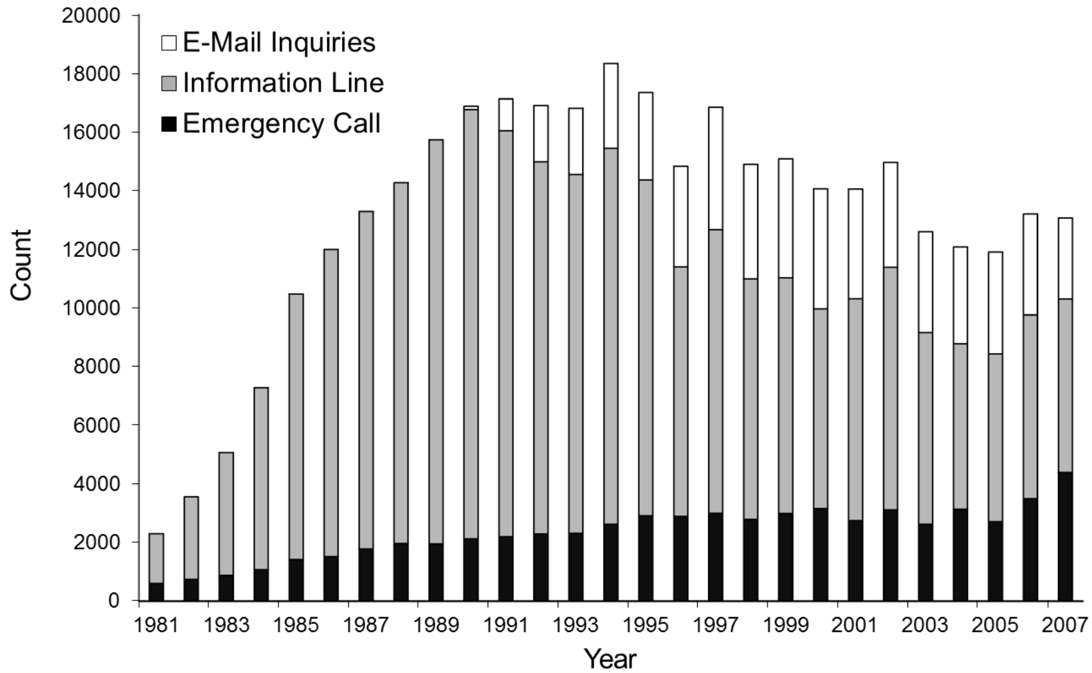

Figure 1.2-1 Emergency calls, information calls and e-mail requests for information

Information on dive injuries is captured by DAN America through the Medical Services Call Center (MSCC). A total of 7,872 calls or e-mails were logged into the MSCC system by DAN medics during the 2007 calendar year. The most common working diagnoses of the reported injuries were decompression sickness (DCS) and barotrauma (both at 26 percent), non-diving related (14 percent) and envenomation (six percent). DCS-like symptoms ranged from mild to severe, with many more cases being classified as possible rather than confirmed. Barotrauma most commonly involved the middle ear (50 percent), the lungs (15 percent), and the sinuses (14 percent). Details are found in Section 3 and Appendix A.

PDE is a prospective observational study of recreational diving that was initiated by DAN America in 1995. The cumulative history of PDE data collection is depicted in Figure 1.2-2. There were a total of 150,739 dives captured through 2007. The data capture for 2007 was 17,758 dives, up 19 percent from the previous year. Air was used as the breathing gas in 69 percent of dives and enriched air nitrox in 27 percent of dives. The vast majority of dives (98.5 percent) were described as uneventful. The most commonly reported problems involved buoyancy (0.9 percent) and rapid ascent (0.3 percent), again unchanged from the previous year. Four mild cases of decompression sickness (DCS) were captured, representing an incidence of 2.3 cases per 10,000 dives, similar to the 2.0 cases per 10,000 dives reported in the previous year. Details are found in Section 2.

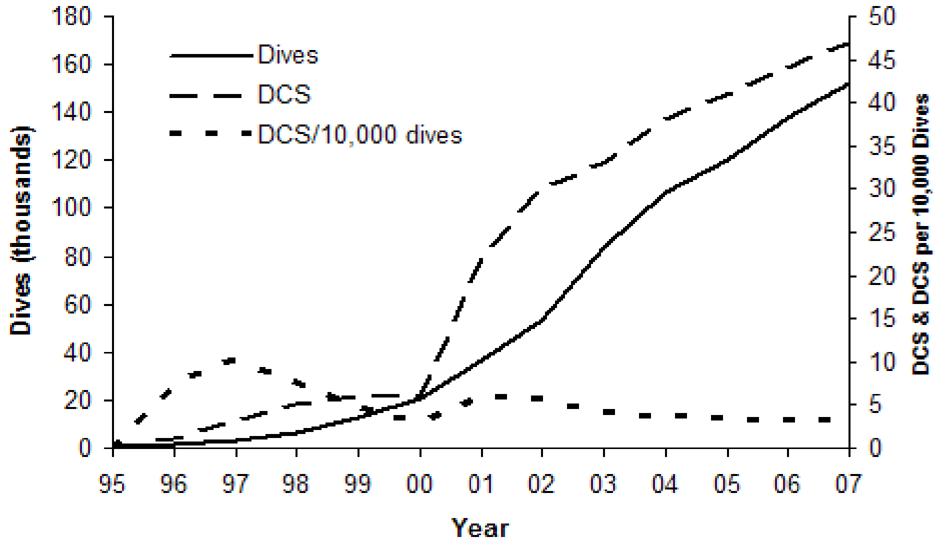

Figure 1.2-2 Cumulative Project Dive Exploration progress

A major effort to track US diving fatalities was started in 1970 by Mr. John McAniff of 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 1.2-3. The annual case intake for the 19-year period from 1989 through 2007 was 90±12 (mean±standard deviation), with a range of 67-114 cases. The 2007 intake was 113 cases, close to the peak for the 19-year period but still within the annual range. The maximum depth of fatal dives varied dramatically, with the largest cluster in the 0-30 ft (0-9 m) range. Approximately 50 percent of fatalities occurred no deeper than 65 ft (20 m). The most common disabling injuries were ranked as drowning, heart problems and arterial gas embolism, respectively. The most common medical history issues known for fatality victims were heart disease and high blood pressure, respectively, but information on medical history was rarely complete. Details are found in Section 4 and Appendix B.

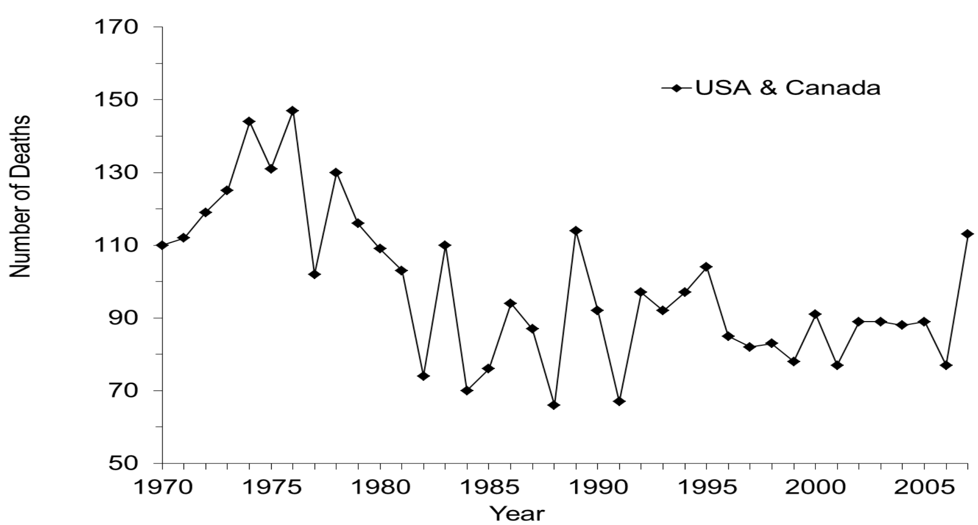

Figure 1.2-3 Annual record of US and Canadian diving fatalities

DAN America has collected unsolicited reports of breath-hold incidents since 1993. A dedicated effort to capture breath-hold case data was initiated in 2005, including cases from 2004 forward. Breath-hold sections were added to the annual report in 2005. Figure 1.2-4 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.

The annual case intake for the four-year period from 2004 through 2007 was 48±14 (mean±standard deviation), with a range of 30-59 cases. The 2007 case capture was 58 breath-hold incidents, 42 fatal (72 percent) and 16 non-fatal, similar to the previous year. Almost half of the events (46 percent) occurred within the US. The majority of victims were male (84 percent). Interpreting the often scant evidence is challenging, but the most frequently represented issues were animal-involved injuries (primarily by sharks), hypoxic blackout (induced by voluntary practice) and compromised medical health, respectively. Details are found in Section 5 and Appendix C.

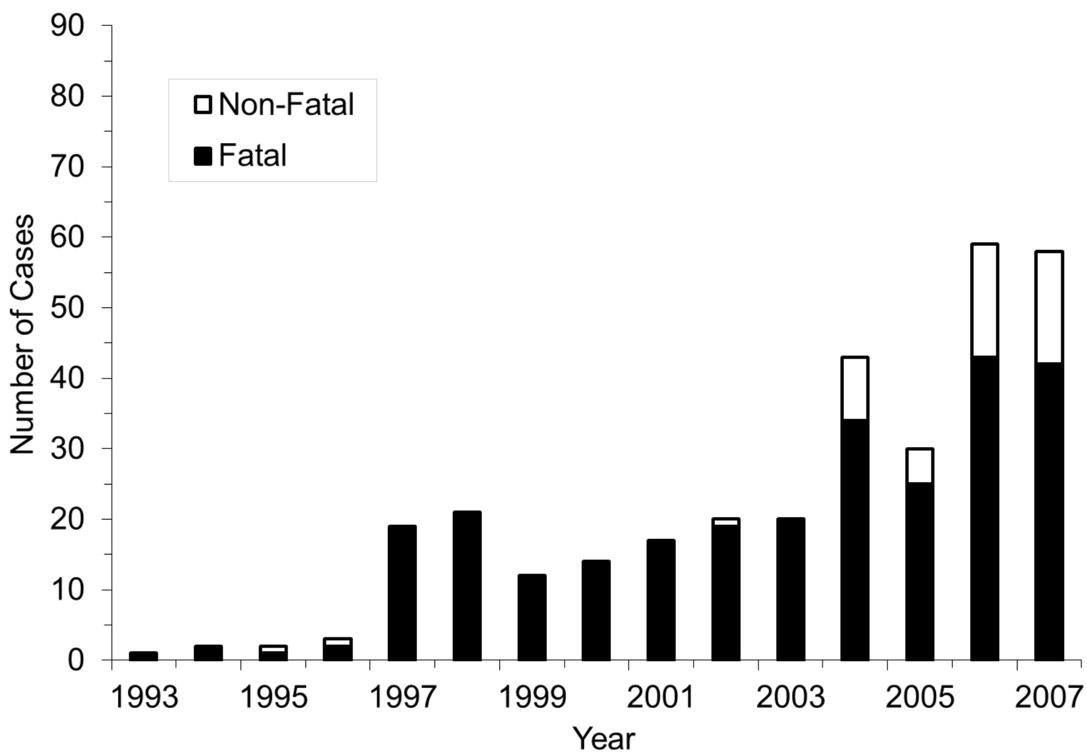

Figure 1.2-4 Annual record of captured breath-hold diving incidents

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. The actual conditions at the time of the dive need to be critically appraised to help ensure problem-free events.

The diving enthusiast will commit a great deal of time mastering the physics, physiology, equipment and environment to be fully prepared. The material found in this diving report can help. 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 and to be able to assist others in case of difficulty. The challenge is in the required level of physical fitness. The broad range of diving conditions makes a uniform 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 life long 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 rough rule of thumb target 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 non-stop in no more than 30 minutes 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

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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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PROJECT DIVE EXPLORATION

Richard G. Dunford, MS

2.1 PDE in 2007

Project Dive Exploration (PDE) collected data from 17,753 dives, 3,252 dive series and 1,064 divers during 2007. The total number of dives logged by PDE through 2007 was 150,739. Figure 2.1-1 shows cumulative data collection from 1995-2007. The reader is referred to the 2005 edition of the DAN Annual Diving Report for details on PDE objectives and methodology (Vann et al., 2005).

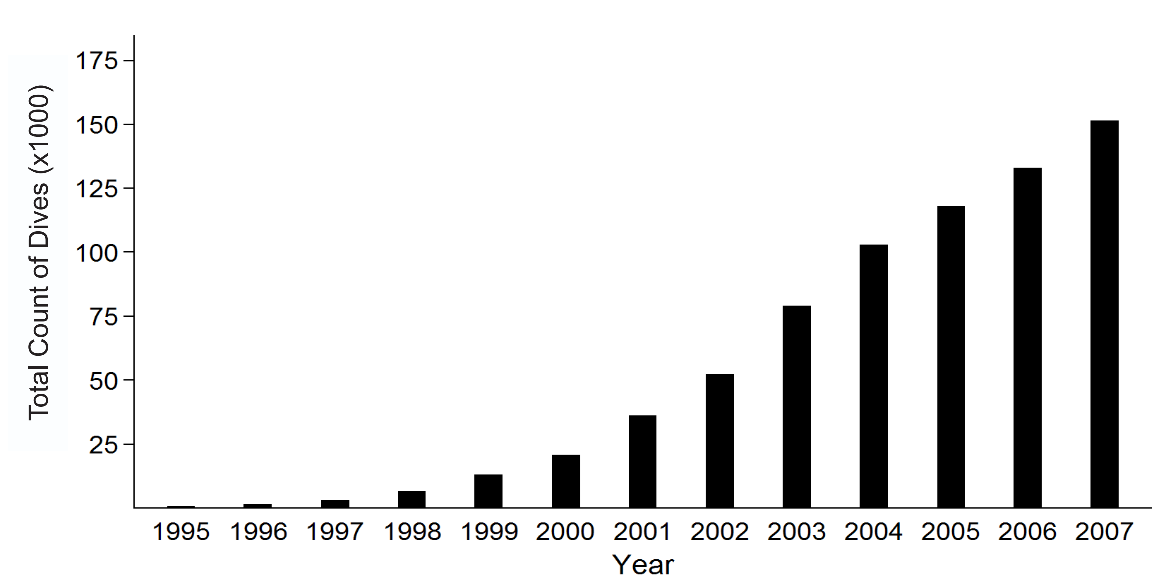


Figure 2.1-1 Cumulative number of PDE dives collected from 1995-2006 (n=150,739)

Table 2.2-1 shows dives in the groups that contributed PDE data for 2007. Individual divers reported the largest number of dives, while research interns at locations other than Scapa Flow, Scotland reported the second most dives. As collections centers stationed on liveaboards were discontinued in 2006, reports from liveaboards are no longer reported as a separate group but instead are rolled into non-Scapa Flow independent sources.

Table 2.1-1 Sources of PDE data

Source of Data	Scapa Flow	Other	Total
Research intern	2,028	4,499	6,527
Independent	1,469	9,762	11,231
Total	3,497	14,261	17758

Most dive logs are submitted directly to DAN by independent divers via the internet using Cochran, DiveRite, Uwatec and Suunto computers. Dive computer manufacturers have contributed to the PDE initiative by incorporating PDE-compatibility into their products. Check the DAN website to learn more about how you can contribute: http://www.diversalertnetwork.org/research/projects/pde/index.asp

2.2 Divers

This section presents information about PDE divers including age, sex, certification level, number of years since certification, chronic and acute medical conditions and body fat estimates.

The 1,032 diver volunteers participating in the 2007 PDE data collection were members of the general diving population but, as self-selected volunteers, it is unknown if they represented the general recreational diving population as a whole. Male divers (74 percent) outnumbered female divers in the dataset (Figure 2.2-1). Male age approximated a normal distribution with a peak in the 40-49 year range. The distribution of female age was similar with a peak in the 30-39 year range. Divers 50 years of age and older represent 25 percent of PDE volunteers, similar to the previous year. The overall mean age was 40.8 years. Males older than the mean age undertook 51 percent of dives by males while females older than the mean age undertook just 37 percent of dives by females. Adjusting for sex showed median age of 42 and 38 years for males and females, respectively. Using sex-specific median age, younger males accounted for 52 percent of male dives undertaken to a mean depth of 65 fsw (20 msw) while older males dived to a slightly greater mean depth of 67 fsw (20 msw) (t test, $p<0.01$). Female divers showed a similar trend with younger female divers undertaking 59 percent of female dives to a mean depth of 58 fsw (18 msw) and older female divers undertaking dives to a mean depth of 67 fsw (20 msw) (t test, $p<0.01$).

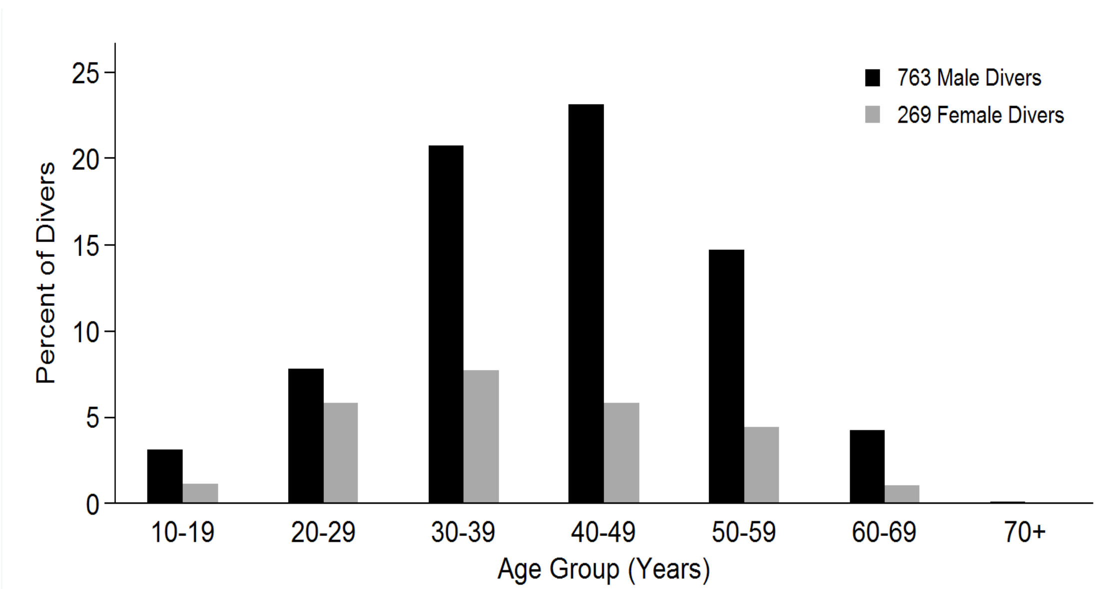


Figure 2.2-1 Age and sex of PDE divers (n=1,032)

Figure 2.2-2 shows the percent distribution of certifications held by male and female divers. Males generally held a higher percentage of certifications beyond basic. The exception is that six percent of males held cave or technical certification while eight percent of female divers held such certifications, an observation similar to the prior year's report. Students comprised 11 percent of combined male and female volunteers, a 10 percent decrease from the previous year. Male and female divers with student, basic, advanced/specialty or rescue certifications represented 61 percent of volunteers while contributing 51 percent of dives to the PDE database, indicating that divers with leadership certifications contributed a higher proportion of dives per diver. Twenty-seven percent of PDE divers held advanced basic or specialty certifications, while 12 percent held similar certifications in the prior year. A possible explanation for this difference is that relatively few PDE reports were generated from Caribbean liveaboards in this year compared to years past and may represent a shift in the demographics of volunteer divers.

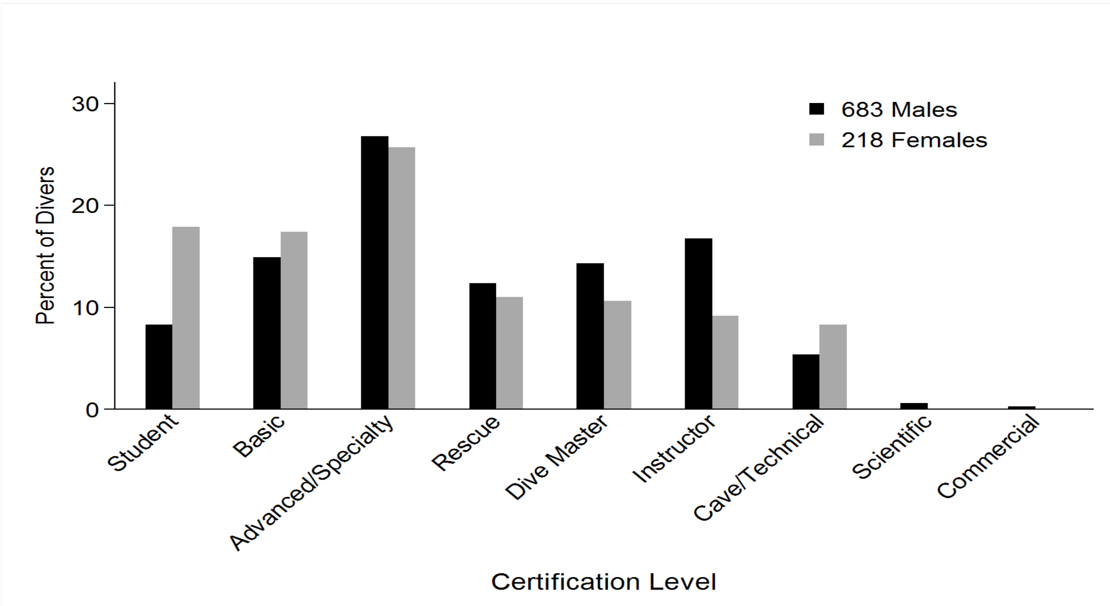


Figure 2.2-2 Certification level for males and females (n=901)

Thirty-one percent of volunteers were within five years of initial certification. This group has declined in size from about 42 percent recorded in 1998 (Table 2.2-1). Divers with more than 10 years since certification increased from 26 percent in 1998-1999 to 45 percent in 2007, demonstrating the continuing aging of the PDE population and reflecting a trend in the general diving population seen elsewhere.

Table 2.2-1 Percentage of PDE volunteers by number of years since certification (n=958)

Years of Diving	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1-5	42.3	42.8	46.3	42.6	40.8	36.3	39.0	34.5	30.9	30.7
6-10	25.3	23.7	21.0	19.4	18.4	20.5	23.4	25.4	27.6	23.8
>10	26.7	26.2	29.3	26.3	30.1	35.6	37.6	40.2	41.5	45.5

Figures 2.2-3 and 2.2-4 report chronic conditions and acute conditions respectively. PDE research interns used electronic forms to log medical conditions and only those reports are included. Thirty-eight percent of this subset of volunteers reported at least one chronic or acute medical condition. As in previous years, allergies, high blood pressure, and ear or sinus problems (cumulative 23 percent) were the most common chronic conditions reported (Figure 2.2-3).

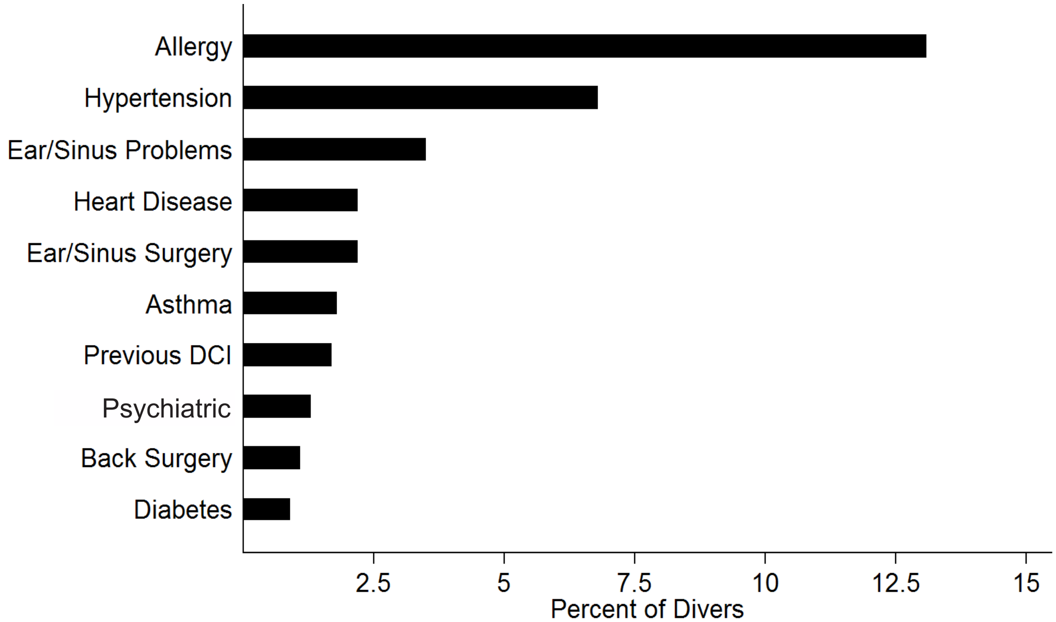


Figure 2.2-3 Chronic health conditions reported by PDE volunteers (n=544)

Acute health conditions were reported in 23 percent of this subset during at least one dive. Seasickness and orthopedic problems (joint, muscle or back pain) were most common at nine percent and eight percent, respectively (Figure 2.2-4). The use of decongestants, while not describing a condition per se, was reported by five percent of divers, possibly reflecting a prophylactic use of decongestants. Common cold or flu-like conditions were reported by two percent of divers.

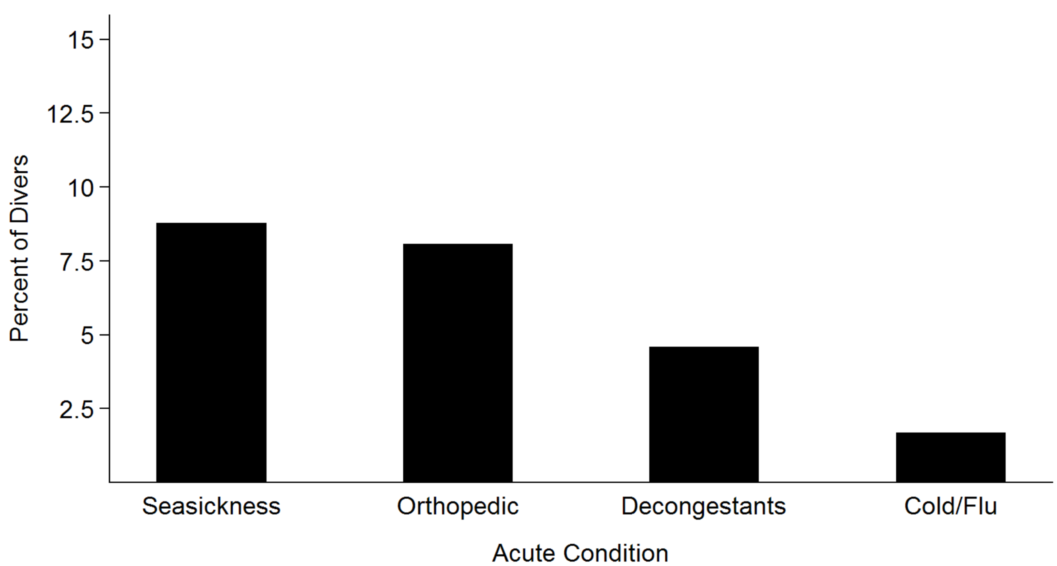


Figure 2.2-4 Acute health problems before diving reported by PDE divers (n=544)

Body mass index (BMI) is a simple population estimator of fatness. The majority of the females (55 percent) fell into the normal weight range (18.5–24.9 kg$\times$m^{-2}) while 42 percent of males were in the overweight range (25.0-29.9 kg·m^{-2}) (Figure 2.2-6). Twenty-three percent of male PDE volunteers and 14 percent of females fell into the obese range (≥30.0 kg·m^{-2}).

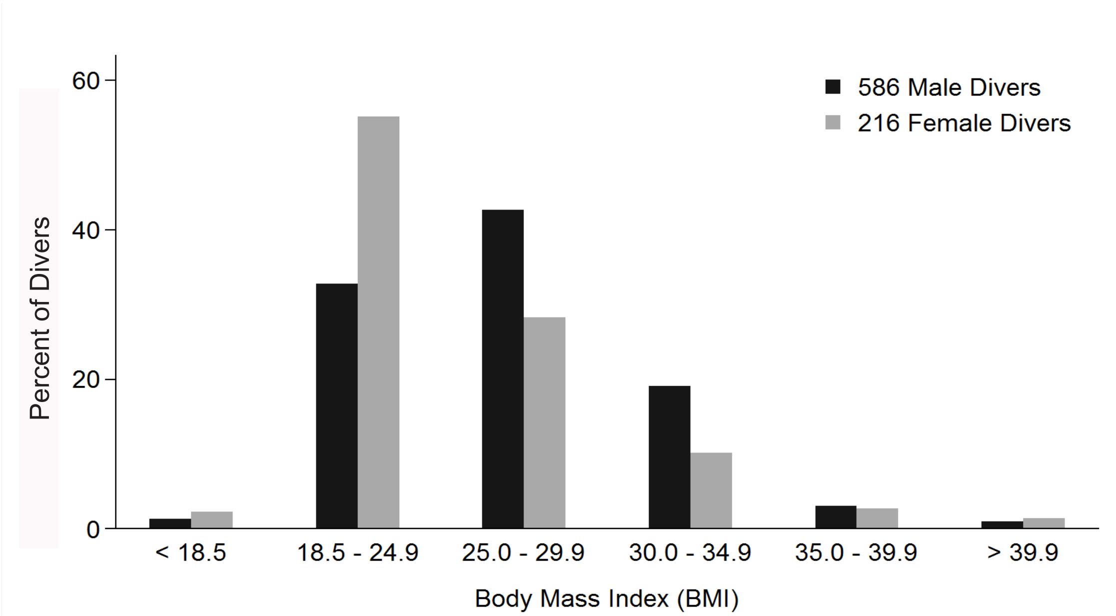


Figure 2.2-5 Distribution of body mass index BMI (kg·m^{-2} units) in PDE divers by sex (n=802)

2.3 Dive Conditions

This section reviews the diving environment, dive platform, breathing apparatus, purpose of dive, thermal protection, subjective thermal comfort, and subjective work rate. One model of dive computer contained a programming error that caused a significant number of dives to be labeled as 'other' in all the following categories but thermal comfort. These 'other' responses were not included in the analysis.

Eighty-seven percent of PDE dives were collected in saltwater while 13 percent came from freshwater. (Note: feet of seawater [fsw] and meters of seawater [msw] are the primary units of depth used in this report. Feet of freshwater [ffw] and meters of freshwater [mfw] are used where appropriate. In cases where saltwater and freshwater depths may be combined, feet [ft] and meter [m] units may be reported.) One percent of dives (n=139) were in caves or caverns. Thirty-two percent of dives were from charter dive boats and 16 percent from liveaboards (Figure 2.3-1). In previous years liveaboards contributed up to two-thirds of collected dives. Ninety-six percent of the dives used open-circuit breathing apparatus and just over four percent used rebreathers. Eighty-seven percent reported sightseeing as the purpose of the dive.

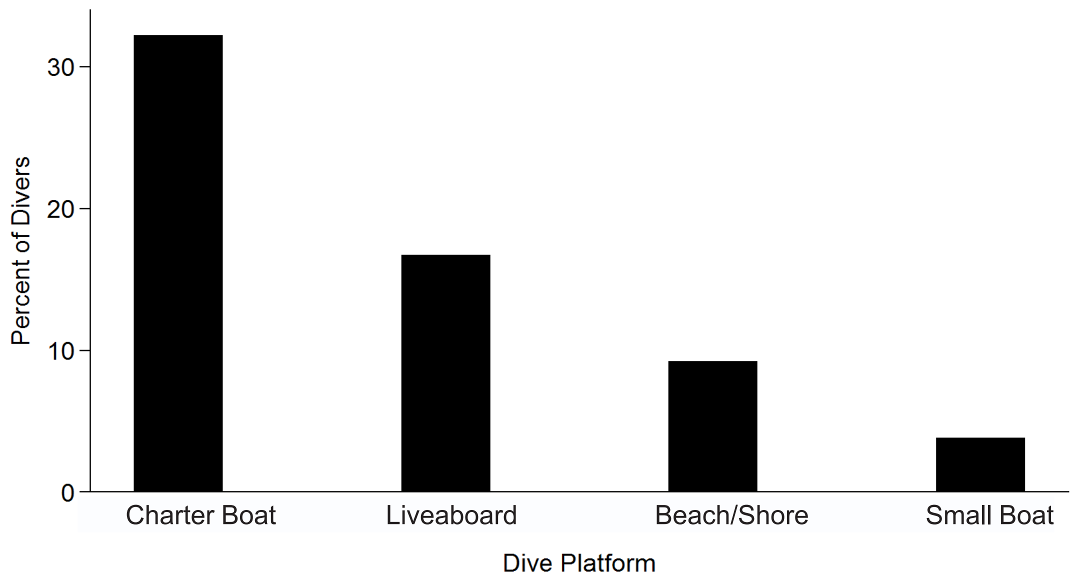


Figure 2.3-1 Percentage of the PDE dives by dive platform (n=10,978)

Thermal protection depended on the geographic area. Sixty percent used wetsuits, 34 percent used drysuits, and six percent used lycra, diveskin or just a swimsuit. Most divers indicated they were comfortably warm (Figure 2.3-2). Scapa Flow divers reported feeling hot on 16 percent of dives and cold on 22 percent of dives while all other divers reported thermal comfort levels as hot or cold on three and four percent of dives, respectively.

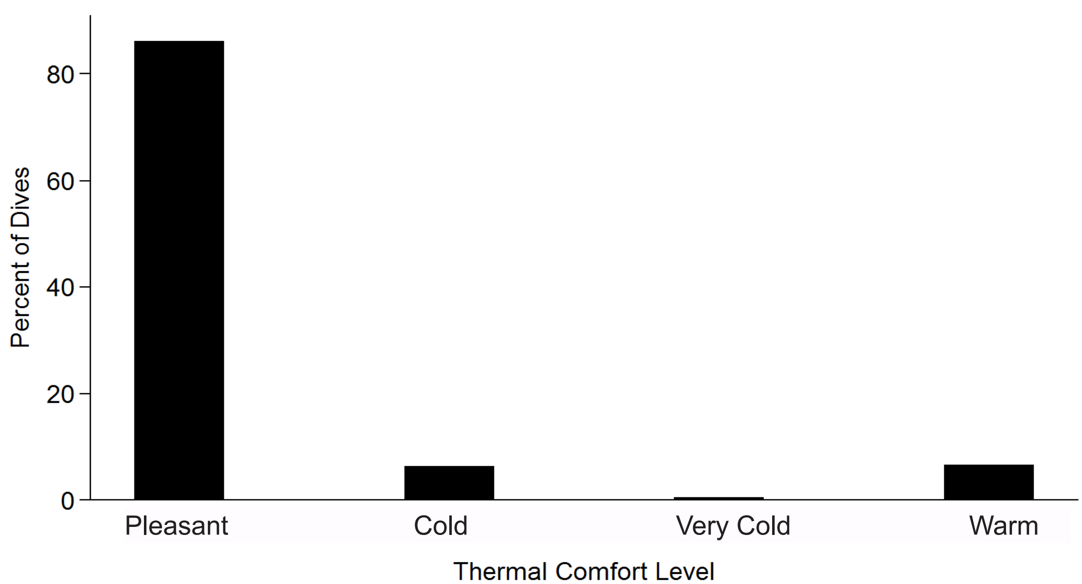


Figure 2.3-2 Subjective thermal comfort of PDE divers by subgroup (n=16,436)

More than 81 percent of PDE divers reported light workloads during dives and 16 percent reported moderate or heavy workloads (Figure 2.3-3). Compared to other methods of entering the water, beach divers described a small (5.1 percent versus 1.3 percent) but statistically significant (Pearson Chi square, $p<0.01$) increase in heavy workload.

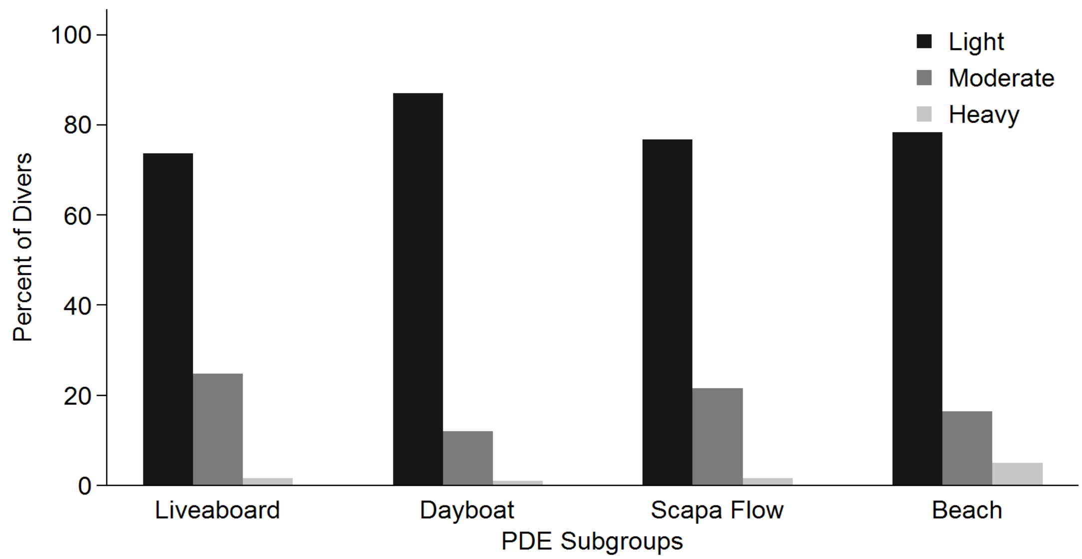


Figure 2.3-3 Reported workload in PDE divers by subgroup (n=10,847)

2.4 Dive Profiles

Section 2.4 describes the breathing gas, repetitive dive status, number of days in the dive series, number of dives in the series, maximum dive depth, deepest and last dives in the series, maximum depth for each day of multi-day series and the dive planning methods.

Air as the breathing gas was reported in 69 percent of PDE dives and enriched air nitrox (a nitrogen-oxygen mix with greater than 21 percent oxygen) in 27 percent of dives. Just under two percent reported using trimix (helium, nitrogen and oxygen) and six divers (0.05 percent) reported using heliox, a mix containing helium and oxygen.

This report defines a dive series as one or more dives separated by a surface interval no greater than 48 hours. This does not necessarily equate to standard definitions for repetitive dives. It is possible that a single multi-day series could include a dive-free span of greater than 24 hours. Fifty-one percent of the dive series were multi-day (Figure 2.4-1). Sixty percent of single-day repetitive dive series consisted of two dives as did 37 percent of multi-day series. Three percent of multi-day dive series were single dive days.

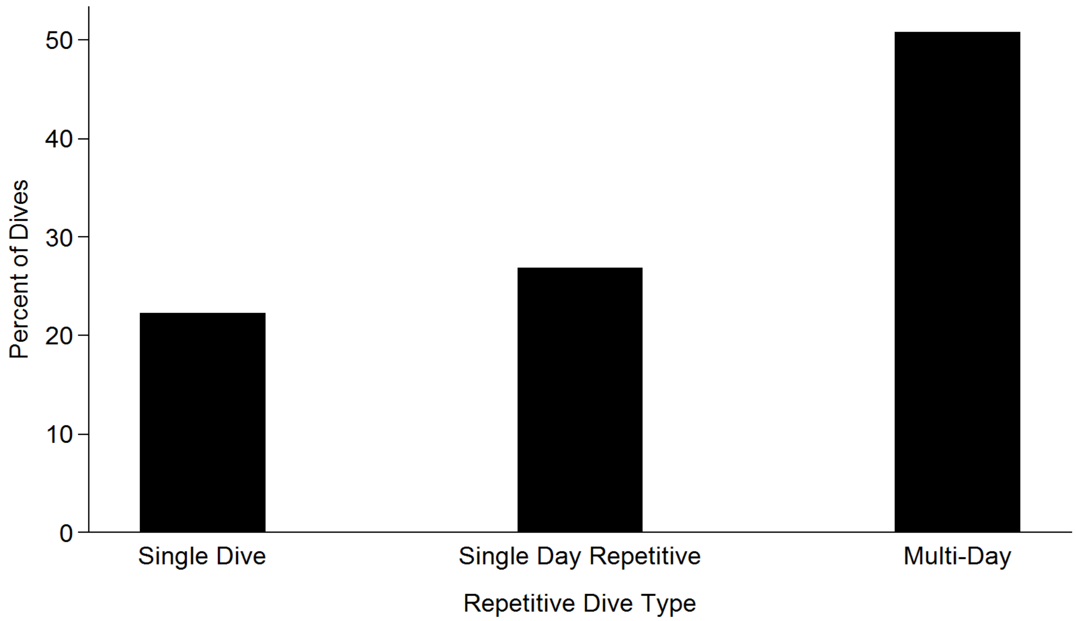


Figure 2.4-1 Repetitive dive type for PDE dive series (n=3,220 series)

Fifty percent of all dive series were single day events (Figure 2.4-2). Forty-two percent of all series consisted of two to four exposures (Figure 2.4-3). The previous year's trend toward fewer multi-day dive series continues with this year's data and is likely due to fewer Caribbean liveaboard reports.

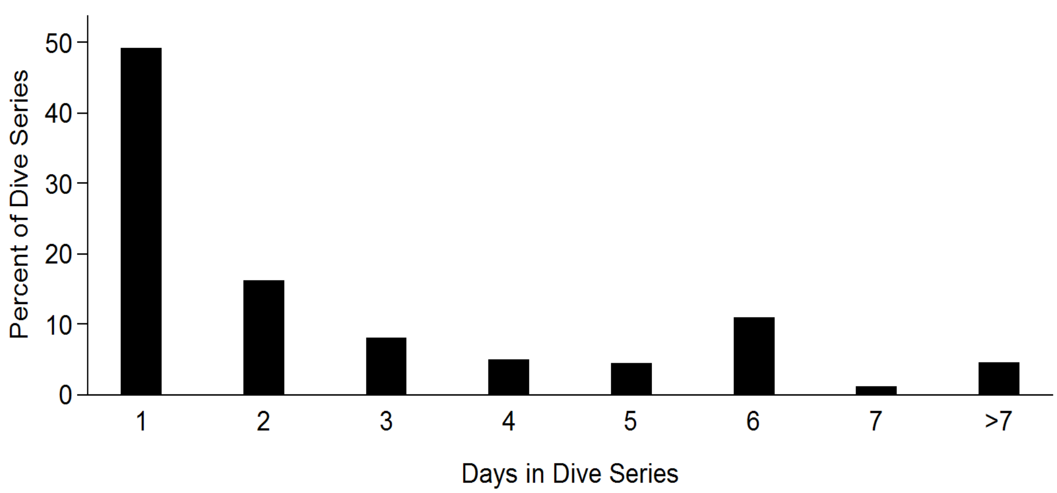


Figure 2.4-2 Number of days in dive series by PDE divers (n=3,220 series)

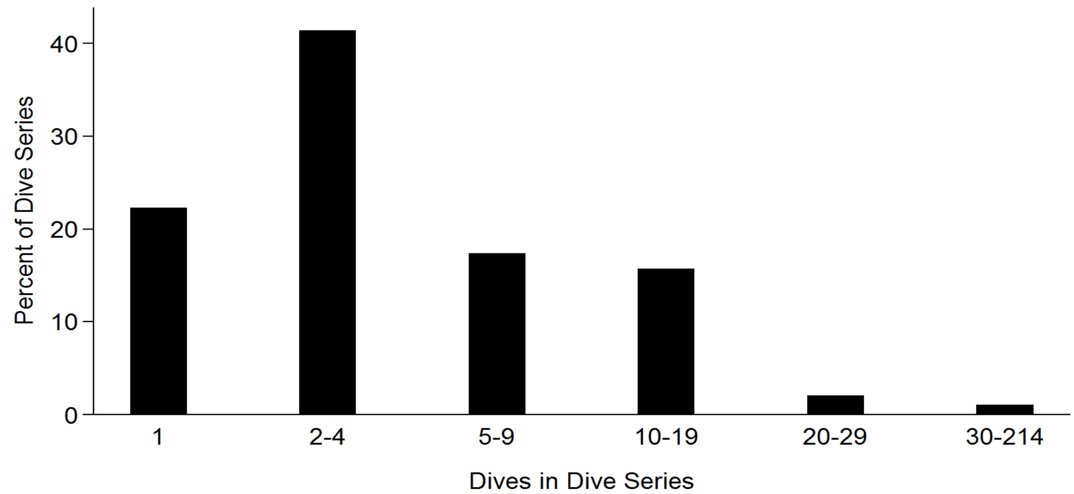


Figure 2.4-3 Number of dives in a series by PDE divers (n=3,220 series)

Twenty-four percent of dives were to maximum depths greater than or equal to 90 ft (27 m) compared to 27 percent in 2005 and 30 percent in 2006. The total number of dives by females decreased from 37 percent in 2006 to 25 percent in 2007 (Figure 2.4-4) while representing 25 percent of the volunteers.

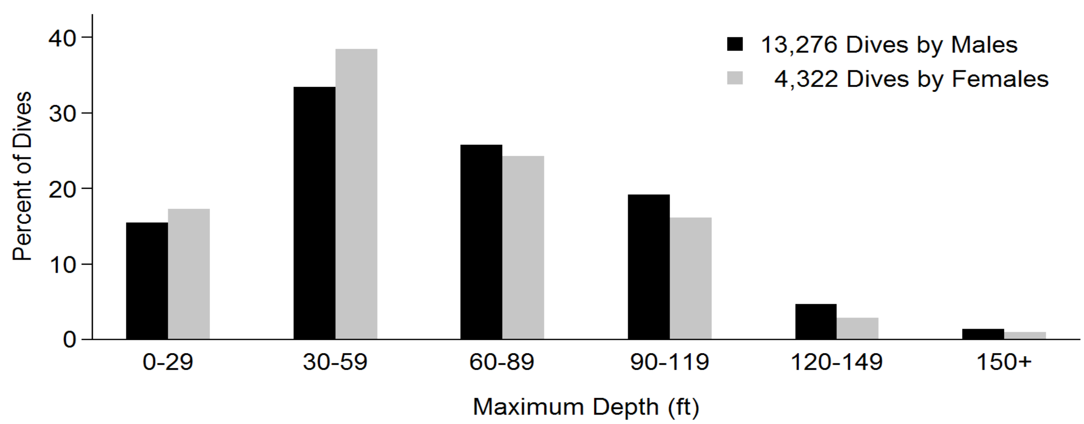


Figure 2.4-4 Maximum depth by males/females in PDE dives (n=17,598)

Seventy-eight percent of dive series were made up of multiple dives. When multi-dive series were grouped by the maximum depth in the series, the mean of the maximum depth exceeded the mean of the last dive depth in all depth groups (t test, $p<0.01$) (Figure 2.4-5), indicating that the last dive was generally not the deepest in the series.

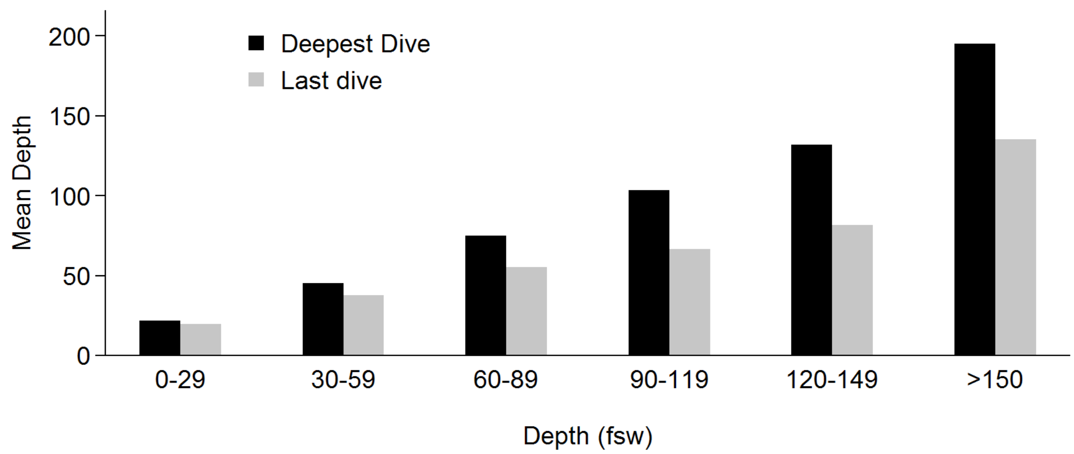


Figure 2.4-5 Deepest and last dive depth (fsw) by PDE divers (n=2,514 series)

There is a progressive decrease in the mean maximum depth with successive repetitive dives (Figure 2.4-6). For dive days consisting of at least of four repetitive dives, the reduction in mean maximum depth was less (Spearman rank coefficient, $p<0.01$) for each repetitive group compared to the prior repetitive group.

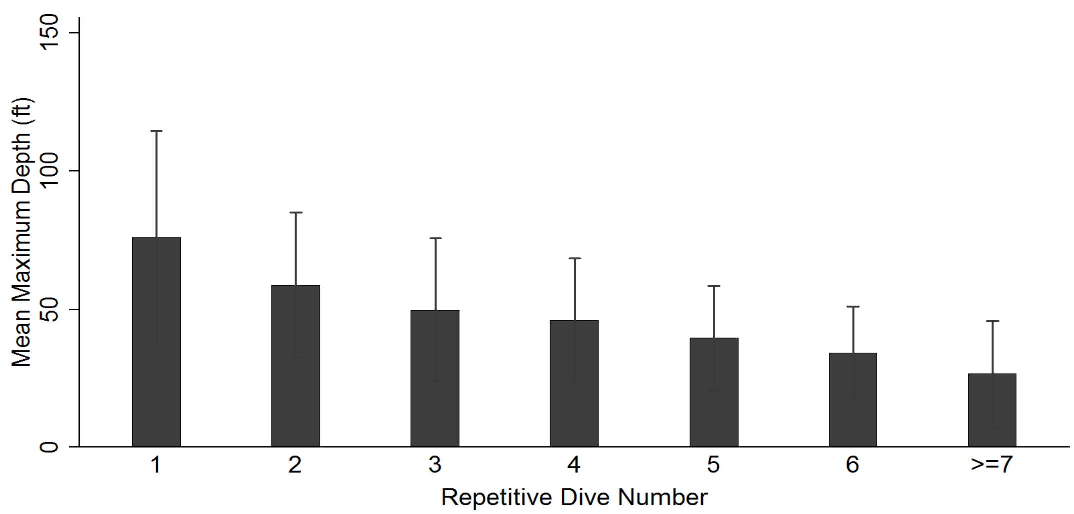


Figure 2.4-6 Mean (with standard deviation) maximum dive depth by repetitive dive number (n=17,758)

Surface intervals for repetitive dives exceeded 60 minutes for dive days with a total of six dives or less while dive days with seven or more dives showed surface intervals of less than 34 minutes (Figure 2.4-7). Surface intervals prior to the first dive of the day within a series were less than 24 hours in 85 percent of dive days, between 24 and 36 hours in five percent, between 36 and 48 hours in 10 percent. Surface intervals exceeding 36 hours likely represent a skip day within a series.

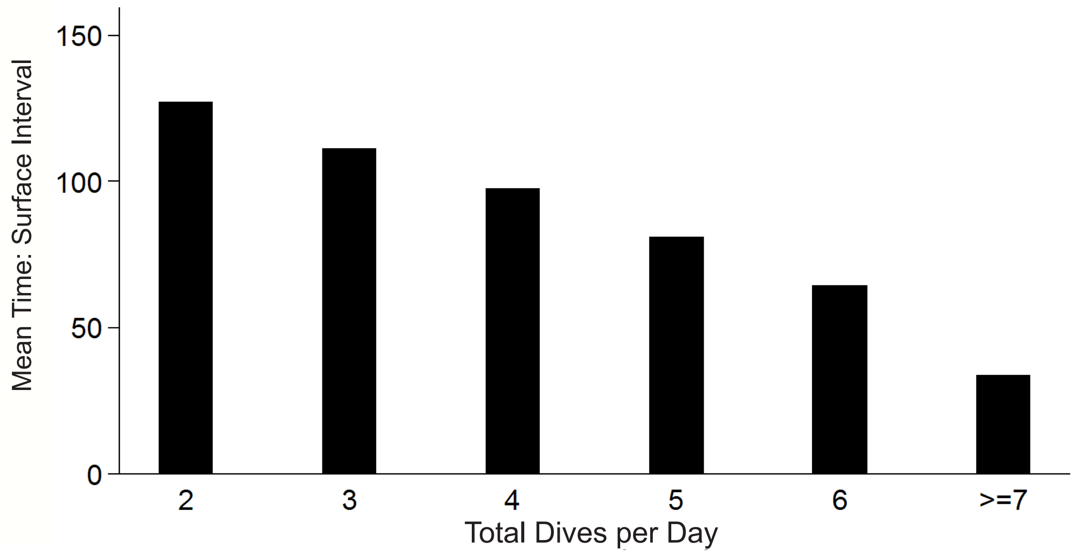


Figure 2.4-7 Mean surface interval times by total dives in a day (n=6,250 repetitive dive days)

Dive records from liveaboard dive boats have been declining since their peak in 2003 while dive records from the beach or shore dives and dayboats have been increasing (Figure 2.4-8). The majority of Scapa Flow, Scotland dives were carried out off liveaboard boats (70 percent), with the remainder off dayboats (30 percent). Scapa Flow dives are almost exclusively on wrecks with deeper depth distributions than other platforms.

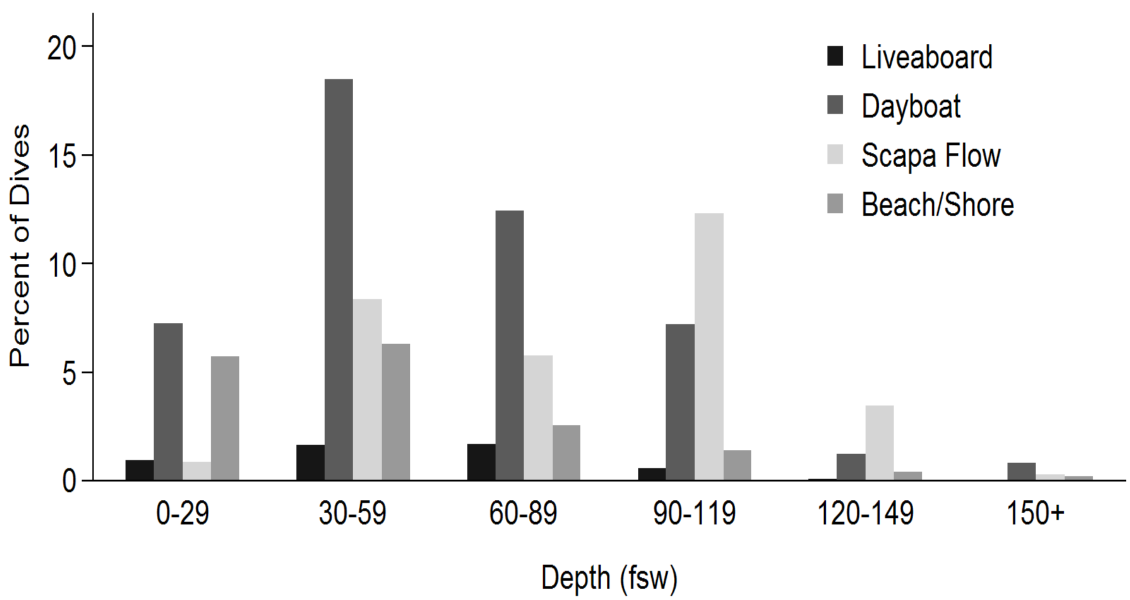


Figure 2.4-8 Distribution of dive depths among PDE subgroups (n=11,257)

Dive computers were used for 91 percent of the PDE dives (Figure 2.4-9). A large number of responses were lost due to dive computer model uploading malfunction and as a result, the category "None" was not included in this year's report. Otherwise, the pattern in 2007 showed little change from the previous two years.

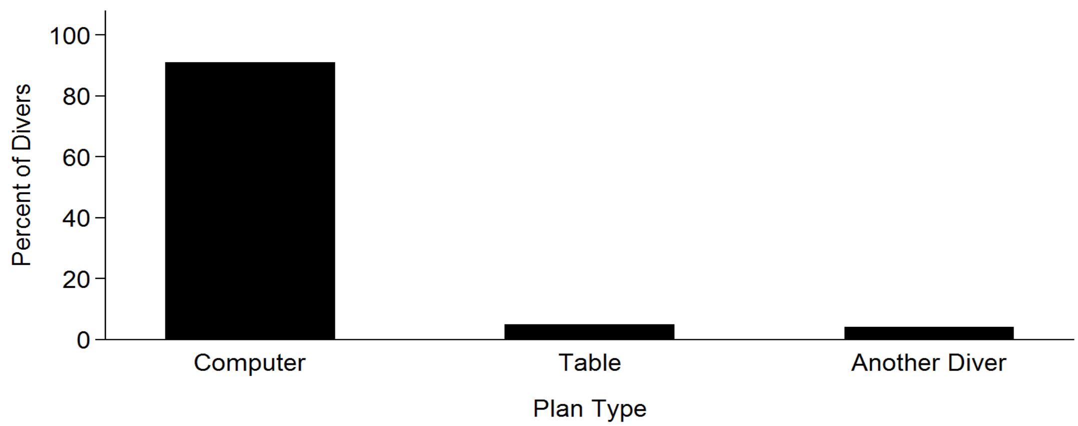


Figure 2.4-9 Dive plan method used by PDE divers (n=10,123)

2.5 Dive Outcomes

Because there are no certain methods of diagnosing decompression illness (DCI, which includes AGE and DCS), we offer operational definitions for six possible outcomes of PDE dives. The outcomes were based on descriptions by PDE volunteers of events, symptoms and daily logs or in the 48-hour reports. Problems that were potentially decompression-related were followed up with the diver or recompression facility. As a measure of decompression stress, the DCS probability (P_{DCS}) was estimated from the dive profile based on the method described by Gerth and Vann (1997).

Definitions for the six possible outcome categories were:

Uneventful

Events, signs or symptoms were denied.

Incident

Incidents include procedural problems or equipment problems that did not result in major harm. Equalization problems were included here, such as temporary ear pain or discomfort. These were not reported as injuries. Potentially hazardous procedural or equipment-related events were described but signs or symptoms were not reported.

Non-DCI Injury or Symptoms

These included injuries, signs or symptoms unlikely to be DCI upon review of medical history.

- Pulmonary barotrauma (pneumothorax, mediastinal emphysema, subcutaneous emphysema) in the absence of neurological or cardiopulmonary signs or symptoms.
- Headache in the absence of other signs or symptoms described by the perceived severity index (PSI). PSI categorizes symptoms in six levels of severity from mild, non-specific symptoms to serious neurological signs (Vann et al., 2005).
- Seasickness and/or transient vertigo.

- Injuries, signs or symptoms not attributable to AGE after a single dive to less than 30 fsw (9 msw).
- Sign or symptom onset times longer than 24 hours after the last dive or post-dive altitude exposure.

Ambiguous

Applied if any of the following criteria were present:

- Insufficient exposure (single dive to less than 30 fsw [9 msw]).
- Signs or symptoms that could be ascribed to a non-DCI cause.
- Confounding medical conditions that could explain the symptoms.
- Spontaneous symptom resolution after less than 20 minutes with surface oxygen or less than 60 minutes without oxygen.
- Inadequate information.

Arterial Gas Embolism (AGE)

Applied if all three criteria were present:

- Symptom onset time of less than 15 minutes post-dive.
- Presence of cerebral neurological signs, symptoms, or findings.
- Symptom duration greater than 15 minutes.

Rapid ascent, out-of-gas, cardiopulmonary symptoms, pneumothorax, or mediastinal or subcutaneous emphysema increase the confidence of an AGE diagnosis.

Decompression Sickness (DCS)

- Onset of signs or symptoms within 24 hours of diving or altitude exposure after diving.
- Signs or symptoms in accordance with PSI categories.
- Type I DCS (DCS I) included PSIs of pain, skin/lymphatic, constitutional/non-specific.
- Type II DCS (DCS II) included PSIs of serious neurological, cardiopulmonary, mild neurological. Other PSIs could also be present.

2.5.1 Incidents

Of 11,305 responses concerning the dives procedural characteristics, 11,135 (98.5 percent) divers reported an uneventful exposure. Procedural problems were reported in 170 dives (1.5 percent) and are shown in Figure 2.5.1-1. The most common procedural incidents were buoyancy problems (one percent) followed by rapid ascent (0.3 percent). The remaining procedural incidents, out-of-air, shared air and missed or omitted decompression, each represented a reported frequency of 0.1 percent or less.

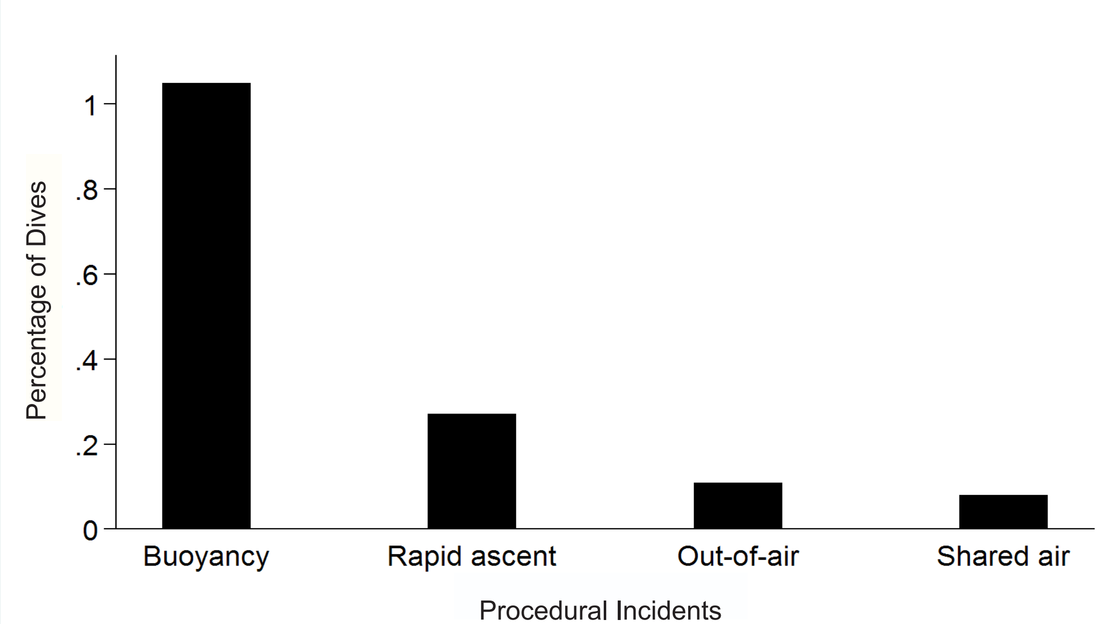


Figure 2.5.1-1 Procedural Problems in PDE dives (n=11,305)

Table 2.5.1-1 summarizes a total of 266 equipment problems of the 15,524 PDE reports received (1.7 percent). Thermal protection issues were the most commonly described, replacing computer issues as the most common reported problem in 2006 and face mask issues as was most common reported problem in 2005. Over 6,000 PDE reports from one model of dive computer defaulted to "none" on download and it is unknown how many positive 'equipment problems' responses were affected.

Table 2.5.1-2 Percent of PDE dives with reported equipment problems (n=15,524)

Equipment Problems	Frequency	Percent
Thermal protection	71	0.46
Buoyancy compensator	47	0.30
Face mask	41	0.26
Fins	34	0.22
Computer	29	0.19
Breathing apparatus	18	0.12
Weight belt	17	0.11
Pressure gauge	6	0.04
Depth gauge	3	0.02

The following incidents were of note although none were associated with injury:
- Reconfigured wreck reel, light, etc. at depth.
- Out-of-air and rapid ascent.
- Lost weight belt.
- First dive in dense kelp beds. Lost mask.
- Computer battery failed during dive.
- Not enough weight when entering the water.
- Rapid ascent.

2.5.1.1 Omitted decompression

Case 1: Rapid ascent with missed decompression

This 25-year-old female diver, first certified in 2004, undertook 10 dives over six days with a maximum series depth of 129 fsw (39 msw) using open-circuit scuba, breathing 26 percent nitrox. On her third dive, the first of the second day of diving, she stated that her "*dump valve on dry suit stuck at about 17 m*" resulting in a rapid ascent and an omission of "*12 or 17 minutes of decompression*" (Figure 2.5.1.1-1). Analysis of the profile shows an ascent rate from 43 fsw (13 msw) at 37 $ft{\cdot}min^{-1}$ (11 $m{\cdot}min^{-1}$). As a precaution, she went on oxygen for two hours and no symptoms were reported.

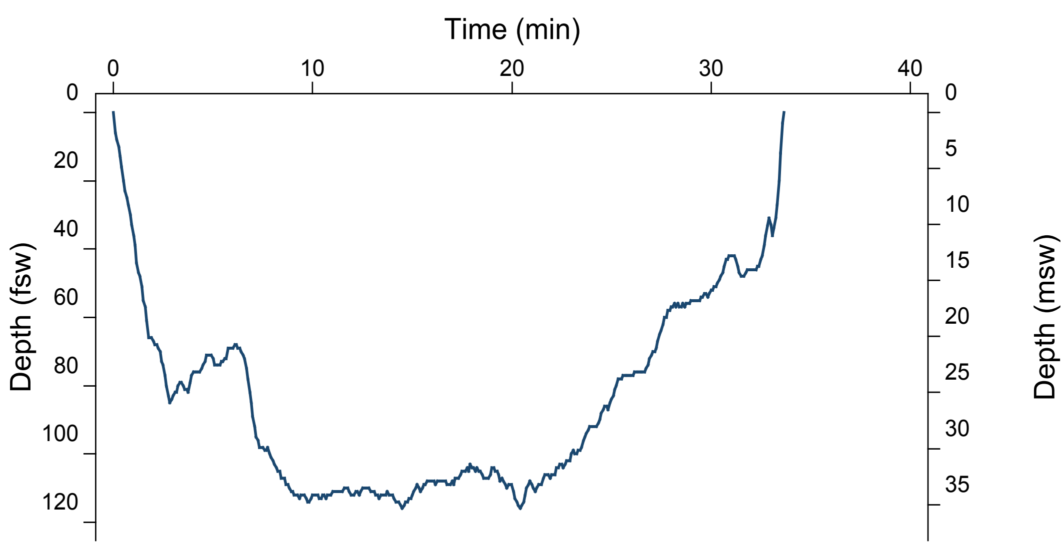


Figure 2.5.1.1-1 Second-to-last dive profile contributing to omitted decompression on last dive

2.5.2 Non-DCI Injury or Symptoms

The most frequent non-DCI injury reported was related to ear equalization (n=245). Seasickness, transient vertigo and headache were reported for less than one percent of dives (Figure 2.5.2-1).

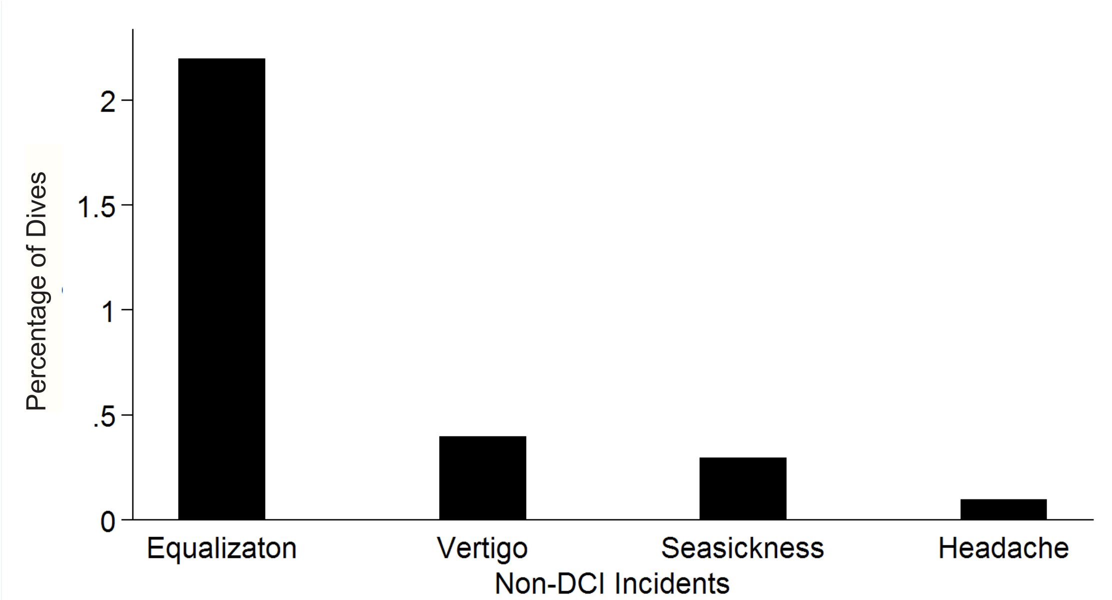


Figure 2.5.2-1 Non-DCI Injury in PDE dives (n=11,305)

2.5.3 Ambiguous Cases

Case 1: Knee pain following trimix dive.

This 34-year-old male experienced diver undertook 12 trimix dives over 13 days. On his sixth dive on the sixth day, he experienced knee pain immediately on surfacing that lasted 30 minutes. No treatments were reported. He did not dive on the day following this episode (day seven) but returned to diving on day eight.

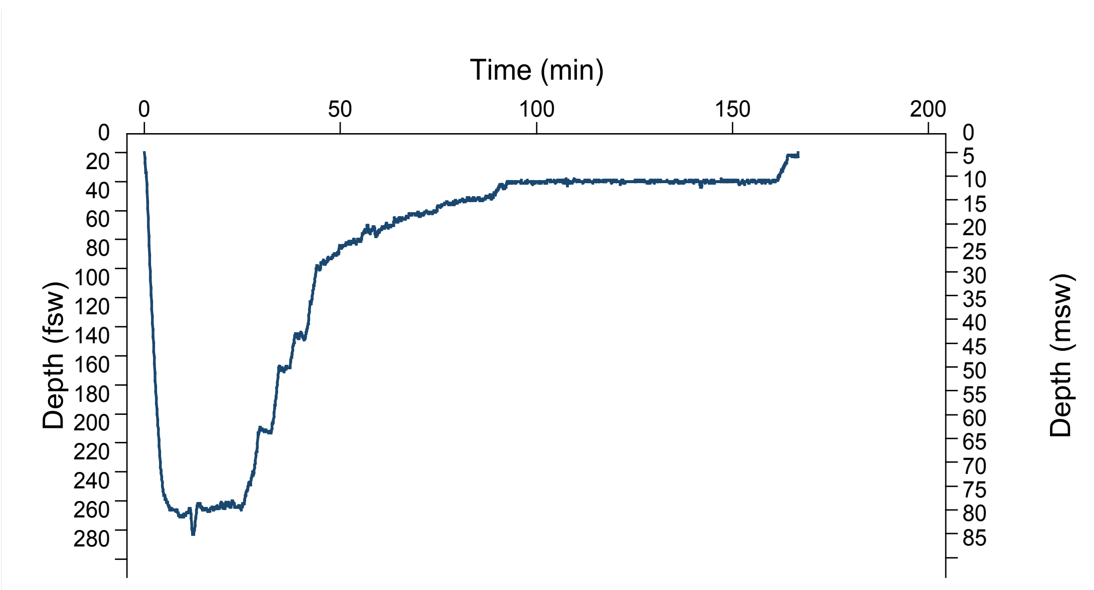


Figure 2.5.1.1-3 Last dive profile contributing to knee pain without treatment

Case 2: Itching in arm

This 49-year-old female diver completed 12 dives in six days to a maximum depth of 130 fsw (40 msw) using open-circuit scuba on 25 percent nitrox. Approximately six hours after her sixth dive she developed a slight itching on the upper outer aspect of her left arm. The symptoms cleared in 12 hours and she continued diving the next day.

Case 3: Joint and upper arm pain

This 32-year-old experienced diver completed 11 dives in six days to a maximum depth of 120 fsw (37 msw) using open-circuit scuba on a range of 23-32 percent nitrox. Following his last dive on the fifth day (the ninth dive overall) he felt an ache in his left elbow and upper arm. He took no action and 19 hours later, dived to 113 fsw (34 msw). The diver stated that it "*felt better next day after dive*."

2.5.4 Decompression Sickness (DCS)

There were four DCS cases for an annual incidence of 2.3 cases per 10,000 dives. Two cases were classified as Type I DCS involving pain or rash and two were classified as Type II involving tingling. All four divers were recompressed with complete relief.

Case 1. Deep shoulder pain (DCS I).

This 42-year-old diver with one year experience completed six dives on open-circuit air over four days to a maximum depth of 108 fsw (33 msw). On the fourth day he undertook a single dive to 82 fsw (25 msw) for 11 minutes. During the dive, his buoyancy compensator inflator hose malfunctioned to cause a rapid ascent from 77 fsw (23 msw) in 45 seconds (106 ft·min^{-1}[32 m·min$^{-1]}$). Upon surfacing, he felt deep left shoulder pain. He was transported by ambulance to the local chamber and treated on a United States Navy Treatment Table 6 (USN TT6). The predicted DCS risk (P_{DCS}) for this dive was 0.56 percent. However, on the day prior, he had dived to 108 fsw (33 msw) for 48 minutes with a P_{DCS} risk value of 1.68 percent, a somewhat stressful dive which may have contributed to the subsequent DCS occurrence.

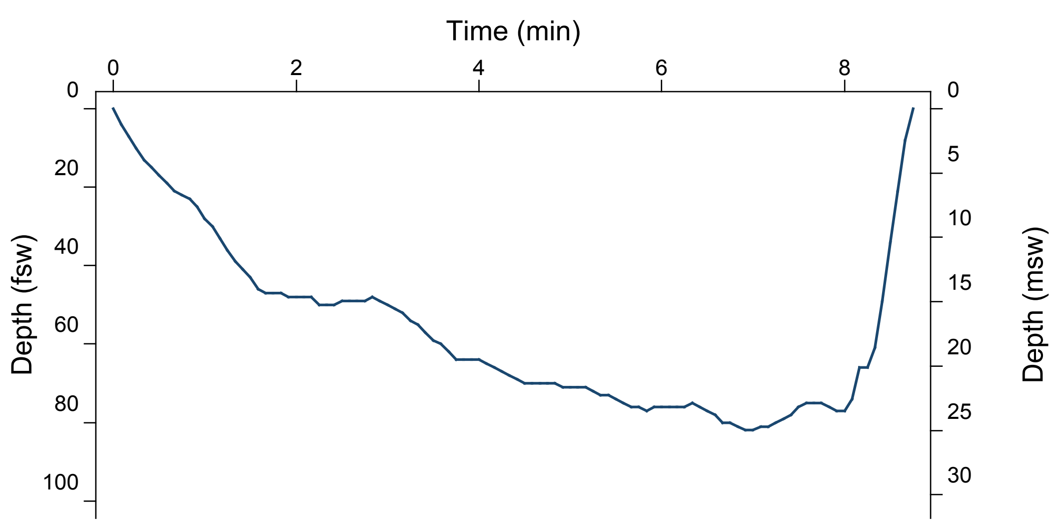


Figure 2.5.4-1 Dive profile preceding a case of pain only DCS

Case 2. Tingling and rash (DCS II).

This 39-year-old male developed DCS following two dives in one day breathing air. The first dive was to a maximum depth of 85 fsw (26 msw) for 75 minutes that resulted in a P_{DCS} value of 1.1 percent. Following a 3:49 h:min surface interval his second and final dive was to 58 fsw (18 msw) for 71 minutes, which produced a P_{DCS} of 1.98 percent. The diver stated that he had made a rapid ascent and missed approximately 10 minutes of decompression. His computer profile indicates his last ascent was 32 $ft \cdot min^{-1}$ from 55 fsw (17 msw). Following that dive he noted "*right middle and ring finger tingling, skin itching with red rash across chest*." He was treated with a USN TT6, reporting complete symptom resolution by the second air break. He remained symptom free.

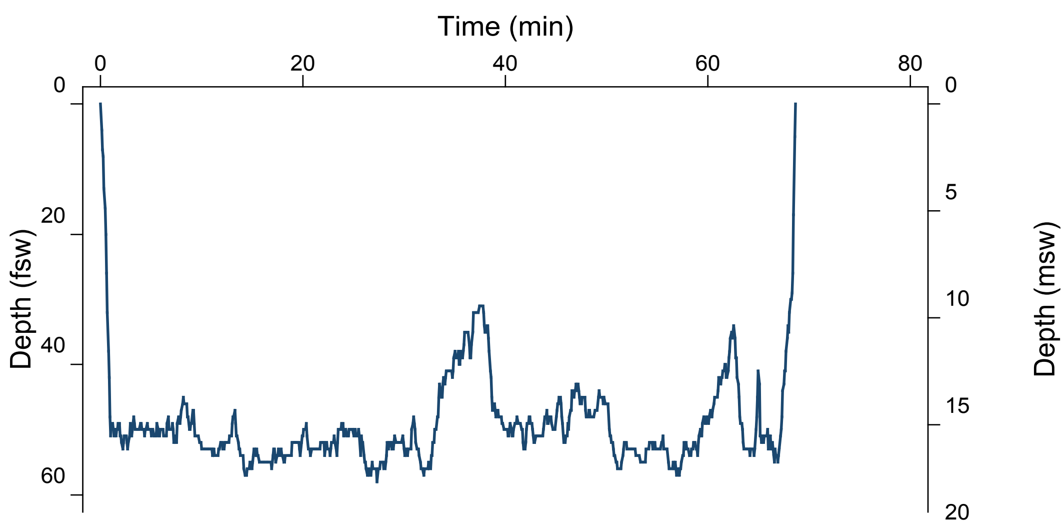


Figure 2.5.4-2 Dive profile preceding a case of mild neurological DCS

Case 3. Itching and rash (DCS I).

This 24-year-old advanced open water female diver undertook 12 dives over six days on open-circuit air to a maximum depth of 108 fsw (33 msw). She developed an uncomfortable feeling in her left shoulder which progressed to itching and red rash over her back shoulder area 50 minutes after surfacing. She went on oxygen and improved and was subsequently transported to the local chamber where she was treated on a USN TT6 with complete resolution.

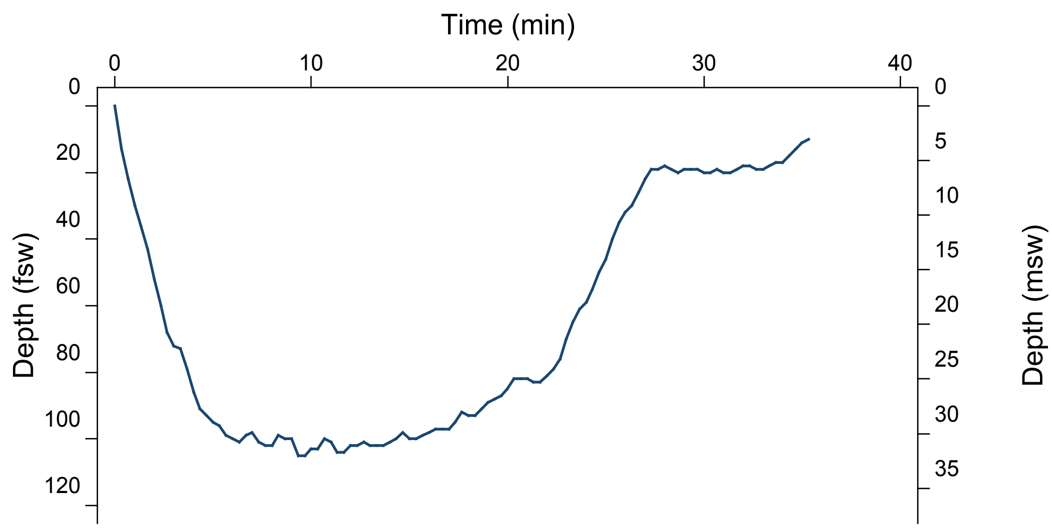


Figure 2.5.4-3 Last profile of a 12-dive series producing itching and rash. The dive computer profile readout did not show the final ascent from 30 fsw (9 msw).

Case 4. Hand tingling (DCS II).

This male diver undertook nine dives over five days on air to a maximum depth of 113 fsw (34 msw). On his final dive, to 98 fsw (30 msw) for 39 minutes, he experienced a low-on-air situation near his maximum depth and began an immediate ascent at a rate higher than normal (Figure 2.5.4-4). At approximately 33 fsw (10 msw) he reported running out of air. According to his dive computer, he missed 21 minutes of decompression. The P_{DCS} for this dive was the highest of the series at 2.29 percent (Table 2.5.4-1). Within 15-20 minutes of surfacing, he felt some tingling on the back of his right hand and left thumb. He was put on oxygen and the symptoms resolved. He was then transported to the local hyperbaric chamber where he was treated with a USN TT5. The TT5 was chosen because the diver had minimal symptoms and those had resolved with first air oxygen. The next day, the diver stated that he had no symptoms or problems following treatment.

Table 2.5.4-1 Case 4 summary data dive series producing hand tingling

Day	Depth (fsw / msw)	Dive Time (min)	Surface Interval (min)	P_{DCS}
1	80 / 24	31		0.413
1	48 / 15	35	124	0.131
2	113 / 34	30		1.132
2	49 / 15	34	207	0.135
3	54 / 16	36		0.214
4	109 / 33	40		0.596
4	51 / 16	40	192	0.333
5	39 / 12	47		0.023
5	98 / 30	39	147	2.290

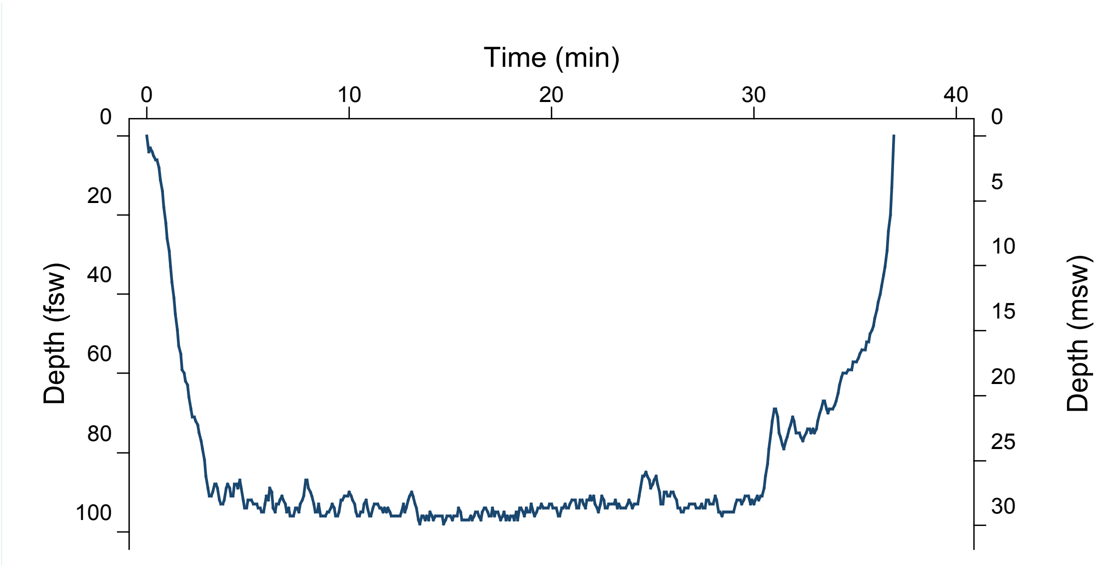


Figure 2.5.4-4 Last profile of a nine-dive series producing hand tingling

2.6 SUMMARY

DAN's Project Dive Exploration (PDE) has acquired information on 150,739 volunteer dives from 1995-2007. In the 2007 dataset, most volunteers were between 30-59 years of age with recreational diving certifications. Males outnumbered females, contributed the most dives and a slightly higher number of dives per volunteer. There were relatively few chronic medical conditions reported with allergy and hypertension the most common. Both male and female divers younger than their respective median ages tended to dive to shallower depths than older divers. The reported dives were primarily completed on charter boat vessels. Beach divers reported higher workloads with greater frequency than other groups. Dive series of two to four dives were most common. For all dives, 70 percent were to less than 90 ft (27 m) and 95 percent were uneventful. Buoyancy and rapid ascent were the most frequent procedural problems and thermal protection the most frequent equipment-related problem. Four mild cases of DCS were reported out of the 17,758 dives collected, representing an incidence of 2.3 cases per 10,000.

2.7 REFERENCES

Gerth WA, Vann RD. Probabilistic gas and bubble dynamics models of decompression sickness occurrence in air and N_2-O_2 diving. Undersea Hyperb Med. 1997; 24: 275-92.

Vann RD, Denoble PJ, Dovenbarger JA, Freiberger JJ, Pollock NW, Caruso JL, Uguccioni DM. Report on decompression illness, diving fatalities, and Project Dive Exploration. Durham, NC. Divers Alert Network. 2005: 48-9.

DIVE INJURIES

Petar J. Denoble, MD, DSc

3.1 Introduction

The Medical Services Call Center (MSCC), introduced in 2006, captures all calls to the DAN America Medical Department. These include requests for information and emergency assistance from divers, dive operators, and first responders, and requests for consults from physicians. There are separate lines for emergency and non-emergency calls, but callers do not always distinguish between emergencies and information requests. In addition, DAN members have 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.

Assistance for emergency cases is similar to tele-medicine although DAN specialists cannot offer definite medical evaluation and treatment. Call records provide an opportunity to study the most common concerns that prompted 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 DCS or AGE.

This year we will look at all concerns regarding possible injury that prompted calls to DAN, regardless of the final diagnosis with emphasis on the most common reasons for calling. This approach is closer to the perspective of the first responder to an emergency who sees a different mix of cases than hyperbaric chambers that may be limited to cases related to DCI.

3.2 Data Sources

A total of 7,872 calls or e-mails were logged into the MSCC system by DAN medics between January 1 and December 31, 2007. The frequency distribution of call origin is shown in Table 3.2-1. There were 5,365 information calls and 2,507 calls regarding actual cases. Twelve percent of information requests came through the emergency line and 27 percent through e-mail. Requests for emergency assistance did not always come through the emergency line. Thirty-one percent came through the information call line, eight percent were transferred from Travel Assist services and three percent through e-mail.

Table 3.2-1 Origin of DAN calls entered into the MSCC in 2007

Source	Information Requests		Cases		Combined	
	Frequency	percent	Frequency	percent	Frequency	percent
Information Line	3,111	58	771	31	3,882	49
Emergency Line	663	12	1,450	58	2,113	27
E-mail	1,472	27	77	3	1,549	20
Referred from Travel Assist	115	2	201	8	316	4
Missing	4	0	8	0	12	0
Total	**5,365**	**100**	**2,507**	**100**	**7,872**	**100**

3.3 DAN Diagnosis

Each call logged by the MSCC is assigned a working diagnosis by the medics or physicians who field the calls. A breakdown of the working diagnoses recorded by the hotline medics and physicians is shown in Table 3.3-1.

Table 3.3-1 Working diagnosis of cases as assigned by case manager (n=1605)

Working Diagnosis	Frequency	Percent
DCS	424	26.4
Barotrauma	411	25.6
Non-diving related	229	14.3
Envenomation	97	6.0
Trauma	37	2.3
Other	407	25.4
Subtotal	1,605	100.0
Not assigned	900	
Total	**2,505**	

The working diagnosis may not reflect the ultimate diagnosis. It is rather an indication of the major concern for which the patient should be tested. DCS was the most frequently assigned working diagnosis in cases involving divers with acute symptoms (26 percent of all assigned working diagnoses; n = 424). Barotrauma, including all injuries of lung, ear, sinuses and mask squeeze caused by pressure changes, was suspected in 25.6 percent (n=411). Non-diving related problems were the working diagnosis of 14.3 percent (n=229), envenomation for 6.0 percent (n=97), trauma 2.3 percent (n=37) and various other causes 25.4 percent (n=407). These numbers most likely do not represent true morbidity among divers as divers most often call DAN when they suspect diving-related injury (DCI and barotrauma comprised 52 percent of all calls involving acute symptoms), when they have an emergency in an area without emergency medical services (many cases designated here as 'Other'), or when they have a problem with which they are not familiar, like envenomation. The number of cases with obvious injuries caused by an external force (trauma) is rather small, probably because divers choose to use local services for non-diving injuries rather than call DAN. For non-diving related problems DAN members call Travel Assist about 130 times a month. If Travel Assist is called in error for dive-related problems, the call is re-directed to DAN.

The probability that initial concerns or working diagnosis reflect the underlying injury was assessed in a retrospective review process. The review criteria are given separately for each condition evaluated.

3.4 Decompression Illness (DCI)

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

3.5 AGE

AGE occurs when alveolar gas enters into arterial circulation and disrupts blood flow. Disruptions within the brain can produce sudden neurological symptoms like loss of consciousness or other functionality. The underlying lung injury causing AGE may be minimal and undetectable. The absence of local

manifestations of lung injury makes it difficult to distinguish AGE from DCS.
In reviewing MSCC data for 2007 we have found only a few cases explicitly labeled AGE. However, to obtain more comprehensive data about AGE, we reviewed all data suspected for DCS/DCI or DCS with the symptoms onset of less than 15 minutes post-dive and all cases with sudden loss of consciousness within 15 minutes post-dive. Our criteria for the diagnosis of AGE are listed in Table 3.5-1.

Table 3.5-1 Certainty levels of AGE diagnosis

Certainty level	Criteria
Certain	Present neurological symptoms indicating brain involvement and onset <15 minute post-dive and insufficient exposure for DCS
Possible	Present or transient neurological symptoms indicating brain involvement and onset <15 minute post-dive Possibly sufficient exposure for DCS OR operational cause and only transient LOC
Unlikely	Operational cause and constitutional symptoms only
Ruled out	Other causes, spinal cord DCS

There were 26 calls concerning symptoms that may have been AGE according to either DAN staff or callers. In addition, in 111 suspected DCS cases with symptom onset time less than 15 minutes there were nine possible cases of AGE.

Table 3.5-2 shows the result of a review of 32 case histories to which the criteria described in Table 3.5-1 were applied.

Table 3.5-2 Certainty of AGE in suspected calls

Certainty of Diagnosis	Frequency	Percent
Certain	0	0
Possible	17	53
Unlikely	5	16
Ruled out	9	28
Unknown	1	3
Total	**32**	**100**

There were no cases that met the criteria for certain diagnosis of AGE. On the other hand, AGE was ruled out in nine cases.

One example of suspected AGE that was ruled out involved a 29-year-old male dive instructor who dived to 60 ft (18 m) for a duration that remained within the no-decompression limits. He was later admitted to hospital with a respiratory rate of 40-50 breaths per minute which had reportedly developed eight hours earlier. The attending physician called for a consultation regarding the possibility of AGE. The patient had a normal chest x-ray and physical examination. The DAN medic receiving the call suggested that AGE was unlikely. For this report, we retrospectively ruled AGE out because of the 24 hour interval between the end of the dive and symptom onset.

In another case a physician from an emergency department called for a consultation regarding a female student diver in her forties. She had completed one dive in a pool about one hour before she was admitted. She thought she may have held her breath during ascent from the dive. She complained of shortness of breath, chokes, and a generalized tingling sensation all over her body. The physician did not find any sign of neurological disease or pulmonary barotrauma. A chest x-ray and a test of oxygen blood level were ordered and the patient was put on 100 percent oxygen. The physician inquired about the nearest hyperbaric chamber for possible recompression treatment. DAN medics advised that the probability of AGE was low, but suggested further evaluation and consideration of pulmonary barotrauma. They provided the requested contact information for the nearest HBO centers. The retrospective review classified this as not AGE based on the absence of focal neurological symptoms.

A nurse from a hyperbaric center called DAN to ask about a possible diagnosis regarding a male diver in his mid-thirties who surfaced from the dive with the worst headache he had ever had. The pain radiated into his eye and he did not want to open it. No other symptoms or signs were present. His dive included some up and down in water column and a rapid ascent. The nurse asked what to do while she was waiting for the attending physician. The DAN medic advised that it did not sound like DCI and that diver needed an ENT evaluation for possible sinus problems. Subsequently, the ENT confirmed that this was a sinus problem and prescribed proper treatment.

One call for consultation from an emergency department was about young diver who did two brief dives to 20 ft (6 m). Twenty-five minutes later he developed nausea and had a 20-30 second period of unconsciousness. Otherwise, he was in good health and had no signs of illness. Although this loss of consciousness seemed relatively late for AGE it was taken seriously. DAN medics suggested that the patient receive a thorough neurological examination with course of action determined by findings. DAN asked to be called back to provide referral for HBO center if any neurological signs were found. Call back was not received and DAN follow up with the patient was not possible. In retrospective, we classified the case as not AGE based on delay to symptom onset and assumption of no neurological symptoms.

Among 17 possible AGE cases there are variety of presentations and severity. In one case the caller was a mid-forties male recreational diver calling from his home. He dived on a wreck the previous day, completing four very brief dives (three minutes each) to 130 ft (40 m) to tie off a marker buoy. The surface intervals were not specified. Approximately five minutes after his final dive he felt numbness in fingers of his right hand and loss of control in his right arm. He also complained of tingling throughout his left side. All symptoms resolved within one hour and he remained asymptomatic through the next day. While the transient symptoms may have been caused by neck problems or other work-related injury (the caller apparently had a lot of chores beyond tying and untying the buoy), AGE could not be excluded. While the diver did not seem to be suffering from any health issues at the moment, he was advised to seek medical evaluation regarding possible causes of his past symptoms.

Symptoms sometimes improve before markedly worsening. In one case, a wife called about her husband being treated in hyperbaric chamber abroad following their second day of diving. They dived first to 92 ft (28 m) for 40 minutes and 90 minutes later to 60 ft (18 m) for 60 minutes. Immediately after surfacing her husband had difficulty seeing but it resolved spontaneously within minutes. They returned to their condominium near the dive site. Forty minutes post-dive the husband became confused, disoriented and nauseated. He vomited twice. They went to a local hyperbaric center for evaluation and treatment. This case fit the criteria for AGE given the type of symptoms and first symptom onset time. The return of symptoms (relapse) following spontaneous resolution has been reported in 6.5 percent of cases (Pearson and Goad, 1982). The preceding exposure and slow symptom progress in this case fits also the DCS diagnosis.

Some cases that meet diagnostic criteria may also have other concomitant injuries. A female diver in her sixties experienced shortness of breath during a dive and vomited upon surfacing. Her shortness of breath persisted on surface and she received therapeutic oxygen. After breathing oxygen for two hours, she reported feeling fine but tired. She was then taken to the hospital where her condition was described as *"still hypoxic, less consciousness, confused, coordination problems and less verbal"*, indicating a much more serious condition than that described at the dive site. Unfortunately, no further information on this case was available. Speculatively, the onset of breathing problems at depth and hypoxia suggest problems other than AGE. The hypoxia itself may have been sufficient to produce confusion and the neurological symptoms described. However, the symptoms and their timing could not rule out AGE. It is possible that while ascending in distress the diver incurred AGE in addition to her initial problem.

In another case, a female diver in her early forties was admitted to the emergency room, a few hours after diving to 20 ft (6 m) for 10 minutes. Reportedly, 30 seconds after the dive she vomited and had some sort of loss of consciousness of brief duration which may have been a vasovagal syncope. She had a history of migraine and was pre-diabetic taking unspecified medication. She had an acute middle ear barotrauma (MEBT), no neurological signs or symptoms and normal head computed tomography (CT) scan. DAN advised that MEBT may be a sufficient cause for the reported symptoms although it did not exclude the possibility of AGE.

The 23 cases of possible, unlikely and unknown AGE categories (Table 3.5-2) represent five percent of the 424 cases suspected for DCI. This is similar to the percentage of AGE described in a recent DAN Annual Diving Report (Vann et al., 2003) for which data was provided by hyperbaric chambers. The report described 29 cases of AGE (7 percent) and three cases of pulmonary barotrauma (PBT; <1 percent) in a total of 414 DCI cases. It may have left an impression with some readers that AGE was much more frequent in diving than pulmonary manifestation of barotrauma alone. However, based on MSCC data we know that referral bias in data reported from hyperbaric centers affected what we captured. In our current dataset there were more cases of barotrauma with pulmonary manifestation alone than with neurological manifestation.

3.6 Decompression Sickness (DCS)

The criteria for certainty of the diagnosis of DCS that we have used in our retrospective review are quite vague (Table 3.6-1). The diagnosis of DCS over the phone is even less reliable than the diagnosis of PBT. Besides an ascending paralysis that occurs immediately post-dive and progresses within minutes or hours, there are few other symptoms that unequivocally confirm DCS, unlike the conclusive findings possible for conditions such as subcutaneous emphysema and PBT. Post hoc classification of DCI depends heavily on the diagnosis established by the treating physician.

Table 3.6-1 Criteria for certainty of diagnosis of DCS

Certainty level	Criteria
Confirmed	Sufficient exposure and symptom onset <48 hours and confirmed by physician upon examination
Possible	Sufficient exposure and onset <24 hours and typical complaints, no physical exam OR resolution upon first aid oxygen (FAO_2) before exam
Unlikely	Sufficient exposure but onset >24 hours OR atypical symptoms OR likely that other cause was present
Ruled out	Insufficient exposure onset >48 hours ruled out by physician upon examination

We have reviewed all cases labeled as DCS by case managers as well as all other calls concerning possible presence of DCS symptoms, post-treatment questions and fitness-to-dive (FTD) questions. The number of calls concerning DCS issues is listed in Table 3.6-2.

Table 3.6-2 Number of calls concerning DCS

Certainty Level	Evaluation and Treatment	Benefits questions, Fitness-to-dive, Other	Count	%
Confirmed	49	2	51	8
Possible	280	41	321	52
Unlikely	70	88	158	26
Not DCS	37	29	66	11
No data	16	0	16	3
Total	**452**	**160**	**612**	**100**

There were a total of 612 cases of suspected DCS reported through the MSCC. There were additional information calls concerning recent cases that were excluded to avoid possible double counting.

There were a small fraction of cases (n=51, 8 percent) considered confirmed DCS. The small fraction is mainly due to incomplete follow up. The follow up for the year 2007 was not yet completed by the time this report was written. In many cases divers called for assistance, received advice and referral, but did not call back to report final outcome. In some cases there was no evidence that injured divers were admitted to a recommended medical institution. DAN case managers try their best to follow up with patients early in the process and after they have been assessed or treated in emergency rooms or hyperbaric centers. However, this is not always successful.

Most cases concerning suspected DCS were classified as possible DCS (n=321, 52 percent). This means that they met all criteria for DCS except they did not undergo medical assessment or symptoms resolved with first aid oxygen (FAO_2) before medical assessment was possible. In some instances medical assessment was indecisive.

Approximately one-quarter of the calls concerning DCS were classified as unlikely to be DCS. To classify symptoms reported by divers after dive as not DCS without hands-on medical assessment is hard to do. Subjective reports by an injured diver or unqualified observer must always be considered incomplete and diagnosis based on such reports tentative. There were also situations when physicians could not confirm or rule out DCS, but retrospective review reclassified them as unlikely DCS based on late symptom onset, atypical symptoms or other possible explanations.

Sixty-six (11 percent) cases were classified as not DCS due to insufficient exposure, late symptom onset or because the attending physician ruled out DCS or established another diagnosis. We did not take into account the evolution of symptoms under the treatment but some physicians may have used it to establish their diagnosis.

3.6.1 Loss of Bladder Control

Among the most severe DCS cases are usually those involving loss of bladder control. We have searched for such cases in the database by selecting all cases with bladder/bowel problems flagged and by searching for keywords in the case history. We found 15 cases altogether. Six cases were confirmed bladder problems and DCS. Three cases resolved with FAO_2 before being admitted to a hospital and thus were not verified. They were classified as possible DCS. Two cases involved bowel dysfunction, probably not related to diving. Other cases could not be confirmed.
Most cases involving bladder dysfunction occurred immediately after deep dives and received FAO_2. One diver received in-water recompression (IWR) breathing oxygen. His dive profile is shown in Figure 3.6.1-1.

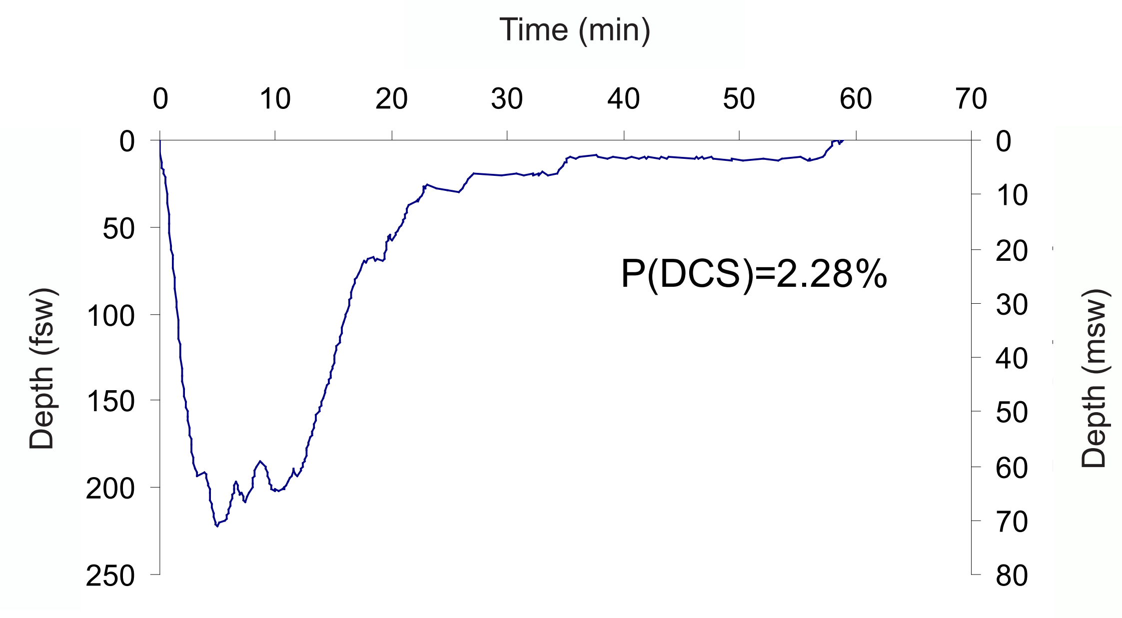


Figure 3.6.1-1 Dive profile which resulted in bladder dysfunction and severe quadriplegia

The call came from an attending physician abroad who just treated this diver with a USN TT6 with no improvement. The patient's symptoms had started one day earlier, soon after surfacing from an air dive to 230 fsw (70 msw). The first symptom was blindness. The victim was immediately re-immersed in water to 20 fsw (20 msw) breathing oxygen for about two hours until ascending symptom-free. Trouble started again in about an hour and he became paralyzed up to his neck. After the relapse, the diver was transported to a recompression facility and treated with successive recompressions in a hyperbaric chamber (12 USN TT6 over nine days) but the progress was slow. After two weeks he was discharged home. He regained the ability to walk with some difficulty but he still did not have a control of his bladder. His muscles were stiff and tender. In the next couple months he went through an intensive rehabilitation program. Three months later he wrote:

"*I am nowhere near "full recovery" just yet. That being the case, I guess I'll just give you a rundown on how I'm doing. Any comments and/or advice that you might have based on your previous experience with cases like mine would be most appreciated. I find myself needing reassurance or medical guidance occasionally. Starting at the top (my head), mentally and emotionally I feel like I've still got a pretty good grip on things and a positive attitude. I'm at the gym or the pool at least four times a week for almost an hour and half at a time. It is during these times and immediately following that I physically and mentally feel the best by far. I'm starting to wonder if I'm going to have work out every single day just to feel better. When I don't work out, my legs feel like they get all knotted up and* *tight. Sitting down for too long also gets me all knotted up. Lying flat and standing are the two best positions for me. I suppose that my biggest fear right now is if the recovery suddenly stops and I'm stuck like this the rest of my life."*

"Functionally, my left leg still lags the right leg appreciably. My walking is probably about 90 percent of normal and most people wouldn't even notice a difference but I can certainly feel the difference, particularly when climbing multiple flights of stairs. I am still utterly incapable of running, although I can jog in the shallow end of the swimming pool. I guess I would rate my left leg at about 50 percent of normal and the right one probably around 80 percent. I can't get full range of motion out of my left hamstring and my left calf remains pretty weak, although vastly improved from a month ago. Functionally, I can do everything I need to do in day to day life, including driving. However, I haven't tried to drive a car with a clutch just yet. That might be a bit more of a challenge with my left leg being worse off. As far as more private functions go, my bladder is maybe 70-80 percent of normal."

This case provides a sobering picture of what recovering from a severe case might entail. The DCS developed after a very deep dive on air which exceeded recommended limits for air diving. Recreational divers are advised to stay within no-stop decompression limits, a requirement that keeps them well shallower than 150 fsw (46 msw). Even commercial divers in the North Sea are not allowed to dive breathing air deeper than 50 msw (164 fsw). The estimated risk for this dive was 2.28 percent, quite high in comparison to most recreational diving which is at 1 percent or less risk according to the same predictive model.

Relapse may occur even if a diver is treated in the best circumstances. This was the case with a diver who started feeling restless and had breathing difficulty immediately after surfacing. He was taken by an ambulance to a local hospital with a hyperbaric center. At admission, the patient was in stable condition with no neurological symptoms and with skin mottling. After the first treatment (USN TT6) all his symptoms were gone. A few hours later he started losing strength in his lower limbs to the point of not being able to walk. He also could not urinate. At the time of the call he was about to receive another USN TT6. He received three USN TT6s and 25 other hyperbaric oxygen treatments. He was able to walk by the eighth day of treatment but he spent 30 days in hospital before he recovered enough to be released. The dive history in this case was not established. In retrospect, he reported reaching 100 ft (30 m) at some point in his dive but he did not recollect details beyond the awareness that he lost consciousness before reaching the surface.

In addition to paralysis and loss of bladder control, there are two other manifestations of DCS that are hard to miss: skin changes and vertigo.

3.6.2 Skin Changes in DCS

The following case represents a combination of skin changes and neurological DCS involving the central nervous system. This woman made four nitrox dives in two days to depths greater than 100 fsw (30 msw). Her dive profiles for the day of injury are shown at Figure 3.6.2-1.

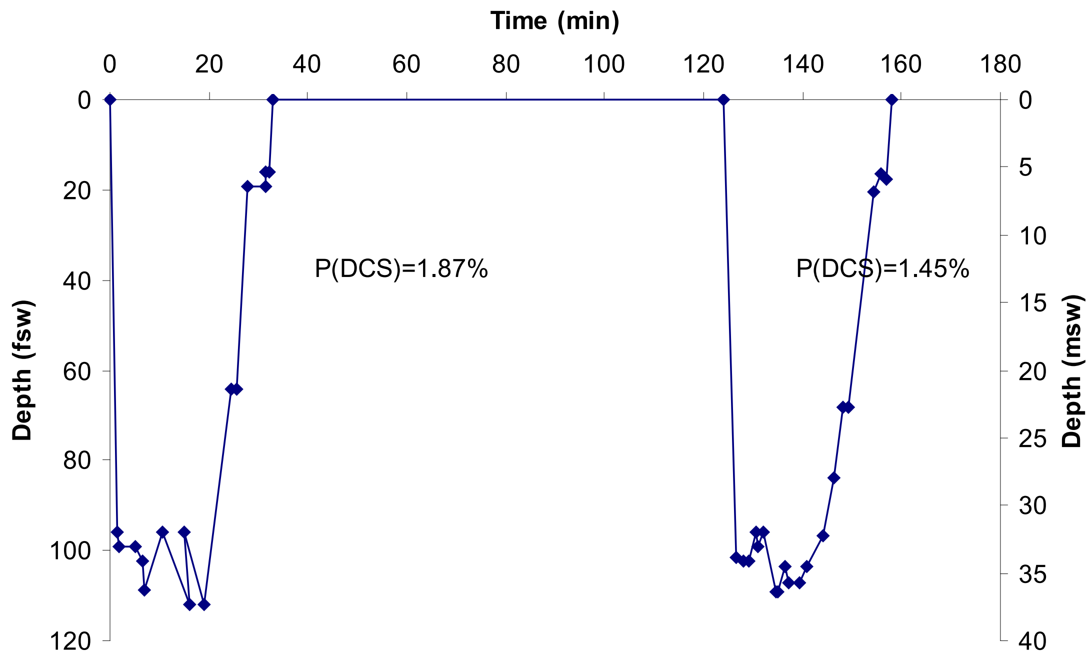


Figure 3.6.2-1 Dive profile in a case that started with skin manifestations and later developed neurological symptoms.

Both dives were square dives with estimated risks of 1.87 percent and 1.45 percent, respectively. After the first dive of the last day she had minor skin symptoms but dived again without consideration of them. Upon surfacing from her second dive she felt well and proceeded to store her gear. Approximately 10 minutes later she had sudden onset of left arm paralysis, numbness and rash accompanied by extreme shortness of breath. The crew immediately administered FAO_2 and her arm symptoms improved during the ride to shore and to hospital. She felt nausea with positional changes, but otherwise was fine. She was diagnosed with DCS with motor involvement, rash and mild chokes. Her fluid volume was depressed as indicated by an elevated hematocrit. Upon consultation with DAN, she was transferred to another hospital with a hyperbaric center. On exam she had left arm weakness, ataxia (a lack of muscle coordination when performing voluntary movements), and a rash. Her left arm was swollen and had 2 cm greater circumference than the right. This is how she described her experience:

"After the first dive I had a rash on my left upper arm and on my lower torso. The rash was blotchy red and white and looked like sunburn. The rash alternatively itched and hurt. However, I thought that it was sunburn and hurt because I laid face down on the bow of the boat. I had approximately a 1 hour and 50 minute surface interval. I subsequently completed my second dive and felt fine. I did not overly exert myself on either dive and followed a similar conservative dive profile with a 2 minute 60 foot safety stop and 3-5 minute 15 foot safety stop. I then stepped on the boat and took off and put away my gear. I then walked towards the front of the boat and felt very dizzy. My limbs felt very heavy and I couldn't catch my breath. I then walked towards the back of the boat and found the mate because I couldn't feel or lift my left arm at all. The mate touched my left hand and I couldn't feel it. He then put me on 100 percent O_2 immediately and I lay down and I was also able to catch my breath. I was coughing a lot as the O_2 was dry. The captain was contacted immediately and the boat was prepared to head back to shore."

This patient was eventually successfully treated.

Skin manifestations were reported in 55 other cases. In 23 cases the diagnosis of DCS was confirmed by the treating physician.

Skin manifestations often preceded or were concurrent with neurological symptoms. Out of 23 confirmed cases, 11 were associated with cerebral symptoms, three with motor weakness of legs, and two with breast pain. Five cases were recurrent, occurring either after more then one dive on the same trip, or being treated previously for the same type of manifestations. Out of 53 cases in which the skin DCS was considered, there were 10 cases with recurrent symptoms. Thirty-two patients were female (60 percent) and 21 were male.

Skin manifestations seem more often reported in female divers. Skin changes alone may be considered a mild form of DCS and in the past were classified as Type I DCS. However, in many cases skin changes are a manifestation that may precede more severe symptoms. Skin manifestations should be taken seriously and diver should be evaluated thoroughly.

3.6.3 Shoulder Pain

One of the symptoms of DCS that seems to occur frequently is shoulder pain. The frequency of reported shoulder pain and classification of diagnosis is shown in Table 3.6.3-1.

Table 3.6.3-1 Frequency of reported shoulder pain and certitude of DCS diagnosis

Certainty of Diagnosis	Frequency	Percent
Confirmed	0	0
Possible	76	58
Unlikely	38	29
Ruled out	18	14
Total	**132**	**100**

Based on MSCC records only with limited follow up, we did not feel comfortable in classifying any cases as confirmed DCS. Unlike severe cases involving neurological symptoms that often had several calls, most of the shoulder pain cases involved only one call. It seemed that shoulder pain was not perceived as a severe enough symptom to warrant multiple calls, either from the diver or examining physician.

DCS was ruled out in cases with pre-existing symptoms, late onset, a progression of symptoms over several days, or the clear presence of other causes. Pain that was intermittent (i.e., waxing and waning) was not considered DCS.

The difficulty of distinguishing shoulder pain caused by DCS from other causes was increased in the many cases that included confounding factors such as physical work during or around the dive or the history of a previous injury. Both of these conditions could strain the shoulder and cause pain independently or create conditions favoring DCS.

Evolution under treatment in case of shoulder pain may be less useful then in other forms of DCS. Improvement under treatment may not confirm DCS since hyperbaric oxygen may help alleviate pain in non-DCS muscle injury as well as DCS. Surface FAO_2 may not be as effective in treating pain only DCS as it may be in treating neurological DCS.

Frequent reports of shoulder pain after diving deserve more attention than we could dedicate in this report.

3.6.4 Vertigo

Vertigo was reported in 54 cases, eight of which had also a confirmed nystagmus. Twenty-eight out of 54 cases with vertigo were labeled as DCS and the remaining cases were considered ear barotrauma without DCS symptoms. Out of 28 cases of DCS with vertigo, ear barotrauma may have caused vertigo in nine cases, inner ear DCS (IEDCS) was likely in five cases and in 14 cases the origin of vertigo was less obvious. Retrospectively, only one out of 28 cases of DCS with vertigo was ruled out as ear barotrauma without DCS, IEDCS was confirmed in five cases and possible IEDCS was assigned in remaining 22 cases.

In this case a medic from the local hospital called DAN concerning a 55-year-old male patient with severe vertigo, left hand and left leg paresthesia. The patient was 160 lb (73 kg), physically fit, with no significant previous medical history. He did one dive breathing nitrox with 30 percent oxygen. His dive profile is shown in Figure 3.6.4-1.

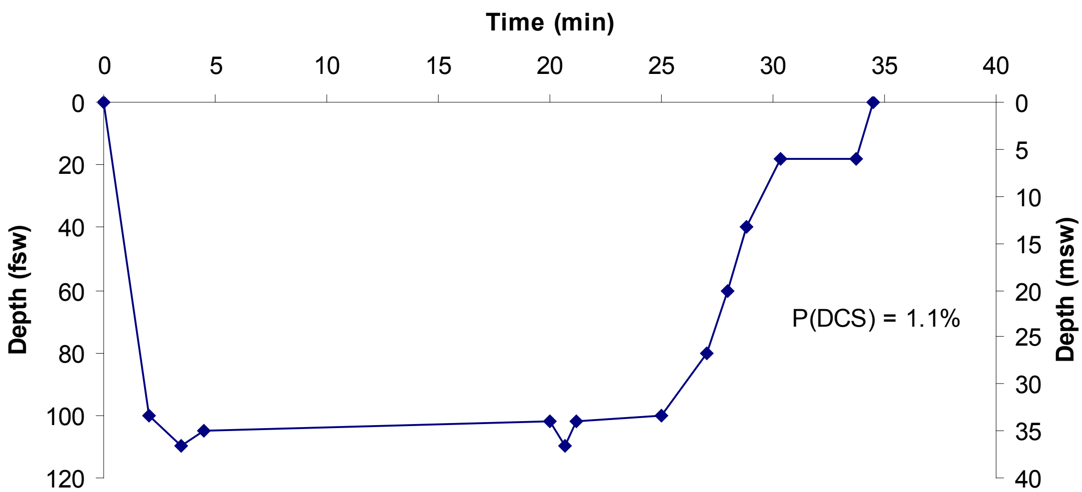


Figure 3.6.4-1 Dive profile on 30 percent nitrox preceding development of vertigo, left-side paresthesia

Vertigo developed 10 minutes after surfacing from the dive. Paresthesia began in the left calf, radiated to the left ankle, and then to the left thigh. It was soon followed by paresthesia in his left hand. After two hours of FAO_2 the paresthesia resolved and vertigo decreased. The patient began to vomit during boat ride back to shore -- the seas were somewhat heavy. At the time of call boat was 30 minutes from the dock. The dive profile was reportedly within the computer no-decompression limits and a safety stop was performed. The estimated risk was 1.1 percent. This means that DCS is expected in approximately one out of hundred repeats of this dive. However, the model used for risk estimation had been calibrated with experimental dives of more severe exposures and dive conditions than this recreational dive. Thus, risk estimates in recreational diving are probably better described as a relative measure of decompression stress. This diver had made many deep dives and was never symptomatic before. In a follow up contact, the diver wrote:

"I was recompressed at hyperbaric center which resulted in resolution of all of my symptoms. I never received a definitive diagnosis as to the cause of my DCS. However, I had several diagnostic tests performed: chest x-ray, MRI brain and spinal scans and Doppler ultrasound echocardiogram. The results from these diagnostic tests did not show any physical damage to my lungs, brain, or spine; and I do not have a PFO. As a consequence, there was no obvious causal relation to the symptoms of DCS.

As I have been diving for many years both as a recreational and technical diver it was my prospective view that the dive was a low risk dive. Retrospectively I now have a different view, but still attribute the DCS to an un-earned hit. There maybe other contributing factors which include high seas which resulted in significant exertion returning to the boat and helping other divers on-board, but this is speculative."

This was a confirmed case of DCS (according to the treating physician) but the nature of vertigo remains unresolved due to incomplete medical report. Quick improvement of vertigo with FAO_2 and association with left-side paresthesia makes this case in retrospect more likely cerebral DCS than inner ear DCS.

In another case a diver made two dives both to 120 ft (37 m) on 32 percent EAN. Immediately post-dive he began to experience acute vertigo, nausea and difficulty walking. His dive profiles are shown in Figure 3.6.4-2.

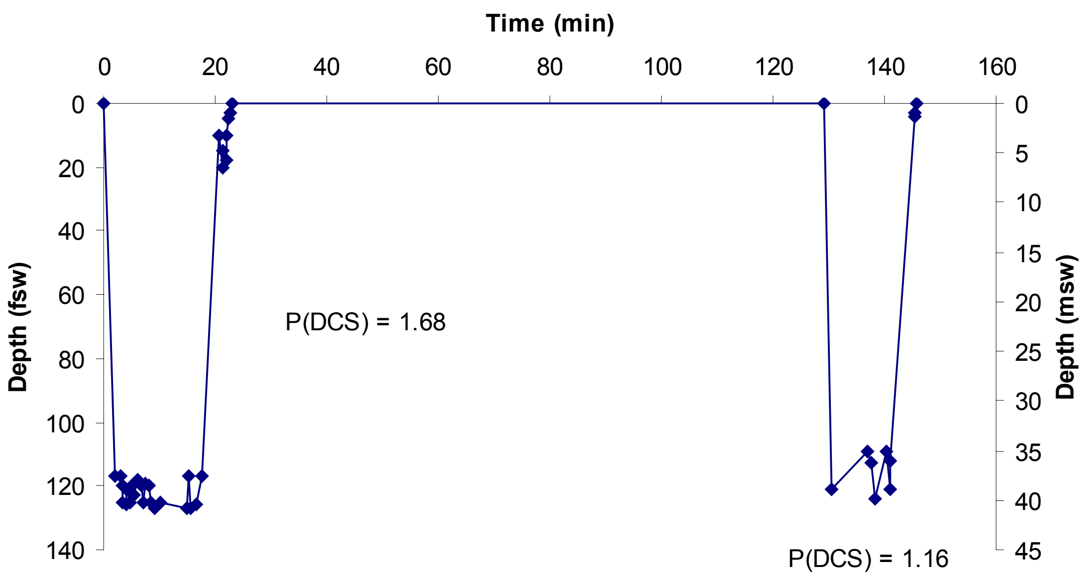
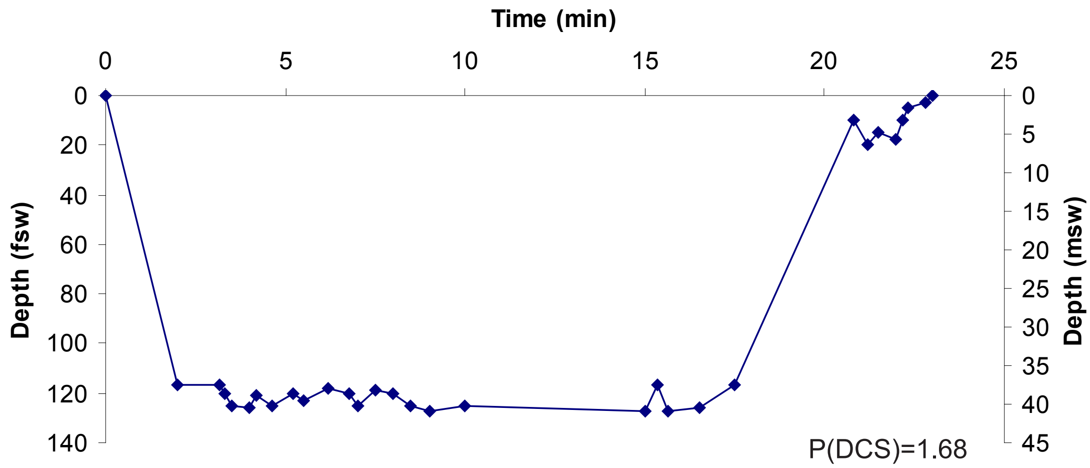


Figure 3.6.4-2 Dive profile that preceded vertigo, nausea and difficulty walking. Breathing gas used for these dives was nitrox 30.

Both dives were square dives. The estimated risk reached 1.68 percent after first dive, despite 30 percent oxygen used in enriched air (nitrox). Indeed, the decompression stops seem rather very short from this graph. His first dive is shown on Figure 3.6.4-3 with more details.



3.6.4-3 Expanded view of dive 1 in Figure 3.6.4-2.

The first dive carried greater risk of DCS then the second dive. In this dive the ascent from 117 ft (36 m) to 10 ft (3 m) occurred at a rate of 39 ft×min^{-1} and the safety stop was brief. It is possible that the first dive created conditions for DCS which developed after the second dive.

This diver experienced DCS twenty years ago but did not provide details about it. This time, after the first treatment he still had residual vertigo and gait problems. Nystagmus disappeared after the third treatment but after the fourth recompression treatment there were no additional improvements. He was released from the hospital with difficulty walking.

On a follow up immediately after release from hospital, the diver mentioned a history of head and neck cancer for which he received heavy radiation concentrated on the right side of his neck six months earlier. He confirmed that vertigo, nausea, difficulty walking occurred immediately after surfacing. Two hours after symptom onset he reached the hospital and received oxygen for six hours via nasal cannula before being transported to a hyperbaric center. He received four HBO treatments over three days. His nausea went away immediately after first treatment. He still had dizziness and trouble walking. At six month follow up he reported no residual symptoms. It took a few months after the treatment for dizziness and difficulty walking to fully resolve. He also noted that his neurologist suggested he not dive anymore.

This was a confirmed case of vestibular DCS. Recovery in such cases takes several months. Despite apparent resolution of symptoms, most cases leave a certain level of permanent damage in the inner ear. The recovery is result of compensation for the lost function rather then resolution of the insult. The compensation may not be effective in dark and/or weightless environments and divers with this condition should not dive anymore.

3.6.5 Technical Divers

There were at least 40 calls by technical divers having some type of symptoms. Technical divers were identified as such either explicitly by the caller or retrospectively based on reported breathing gas used. Deep air dives that qualify as technical dives were not specifically screened for, since dive details were missing in many cases or the details were incomplete. Some callers in this group called after their self-treatment, either with FAO_2 (n=8, 20 percent) or IWR (n=3, 7.5 percent) failed.

One caller was a male technical diver in his late twenties who completed two dives in two days. His last dive on trimix was to 173 fsw (53 msw) with a total run time of 73 minutes, including decompression stops with 100 percent oxygen. As he ascended to 10 fsw (3 msw) on his way to the surface, he felt right shoulder pain severity 7-8 on a 0-10 scale (0 being no pain and 10 the worst pain imaginable). After reaching the surface with same pain, he thought he was suffering from DCS. He re-descended to a depth of 20 fsw (6 msw) and stayed there for 25 minutes breathing oxygen as an attempt at IWR. His pain subsided during this time but reoccurred after returning to the surface.

Another technical diver fell on the swim platform before the dive and injured a wrist. After the dive, which was on trimix, he developed pain in the same arm. Decompression stops were performed according to protocol and with oxygen-enriched gasses. Elbow pain started at 15 ft (5 m) and lasted throughout the remaining decompression time. The diver returned to the water after obtaining a new gas supply. At 60 ft (18 m) the pain resolved but returned upon surfacing. He denied any other symptoms. At the surface the diver self-administered oxygen for another 30 minutes whereupon the symptoms again resolved. He called DAN because the symptoms were back two days after the original incident. This time he rated his elbow pain at 2-3 out of 10.

Re-occurrence of symptoms two days after the original incident is not likely related to DCS. In this case the pain probably was not caused by DCS in the first place. The IWR may not have been warranted and exposed diver to unnecessary risks.

The third case of IWR involved a young male technical diver calling from his home. He did two cave dives breathing 24 percent nitrox. The first dive was to 42 ffw (13 mfw) for 65 minutes. After a surface interval of 2:49 h:min he dived to 219 ffw (67 mfw) with a total run time of 72 minutes. This included decompression stops on 50 percent oxygen and 100 percent oxygen. After he surfaced from his final dive he immediately noticed the right shoulder pain (7/10), deep in the joint with radiating tingling sensation along the outside of the forearm into his hand. He re-descended to a depth of 20 ffw (6 mfw) for 20 minutes breathing 100 percent oxygen as an attempt at recompression therapy. At the surface he continued breathing 100 percent oxygen for another two hours during his ride home. His pain was reduced to a 3/10 but did not completely resolve. During the night he was awakened by an increase in right shoulder pain (7/10) and he decided to call DAN. In this case DCS was the likely problem but short duration IWR was unlikely to be of any positive value. The toxicity risks associated with prolonged oxygen breathing in hyperbaric conditions are known to technical divers, which could prompt efforts to keep exposures short.

We must recognize that these calls were mostly because the attempted IWR failed. In case the IWR were successful, divers would likely not have called to report the event. Thus we do not know how often IWR may have been used successfully.

The extensive use of FAO_2 and occasional use of IWR by technical divers may partially explain the apparently low incidence of DCS in this group when judged according to numbers reported by recompression chambers. The MSCC captures not only divers treated in hyperbaric centers but also divers calling when the treatment fails or for other discussion of aches and pains.

3.7 Barotrauma (BT)

Barotrauma was the second most frequently considered condition with 411 identified cases. Table 3.7-1 shows barotrauma by affected area and specific injury. Data were available for 347 of 410 cases (85 percent) initially diagnosed as barotrauma. Ears were affected in 216 cases: in 211 cases alone and in five cases in combination with other injuries. Middle ear barotrauma (MEBT) was confirmed or suspected in 175 cases (50 percent of barotrauma cases with data and 7 percent of all MSCC cases). In four more cases MEBT were associated with sinus barotrauma and in one case with mask squeeze. Inner ear barotrauma (IEBT) was suspected in 16 cases (4.6 percent of barotrauma cases with data and 0.6 percent of all MSCC cases). Sinus barotrauma was reported in 57 cases (14.4 percent of barotrauma cases with data and 2 percent of all MSCC cases).

Table 3.7-1 Cases suspected of barotrauma

Area Affected	Count	Injury	Frequency	percent
Ear	212	Middle ear barotrauma (MEBT)	175	50.4
		Inner ear barotrauma (IEBT)	16	4.6
		Ear, unspecified	7	2.0
		Multiple manifestations	9	2.6
		Otitis externa	2	0.6
		Facial baroparesis	2	0.6
		Alternobaric vertigo	1	0.3
Sinuses	57	Sinus barotrauma	50	14.4
		with MEBT	4	1.2
		with mask squeeze	3	0.9
Lungs	51	Pulmonary barotrauma	51	14.7
Face	21	Mask squeeze	17	4.9
		with sinus barotrauma	3	0.9
		with MEBT	1	0.3
Stomach	3	Gastric barotrauma	2	0.6
		Aerophagia	1	0.3
Teeth	3	Barodentalgia	2	0.6
		with sinus	1	0.3
Total	**347**		**347**	**100.0**

3.7.1 Ear Barotrauma

Middle ear barotrauma is often suspected by injured divers because of acute onset of ear pain during descent. It is often preceded by equalization problems. The degree of barotrauma is difficult to establish without an otoscopic examination of ears by a trained physician. MEBT may feel like a mild soreness in ear, like a fullness due to fluid filling the middle ear, or may present as bleeding from the ear canal due to eardrum rupture. Any tinnitus or vertigo must be evaluated for inner ear barotrauma.

Most divers have experienced some degree of equalization problems and probably minor ear injuries in their diving careers. Because of the high frequency of mild symptoms, divers may tend to underestimate the importance of ear symptoms and forgo proper evaluation and treatment. The real incidence of ear barotrauma may be much higher than it appears from MSCC statistics. While some divers may ignore symptoms, others may be taken care of by their primary physicians. The attitude of some divers toward ear barotrauma may be illustrated with several cases of divers suffering from ruptured ear drums.

A recreational diver in his early forties, a medical professional, was on his liveaboard diving vacation. He reported experiencing "*considerable difficulty equalizing*" in his right ear during a dive the day before. After the dive he self-treated with ear drops containing an anesthetic drug. However, after applying ear drops he was able to taste the trace of that drug in his mouth and he suspected that drug leaked from his ear canal through the ruptured eardrum, middle ear and Eustachian (auditory) tube into his pharynx. He was eager to continue diving and called DAN to ask about possible consequences of diving with a ruptured eardrum. This case illustrates the limitation of self-evaluation (diver suspected a rupture of eardrum only after the leak of drug). In addition, it shows how motivated divers, regardless of their medical education, may choose to ignore problems.

Eagerness to dive despite difficulties is illustrated in the case of a middle-aged, newly certified diver who had a history of ear equalization problems including the recent rupture of the ear drum. His problems seemed to be caused by scar tissue around the opening of the Eustachian tubes which he incurred as a result of surgery to correct sleep apnea. His primary physician discouraged various options to continue diving that he proposed such as wearing ear plugs or even implanting tubes in his eardrum to enable equalization. DAN did not endorse any of his plans either and he was referred to an ENT physician.

Another diver called DAN one day after a local physician diagnosed rupture of his right eardrum. He experienced difficulty equalizing his ear on descent and had to ascend very slowly because of pain in his ear that prohibited normal ascent. He was evaluated the morning after he awoke with a blood on his pillow and called DAN to ask what to do about his dive trip coming up in two days. DAN advised that for the healing of ruptured eardrum in uncomplicated cases it takes one to two weeks and in rare cases it may require a surgical repair. Diver must avoid further diving until otoscopic examination shows complete resolution and diver can easily autoinflate both ears at the surface.

Most divers with a suspected rupture of eardrum called to ask when they could go back to dive rather than what to do about their injury.

IEBT was suspected by injured divers, their physicians and/or DAN medics in 18 cases. In seven cases the call was initiated by physician asking for a consultation. In two more cases divers called after being diagnosed with IEBT. These were the only two cases with a confirmed diagnosis. In 10 cases IEBT was unlikely in light of some other competing diagnosis. Symptoms included dizziness and mild transitory vertigo. In four cases inner ear DCS was also a possibility. IEBT is quite a rare injury and requires specific tests for confirmation of diagnosis. Including IEBT in diagnostic considerations whenever there is vertigo or loss of hearing helps to reduce chances of missing the condition.

There were only two calls complaining of painful infection of the external ear canal (otitis externa). This was surprisingly low since many divers dive for hours in warm waters which can increase the risk of ear infection. Some divers use commercial eardrop solutions to prevent ear infection, possibly indicating that they had experienced problems with their ear canal in the past. The low number of cases reported through DAN medical lines probably reflects referral bias rather than true low incidence.

In two cases MEBT was associated with facial drooping or weakness of facial muscles on the same side. This has been called facial baroparesis, a rare injury that may occur when the facial nerve which passes through the bony wall surrounding the middle ear is not completely enclosed in bone. This makes the facial nerve vulnerable to large pressure changes if there are difficulties with equalization. The injury is usually transient but requires evaluation to rule out other causes of facial paresis.

One case not mentioned in table 3.7-1 probably involved Bell's palsy, or facial paralysis of unknown origin. Its onset was gradual and the diver continued diving for two more days. He might have continued diving despite difficulty in keeping his mouthpiece in place due to weakened oral muscles, but his instructor became concerned and called DAN for advice. DAN advised him to stop diving and to visit his primary physician.

There was one case of suspected alternobaric vertigo, a condition caused by unequal pressures in the left and right middle ear cavities during ascent or descent or by unequal sensitivity of vestibular organs to pressure changes. This diagnosis is usually confirmed after several recurrent episodes of vertigo with or without obvious equalization problems but with a measurable pressure difference between the two middle ears during ascent. In this case alternobaric vertigo was suspected in a 40-year-old diver who suffered vertigo during several repeated ascents from 10 ft (3 m). Definite diagnosis requires a thorough ENT evaluation before a return to diving should be considered.

3.7.2 Pulmonary Barotrauma (PBT)

PBT is an injury due to excessive stretching of lung tissue by expanding alveolar gas during ascent from depth. The consequence is that gas can leak from injured alveoli into the surrounding space. Manifestation of PBT may be neurological in the case of AGE (see section 3.5 for more details) or local in the forms of pneumothorax and pneumomediastinum.

Pneumothorax occurs when the alveoli on the surface of the lungs rupture and let gas into the pleural potential space (it is a ‘potential’ space since there is no actual space, just a fluid lubricating the facing membrane surfaces to minimize friction). The relative vacuum of the pleural potential space that normally keeps the lungs in close contact with the chest wall is lost when either the chest wall or lung wall is breached. At this point the lungs will begin to collapse. Manifestations may include sudden sharp chest pain made worse by a deep breath or a cough, sudden shortness of breath, pain in the chest, back and/or arms, dry coughs and cyanosis (turning blue), rapid heart beat and falling blood pressure. In case of tension pneumothorax the volume of gas in the pleural space is increased progressively, impairing the function of the unaffected lung and heart, ultimately leading to a severe hypoxia and a potentially deadly drop in blood pressure.

Untreated, a severe pneumothorax can lead to death within minutes. This is usually recognized based on manifestations alone. If there is medical professional on the scene, he or she may find the absence of audible breath sounds through a stethoscope and a higher pitched response than normal to percussion (tapping) of the chest wall. In milder cases, symptoms are less dramatic and diagnosis may not be established without a chest x-ray.

In our retrospective review we have diagnosed pneumothorax if the symptoms described above occurred suddenly during ascent or immediately upon surfacing. Confirmation of the diagnosis included auscultation (listening) by stethoscope, percussive signs and chest x-ray evidence. Identification of an operational cause such as rapid ascent helps with the diagnosis but the absence of an obvious cause does not rule out pneumothorax. Pneumothorax may occur spontaneously independent of diving. There are approximately 8,000 cases of spontaneous pneumothorax in the US every year (American Lung Association, 2005). Spontaneous cases are more common for young, tall men preponderantly and recurrence is seen in about 30 percent of cases. Many cases are associated with pre-existing blebs at the surface of the lung that burst during everyday life activities. Smoking is a known risk for pneumothorax. Because of the tendency to recur, the relatively dramatic pressure changes of diving, and the potentially severe complications of pneumothorax during diving, persons with a known history of pneumothorax should be disqualified from scuba diving.

There were 52 cases of suspected PBT in the MSCC in 2007 but there was no confirmed case of pneumothorax. Most cases were suspected for pneumomediastinum.

Pneumomediastinum occurs when gas leaks out of stretched or ruptured alveoli into the tissue spaces between alveoli and migrates along tissue planes past the bronchi and blood vessels into space enclosing the lungs and heart known as the mediastinum. From there it can move upwards into the neck, causing changes in the voice and distortion of the skin (subcutaneous emphysema). These are the two most obvious symptoms of pneumomediastinum. The escaped air may also move in other directions, but this is rarely seen in diving-related cases.

Symptoms and findings in pneumomediastinum may include chest discomfort and chest pain, shortness of breath, difficulty swallowing, pain and swelling of the neck, hoarseness of the voice, subcutaneous emphysema, and a specific auscultatory finding called the Hamman sign (a crunching, rasping sound, synchronous with the heartbeat). Chest x-rays may show gas in the chest and neck. In milder cases the gas may be shown only by more advanced imaging of the chest called the computerized tomography (CT). Sometimes it may take hours before a person becomes aware of any symptoms. Characteristically, patients with pneumomedisatinum generally feel well.

The chance that pneumomediastinum will be suspected when the DAN emergency line is called depends both on reported symptoms and the availability of additional test results. If a caller complains of subcutaneous edema (swelling) that feels like crackling beneath the skin on mild compression, or of a sudden hoarseness in the voice and a feeling of a swollen neck that occurred within hours post-dive, the condition is very likely caused by PBT. However, in the absence of these characteristic symptoms, diagnosis depends on clinical findings.

The criteria we used to review and classify emergency calls concerning PBT are listed in Table 3.7.2-1

Table 3.7.2-1 Criteria for diagnosis of pulmonary barotrauma

Certainty of Diagnosis	Symptoms and Signs
Certain	Positive chest x-ray Subcutaneous emphysema Hoarseness of voice Temporal proximity to diving
Possible	Onset within hours post-dive Chest discomfort, neck pain and neck swelling, cough, hemoptysis Operational cause
Unlikely	Late onset, negative chest x-ray, no operational cause
Excluded	Onset >24 hours post-dive, other clear cause of symptoms

Table 3.7.2-2 shows the origination of the call in 51 cases of suspected PBT.

Table 3.7.2-2 Origination of calls and reliability of diagnosis in 51 cases of suspected PBT

Calling from	Diagnosis of PBT					
	Certain	Possible	Unlikely	Excluded	Frequency	Percent
Home	4	17	7	1	29	57
Hospital	4	3	0	7	14	27
Dive site	1	2	2	0	5	10
Post-treatment	2	0	0	1	3	6
Total	**11**	**22**	**9**	**9**	**51**	**100**

Most calls (57 percent; n=29) were originated by divers from home reflecting the mildness of typical cases and the time required for symptoms to develop or to become concerning. In 14 cases (27 percent) calls were by attending physicians seeking consultation. These were usually more severe cases with victims taken directly to the local emergency department. There were only five calls (10 percent) from dive sites. Three calls were placed by divers after the treatment asking for explanation. The distribution of symptoms and findings versus reliability of diagnosis is shown in Table 3.7.2-3.

Table 3.7.2-3 Distribution of symptoms and findings vs. reliability of diagnosis of pulmonary barotrauma

Symptoms	Pulmonary barotrauma				
	Certain	Possible	Unlikely	Not PBT	Total
Chest pain	3	11	2	4	**20**
Shortness of breath	0	9	1	5	**15**
Hoarseness	6	2	0	0	**8**
Subcutaneous emphysema	6	0	0	0	**6**
Chest x-ray positive	5				**5**
Chest x-ray negative		2		3	**5**
Hemoptysis	0	3	0	0	**3**
Operating cause	1	7	3	3	**14**
Consultation call	4	4	0	6	**14**
Number of cases	11	23	8	10	**52**

When divers called from home, PBT was considered nearly certain only in four cases with a clear description of subcutaneous emphysema and verification of voice hoarseness which occurred early after the dive or within hours post-dive. In one case symptoms occurred more than 24 hours post-dive and were not considered dive-related. In seven other cases the PBT was considered unlikely. However, the majority of cases may have been caused by PBT and without medical examination it was not possible to confirm or to exclude PBT. All callers were properly referred to centers where they could be appropriately evaluated and treated.

In out of 14 consultation cases with an extensive workup already done, it was possible to confirm diagnosis in four and exclude it in seven. The workup was not yet completed at the time of the call in three cases and it was too early to make a determination. In some cases symptoms may subside and signs of gas may disappear before a patient is admitted for evaluation and thus some calls classified as possible PBT may remain unconfirmed even after a complete work up.

Calls from dive sites involved at least one ‘certain’ case of PBT judged by the presence of subcutaneous emphysema, hoarse voice and a reported operational cause. Two cases were considered possible PBT and two cases were classified as unlikely to be PBT.

Divers calling post-evaluation were typically interested in when they could return to diving. It was not uncommon for divers to be more concerned about being able to return to diving than about their actual symptoms.

Medical determination for return to diving requires evaluation of the causes and possible underlying causes of PBT (Moon, 2005). The medical fitness to dive evaluation must be done on a case-by-case basis by a qualified physician. DAN can help in finding diving physicians in a local area and in providing consultations between evaluating physicians and DAN medical specialists.

3.8 Immersion Pulmonary Edema (IPE)

IPE has been known in the scientific literature for the past 20 years, but the classic position was that it was a rare condition. This view has been shifting (Hampson and Dunford, 1997; Cochard et al., 2005), particularly as awareness in the diving community has grown. Following the publication of an article on the DAN website the number of calls regarding this condition has increased (McCafferty, 2008).

“Symptoms of IPE include shortness of breath or the sensation of not getting enough air while at depth, often after only a few minutes in the water. Typically the symptoms start before ascent. As divers with this condition ascend, they experience no improvement. In fact, they usually cough up pink, frothy sputum: Such fluid in the lungs can reduce the amount of oxygen reaching the blood. The diver may have noisy breathing that can be heard without a stethoscope. The condition usually occurs after only a few minutes in the water at a shallow depth, so it is not usually confused with cardio-respiratory decompression sickness (or “chokes”). Chest pain is usually absent, unless the condition is due to a heart attack. If the diver lacks sufficient amounts of oxygen, he or she may exhibit confusion or loss of consciousness.” (McCafferty, 2008)

IPE is an emergency that may present less or more dramatic symptoms at onset. Mild cases frequently recover spontaneously soon after the diver exits the water while severe cases require medical assistance.

In 2007, there were 20 calls regarding patients under consideration for IPE. Among them were nine cases with either confirmed diagnosis by clinical tests or considered very likely based on symptom presentation. In another nine cases there were conditions or symptoms not typical of IPE. In two cases, the presence of IPE could not be determined.

Out of nine confirmed IPE cases, four were consultation calls from physicians in emergency departments. Two calls were made by a spouse on a behalf of partner already in hospital. One call was from a bystander reporting a case he witnessed that appeared to be IPE based on material he read on the DAN website. Only one call came from diver who thought he may have suffered from transient symptoms of IPE.

One case involved a 58-year-old instructor. His medical history included atrial fibrillation, a cardiac rhythm disorder which was treated surgically several years earlier. One year earlier he was diagnosed and treated for an aspiration lung injury. He aspirated water while on the surface talking to students before a dive. During the dive he had difficulty breathing which continued on the surface. He recovered and had subsequently completed 58 dives. The case he called about occurred a few weeks earlier when he was diving again as an instructor. The dive involved multiple ascents and descents. He experienced difficulty breathing in the later stages of the dive. After the dive he felt pulmonary congestion and heard lung sounds. He was not seen by physician and all his symptoms resolved by the next day. The article he read on the DAN website made him think that he may have suffered from IPE.

Without proper medical evaluation it was impossible to establish a diagnosis in this case. The symptoms may have been caused by IPE, but it was rather mild form that resolved spontaneously. Nevertheless, this diver was advised to have a thorough medical examination and evaluate his risks for IPE or acute heart problems before resuming diving.

In another case, an instructor reported a possible IPE case that he witnessed. He observed two females - a student and an instructor - conducting an open water dive. Shortly after submerging, they surfaced and student seemed to be in a little bit of distress by the sounds of her voice. The instructor towed the student back to shore. Our observer helped to remove the equipment from the diver in distress, but while doing so, he could hear a gurgling sound coming from her whenever she was breathing. The injured diver was immediately given FAO_2 and started improving. The instructor reported that this was a pleasure dive with this newly certified student. They both made a slow ascent and a safety stop. The student did not signal any problems until they surfaced. At the surface she reported shortness of breath and produced a gurgling sound with each breath. By the time ambulance arrived, coughing symptoms and difficulty breathing were already relieved. The instructor who reported the case thought that the case fit what he read about IPE on the DAN website and he decided to report it.

This may well have been IPE. The flooding of the alveoli with fluid leaking from capillaries may arise quickly and produce the gurgling sound of gas passing through fluid at which time the patient would suffer from insufficient oxygen to exaggerate the discomfort. Breathing 100 percent oxygen speeds recovery and may contribute to a complete resolution of symptoms in a short time.

IPE cases in the literature typically involve breathing difficulty while at depth. The previous case, however, reported symptoms upon surfacing without explicit mention of when they first occurred. In another case a diver reported that symptoms occurred on the surface after the dive. This diver called from a hospital abroad to check with DAN about necessary action after she was diagnosed and treated for pulmonary edema. She developed symptoms after a dive to 45 fsw (14 msw) for 15 minutes. Upon surfacing she felt slight difficulty in breathing and produced “orange” sputum. The diver described her condition as a sudden onset of bronchitis. She was seen locally by a physician. Her chest x-ray revealed minimal infiltrates bilaterally. Auscultation of lung revealed bilateral rales. She was treated with oral steroids. At the time of the call, she still had a slight cough but no dyspnea.

In four cases the diagnosis was confirmed by the finding of low arterial oxygen saturation and a positive chest x-ray. The patients were divers between 45 and 58 years of age, representing both sexes. In all four cases difficulty breathing started at depth. One case was associated with a rapid ascent. Consults were requested for the possibility that barotrauma or DCS may have been involved, neither of which was confirmed for any of these cases.

3.9 Saltwater Aspiration

Out of nine cases that were considered not likely to be IPE, saltwater aspiration was reported in six. One was most likely related to heart problems and one to pneumonia. In another case, a 66-year-old male diver reported symptoms developing one week after returning home from his dive vacation. Because of difficulty breathing he had an extensive medical workup including both lung and heart tests.

His arterial oxygen saturation was low (P_aO_2 = 70 mm Hg, 100 mm Hg is normal) and his CT scan showed signs of pulmonary edema. The diver called DAN from the hospital because he was concerned that his symptoms may have been caused by IPE. However, despite the diagnosis of pulmonary edema in this case, it was clearly not the IPE since the symptoms were unrelated to immersion.

In one case aspiration was clearly involved. A male recreational dive student in his late sixties completed his open water certification during the previous weekend. At the beginning of his dive, he forgot to replace his snorkel with his regulator and he aspirated freshwater as he submerged. He returned to the surface, cleared his throat and continued his dive without incident. Post-dive he experienced respiratory discomfort and discovered he was coughing up pink tinged sputum. He was placed on oxygen and transported to the nearest emergency department where he was diagnosed with pulmonary edema. He was treated with Lasix (prescription diuretic). By the next day his symptoms were resolved and he was discharged from the hospital. He wanted to undergo an evaluation for medical fitness to dive and called DAN to obtain a referral to a diving physician in his area. This case did not fit the definition of IPE despite the finding of lung edema by the attending physician. Aspiration was the tentative diagnosis of his respiratory symptoms. Regardless of the final diagnosis, this diver needed and received proper medical attention and treatment. Evaluation for medical fitness to dive should precede return to diving after any similar accident.

In three other cases, aspiration was less dramatic. All included regulator trouble. One 16-year-old female student completing a training dive to 20 ft (6 m) returned to the surface and changed her regulator. She went back to 20 ft and on the subsequent ascent aspirated water. She started coughing up pink frothy sputum. In hospital she was diagnosed with pulmonary edema. In this case, although the dive was in cold water, the symptoms occurred after saltwater aspiration which can alone produce pulmonary edema.

Another call came from an emergency department regarding a diver who was admitted with difficulty breathing after a dive in which he claimed he aspirated saltwater. The diver had no hypertension and was in a good physical shape. The chest x-ray showed fluid in the right lung with no other significant findings. The diver recovered within one day and was released. This was also not considered IPE since the findings were more typical of aspiration. Due to the size and position of the right bronchus, aspirated content more often ends up in the right lung than the left lung.

3.10 Conclusion

Injury data in DAN's MSCC database, collected through DAN emergency and information lines, reflect the wide range of injuries and concerns encountered in recreational diving. The range of cases seen through MSCC data provides a broader spectrum of recreational diving injuries than reports from individual hyperbaric centers. However, the MSCC probably does not reflect the true morbidity in recreational diving because of incomplete reporting, self-administered treatment and referral bias.

A weakness of MSCC data is the common absence of verified diagnoses. Follow-up is required as a standard procedure, and completion rates are improving, but final records are often incomplete. DAN is also training hyperbaric centers in use of the MSCC as a case management tool. The MSCC has been in use at these centers for two years with increasing participation by medical care providers and improved follow-up compliance. Divers who call the DAN emergency line can contribute by calling back after evaluation or treatment to provide outcome information.

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DIVE FATALITIES

Petar J. Denoble, MD, DSc

4.1 Introduction

The purpose of collecting and studying diving fatality case data is to learn about risks, to identify preventable risks and to avoid unnecessary deaths in the future. To achieve that goal, we always must listen to whether we were successful in conveying to our readers what we have learned. The readership of the DAN Diving Annual Report is broad. The impact is augmented by many other media spreading lessons learnt presented in our reports. However, not all media are always true to our report. The following is an excerpt from one website:

> *Divers Alert Network (DAN) (www.diversalertnetwork.org), a US non-profit scuba diving and dive safety association, reported 138 diving deaths worldwide in 2006, with the recorded incidents mostly self-inflicted due to recklessness or ignorance — ….*
> *"Almost all scuba diving accidents can be avoided by following good diving practices," says John Doe, an instructor at 5 Star Dive centre and training facility.*

Whether good diving practices are prevailing or not, the fact is that deaths in recreational scuba diving are rare events. However, regardless of how low the risk of dying while diving is, it is never insignificant since every life is priceless. In order to help prevent deaths, we must identify preventable causes and make them known to the diving community. The conclusion that most fatal injuries were *"self-inflicted due to recklessness and ignorance"* does not provide much incentive for preventive action and we hope that it is not the most correct summary of our previous report. We have shown that most fatal accidents have more than one cause. Good diving practices help to reduce hazards and to mitigate consequences but there may be other causes that could be addressed directly.

For example, in previous reports and papers we have shown that acute disruption of heart function may be a root cause of some diving fatalities. As with other sudden cardiac deaths, some may be preventable and others not. Divers who have known risks for heart disease, and especially those who have heart disease symptoms, should discuss their fitness for diving with physicians knowledgeable about diving medicine. At-risk divers may choose to abstain from diving if the risks are unacceptable. Others may continue diving if the risks are outweighed by their desire to continue. In any case, there will also be a number of people who will die of sudden cardiac death although they had no known risk factors and no obvious heart disease. It can happen in golfing as well as in scuba diving. These deaths are practically unpreventable.

Some deaths may well be preventable, like drowning due to sudden loss of consciousness caused by hypoxia or oxygen toxicity seizures. When the hazards of hypoxia or hyperoxia exist, using a full face mask seems a reasonable measure to reduce the risk of drowning.

We believe that previous DAN diving reports (Vann et al., 2006; Pollock et al., 2007, 2008) have helped to identify some preventable causes of diving fatalities and we prepared this report with the intent to further that understanding.

DAN has maintained a recreational diving fatality surveillance system since 1989 to help learn why divers die and how deaths might be prevented (Vann, 2007; Denoble et al., 2008). Similar surveillance is maintained by the British Sub-Aquatic Club (BSAC) in Great Britain (Cumming, 2007, 2008) and in Australia with Project Stickybeak (Acott, 2003). The numbers reported by DAN, BSAC and EDAN are shown in Figure 4.1-1. The populations of recreational divers are much smaller in Great Britain and Australia than in the US and Canada. In addition, BSAC only includes data for BSAC membership and not for British divers affiliated with other organizations.

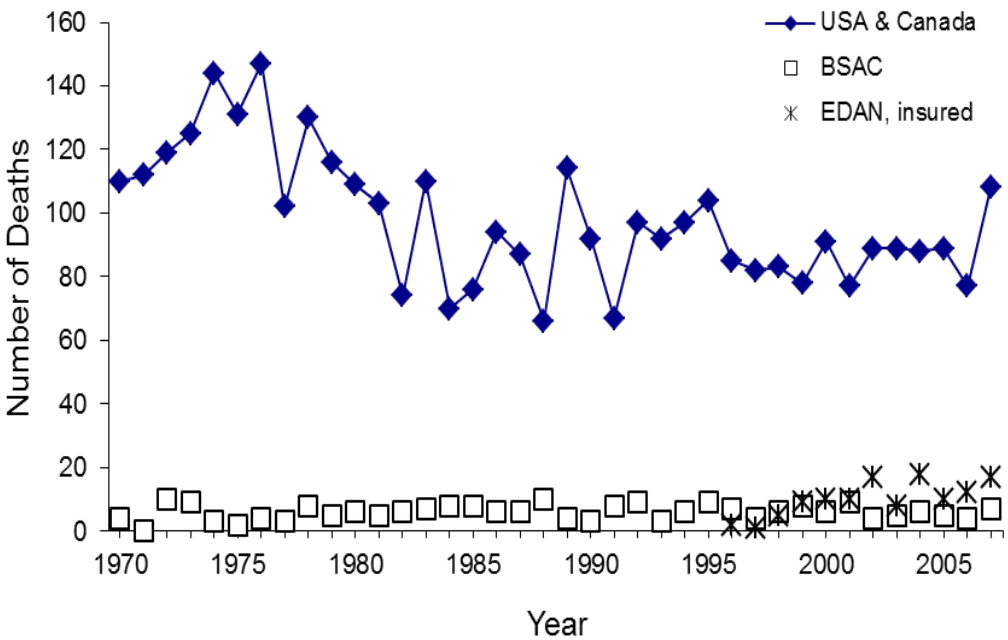

Figure 4.1-1. Annual counts of deaths related to recreational scuba diving for three distinctive populations

The annual count of deaths alone does not tell the whole story. The increasing number of deaths among insured EDAN members parallels the increase in the number of insured EDAN members. This does not include all deaths in Europe since only a fraction of European divers are EDAN members.

BSAC data are presented in Figure 4.1-2. Over the last 20 years, fatality rates remained at 20 or less per 100,000 BSAC members. The increase in 2007 and 2008 in comparison to the previous five years could be a random variation. The rates were calculated on BSAC members only and do not include all deaths in the UK or among British divers. In 2007 there were seven BSAC deaths and five non-BSAC British deaths in the country. In addition, there were three more British diver deaths overseas.

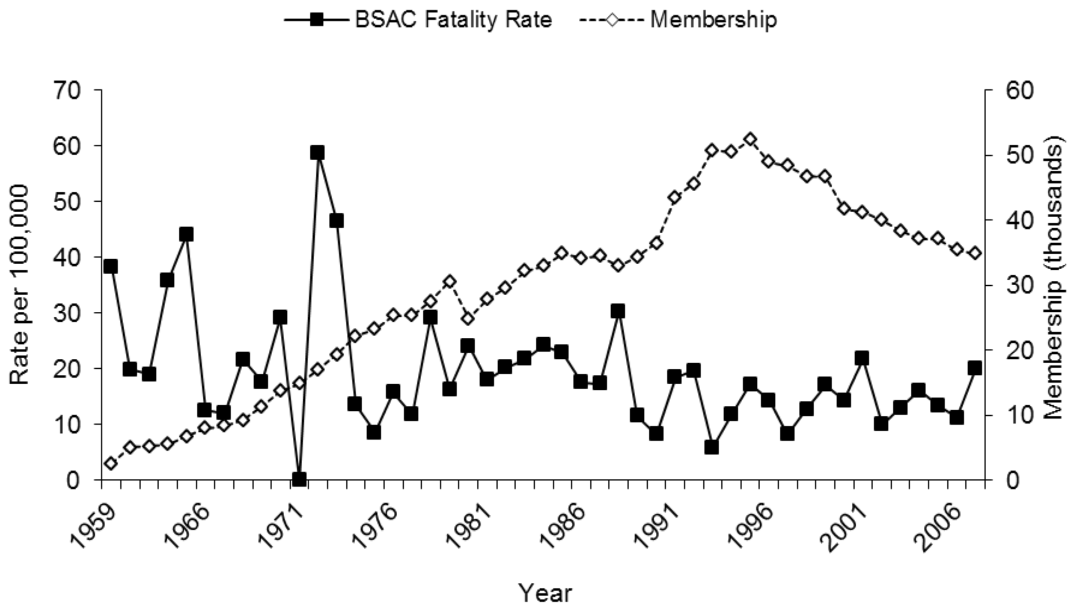

Figure 4.1-2. BSAC annual membership numbers and annual fatality rates

Figure 4.1-3 shows the dive fatality rates among DAN and BSAC members from 1997 through 2008. The BSAC rates decrease from the peak value of 60 per 100,000 members in 1972 to 15 per 100,000 in 2006. In 2007, the annual fatality rates for both memberships were slightly above the previous 10-year average, but not sufficiently to call it an increase.

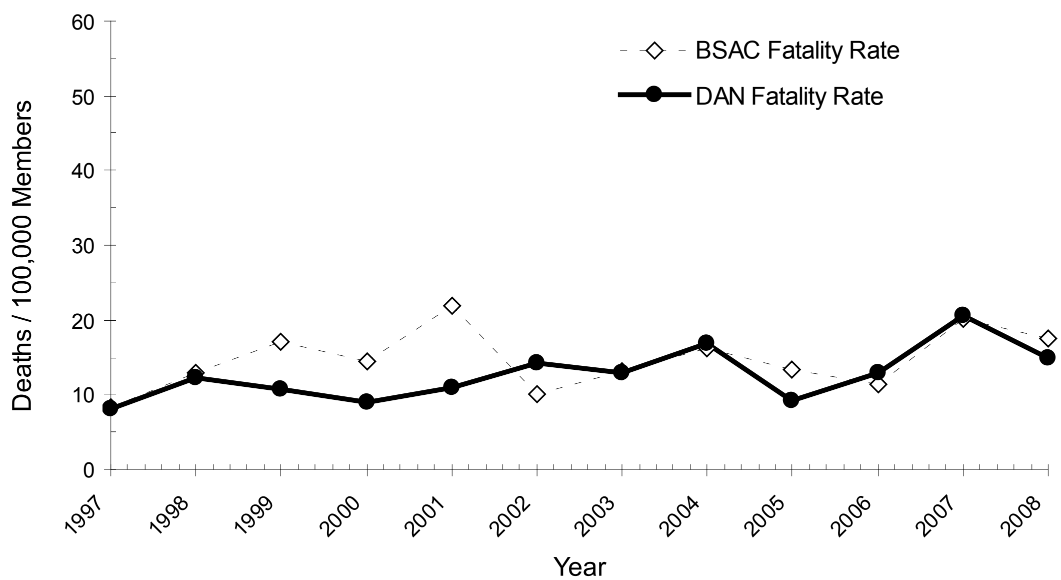

Figure 4.1-3 Recent fatality rates among BSAC and DAN members

A study based on an analysis of DAN membership data indicates both that the membership is aging and that the mean age of fatality victims among DAN members is increasing (Denoble et al., 2007).

The mean age of all decedents in US and Canadian diving accidents increased from 42 in 1998 to 48 in 2005 (Figure 4.1-4) but in the last five years it seems relatively stable at close to 50. The decedents among insured DAN members were about one year older than the non-members.

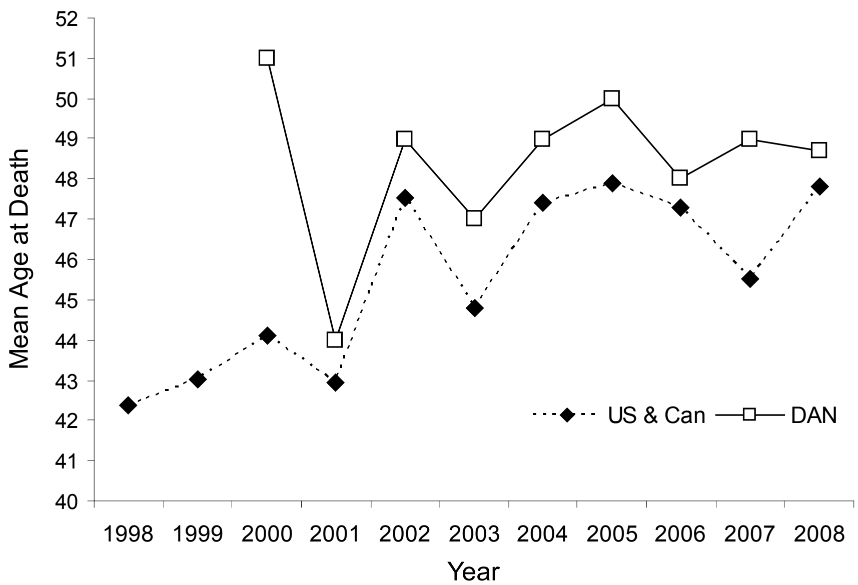

Figure 4.1-4 Mean age of US and Canadian fatalities DAN members and non-members.

4.2 Geographic and Seasonal Distribution of Fatalities

Worldwide, DAN received notification of 183 deaths involving recreational scuba diving in 2007. This is shown in Table 4.2-1. Only the deaths of 113 US and Canadian recreational divers have been actively investigated by DAN America. Reports of dive-related deaths from other regions were recorded but due to geographical limitations were not investigated.

Autopsies were conducted in 72 cases and reports available for 52 cases. Coroner summaries were available for four cases and three cases included death certificates. The body of the decedent was not recovered in eight cases. An autopsy was not performed in four cases. It was unknown if an autopsy was performed in 27 cases. Witness reports were obtained in 46 cases (39 percent), 64 (54 percent) occurred without witness and for 8 cases there were no data.

Most US citizen scuba fatalities occurred in the US (89 out of 113, 79 percent) and all nine Canadian citizen deaths occurred in Canada. The increase of the number of fatalities in comparison to the previous two years seem to be mainly because fatalities occurring at home while the number of fatalities abroad decreased or stayed the same. This may indicate less diving in the comfort of Caribbean and more in harsher domestic conditions. It can be also due to the increased coverage of internet and improved search technology.

Table 4.2-1 DAN received notifications about fatalities by country

Region	Country	US & Canada Residents	Non US & Canada Residents	All Cases
America	Anguilla	1		1
	Aruba	1		1
	Bahamas	3	1	4
	Bermuda	2		2
	British Virgin Islands	1		1
	Canada	9		9
	Cayman Islands	5		5
	Jamaica	0	1	1
	Puerto Rico	1		1
	US Virgin Islands	1		1
	United States	78	1	79
	America Totals	**102**	**3**	**105**
Central America	Belize	3		3
	Honduras	1		1
	Mexico	6	5	11
	Central America Totals	**10**	**5**	**15**
South America	Brazil		1	1
	Chile		1	1
	Ecuador		1	1
	Venezuela		1	1
	South America Totals		**4**	**4**
Europe	Croatia		1	1
	Egypt		13	13
	Greece		2	2
	Ireland		3	3
	Italy		2	2
	Malta		2	2
	Scotland		2	2
	Spain		1	1
	Switzerland		1	1
	United Kingdom		10	10
	Europe Totals		**37**	**37**
Japan	Japan	1		1
	Japan Totals	**1**		**1**
Asia-Pacific	Australia		5	5
	Bahrain		1	1
	Guam		2	2
	Indonesia		1	1
	New Zealand (Aotearoa)		8	8
	Northern Mariana Islands		1	1
	Singapore		1	1
	Asia-Pacific Totals		**19**	**19**
South Africa	South Africa		2	2
	South Africa Totals		**2**	**2**
	Total	**113**	**70**	**183**

The 113 cases involved both US (100) and Canadian (9) divers. Table 4.2-2 shows the geographic distribution of domestic US and Canadian fatalities by state or province. Thirty-eight percent of 84 US domestic scuba fatalities occurred in Florida and 18 percent in California. Most of the Canadian domestic fatalities occurred in Ontario (55 percent).

Table 4.2-2 Domestic US and Canadian fatalities by state or province (in 2007 n=93)

State or Province	**2005**	**2006**	**2007**
Florida	17	17	32
California	9	11	15
Ontario	4	4	5
Hawaii	3	1	5
Washington	5	7	5
Ohio	0	0	4
Massachusetts	3	1	3
Michigan	0	4	2
New Jersey	0	2	2
New York	4	2	2
North Carolina	3	1	2
Alaska	0	0	3
Pennsylvania	2	0	2
Texas	3	0	2
British Columbia	5	2	1
Illinois	2	1	1
Indiana	0	0	1
Newfoundland	0	1	1
Alabama	0	0	1
Alberta	0	0	1
Manitoba	0	0	1
Rhode Island	0	0	1
Maine	1	2	0
Louisiana	0	1	0
Minnesota	0	1	0
Quebec	0	1	0
Connecticut	1	0	0
Nova Scotia	3	0	0
Oregon	1	0	0
South Carolina	1	0	0
Utah	0	0	1
Vermont	1	0	0
Total	**68**	**59**	**93**

Figure 4.2-1 shows the month of death for fatalities in 2007 and fatalities in 2004-2006. The rate tends to increase in the summer months (June through August). In 2007, July presented a singular peak with 20 cases (18% percent).

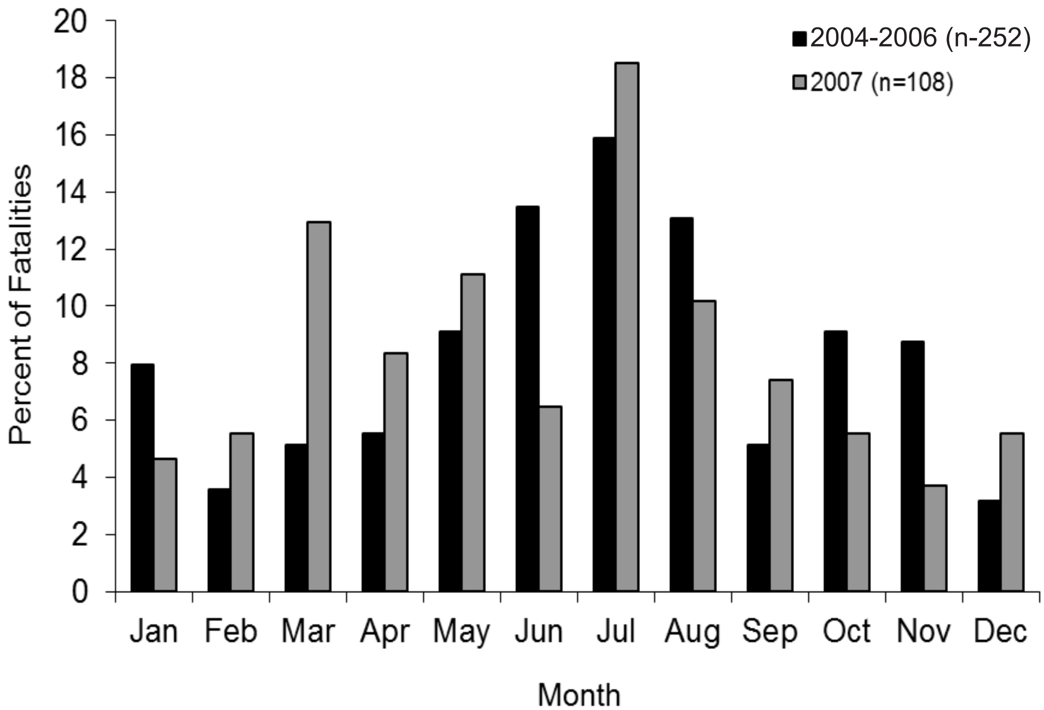

Figure 4.2-1 Month when diver deaths occurred

It appears that the number of fatalities in Florida and Washington peak in the summer coinciding with the common vacation season. Cases in California are distributed more evenly from May through November.

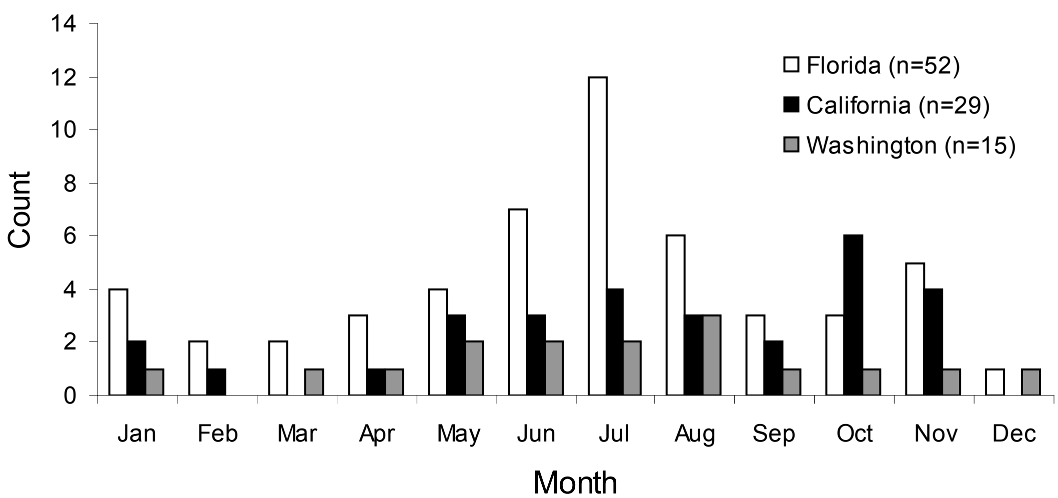

Figure 4.2-2 Month of accident by states with the most diving fatalities in 2004-2006

4.3 Age and Health of Decedents

Figure 4.3-1 shows the age distribution for dive fatalities. Eighty-two percent of females and 72 percent of males were 40 years or older. The median age of male victims was 50 years. The median age of female victims was 43 years.

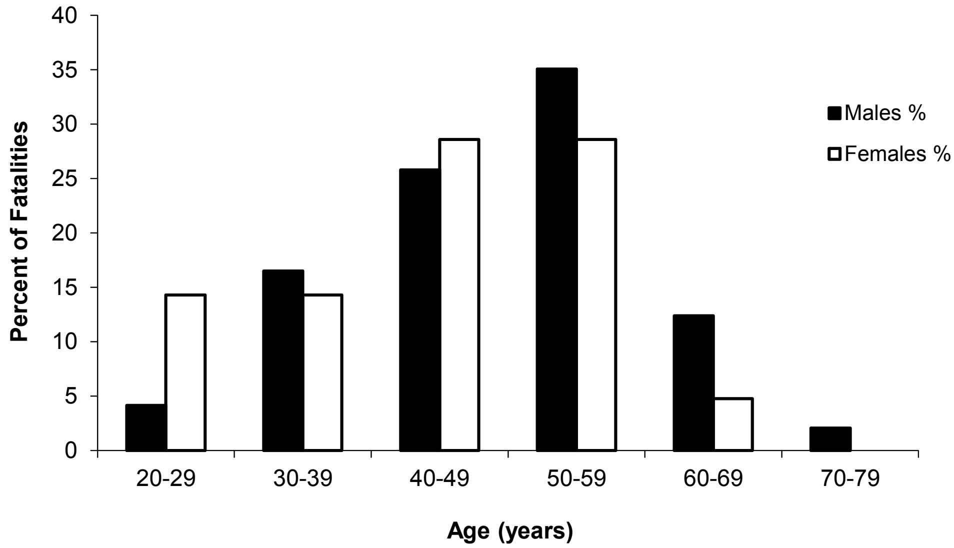

Figure 4.3-1 Distribution of fatalities by age and sex

There were two teenagers among the victims. One 19-year-old male went cave diving with two older divers. No one in the group had cave diving training. They did not adhere to cave diving safety rules and the teenager drowned. Another teenager was a 16-year-old girl diving with her father. She panicked and drowned. More teenagers were involved as buddies in accidents.

Medical history was in most cases incomplete. The most frequently revealed medical conditions in decedents were heart disease (n=16; 13.6 percent of all cases) and high blood pressure (n=9; 7.6 percent).

Table 4.3-1 Available medical history on decedents.

Medical Condition	n	%
Heart Disease	16	13.6
High Blood Pressure	9	7.6
Diabetes	5	4.2
Asthma	4	3.4
Ear/Sinus	3	2.5
Back Pain	2	1.7
Depression	2	1.7
Allergies	1	0.8
Nervous System	1	0.8
Lung Disease	1	0.8
Diarrhea	1	0.8

Although deaths in diving are often associated with specific dive-related causes, some may occur as a sudden death as in any other life situation. Most sudden death is associated with heart disease. Risk factors include male sex, age greater than 40 years, smoking, high blood pressure, diabetes, overweightness and sedentary lifestyle. The presence of heart attack risk factors among diving fatalities is difficult to evaluate retrospectively. Our reporting form for fatalities provides explicit fields for reporting a presence of heart disease and four risk factors: high blood pressure, diabetes, smoking and high body mass index (BMI). There is no explicit question regarding physical exercise. Based on available information in our database, at least in 31 cases there were some risk factors present other than sex and age. All four risks were revealed in one case, at least three risks in four cases and two risks in 11 cases.

Diabetes was known in five fatalities. The age of decedents ranged from 50 to 71 years. Three had known heart disease and two were considered healthy. The medical examiner found signs of advanced heart disease in one case. For the other decedent, the autopsy results were not available but the family reported that he had a recent fainting episode which was likely caused by serious heart dysrhythmia. Thus, all five scuba fatalities with known diabetes also had some form of heart disease.

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 instituted. 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. Divers with diabetes must consider these facts when deciding about conditions for their participation (ADA; AHA; Pollock et al., 2007).

Obesity was estimated in 53 victims using BMI shown in Figure 4.3-2. Eleven (20 percent) were classified as normal weight (18.5-24.9 $kg \cdot m^{-2}$), 20 (38 percent) as overweight (25.0-29.9 $kg \cdot m^{-2}$), 16 (30 percent) as obese (30.0-39.9 $kg \cdot m^{-2}$) and 6 (11 percent) as morbidly obese (≥40 $kg \cdot m^{-2}$). One teenage girl had a BMI below 18 $kg \cdot m^{-2}$, considered underweight, but the medical examiner described her body build as normal.

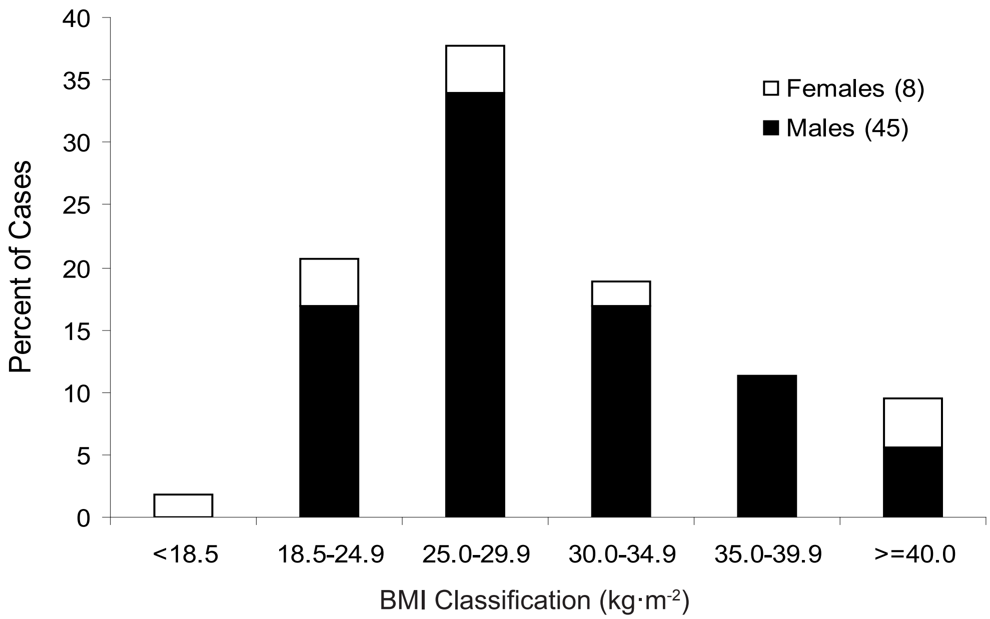

Figure 4.3-2 Classification of fatalities by BMI (n=53)

Asthma was reported in four decedents but its contribution to death could not be always established. Two of the victims with asthma used inhalers and the other two used Advair. One was an instructor in his early forties. For three days he was instructing diving under ice. When the last dive of the course was complete, both the instructor and the student continued diving to collect crayfish from the bottom under the ice. Both ran out of air. The student was tethered from the surface and he found his way out while the instructor, who was not tethered, did not come back. Asthma did not seem to be an issue in this death, but still it is not considered advisable for a person with active asthma to dive in extremely cold conditions.

In another case, a young female, who was using an Albuterol inhaler for asthma, died on her fourth lifetime dive. Immediately after descent in cold water to 85 ft (26 m), her buddy noticed something strange about how the victim was moving around but she gave him an OK signal and he turned away for a moment. When he looked back, her face was pale and unresponsive. He could not get her to surface so he surfaced alone to look for help. The victim was soon brought up but resuscitation was unsuccessful and she was pronounced dead in hospital. It was later found that her regulator was very hard to breathe from, probably too much so for somebody with already impaired breathing. Both cold water and the faulty regulator, in combination with asthma, likelycontributed to the death of this inexperienced diver.

Even if numerous medical conditions were present in victims, they did not necessarily constitute the cause of death. This sexagenarian male, certified for the first time 30 years ago, returned to diving after completing a recertification class in the year prior to the accident. His medical history included obesity, asthma, heart disease, arthritis, previous knee replacements and diabetes. A physician cleared him to dive the day before this dive in a quarry with a buddy. He was wearing a drysuit, but had no drysuit certification. He replaced the exhaust valve of his drysuit one day prior to the incident. At 50 ft (17 m) he had trouble venting his suit and it overinflated. He was seen to surface feet first, kicking violently. By the time help reached the victim, he was unresponsive and not breathing, regulator out of his mouth, and his mask and hood off. He did not regain consciousness and was pronounced dead in hospital. According to the coroner, the valve, bought on E-bay, was working normally but the drysuit was cut during the attempted rescue so it could not be properly tested. The accident was attributed to inexperience and lack of training. Being in an inverted position in a drysuit is a hazardous situation but not necessarily unmanageable. Poor health and fitness of this diver may alos have contributed to his death.

The fourth case involved another 66-year-old diver with history of asthma and Advair use. He surfaced after a five to six minute dive on trimix to 200 fsw (61 msw) for spearfishing. He complained of weakness after surfacing. Soon after he collapsed and lost consciousness. He did not breathe regularly but had two to three gasps per minute that was possibly agonal breathing. An audio recording of agonal breathing is available at this link: http://www.americanheart.org/downloadable/heart/1226933999454agonal%20clip.wmv. The victim arrived at the hospital unconscious, paralyzed and unresponsive. A CAT scan of the brain showed air in his ventricles. During examination, his blood pressure became too low and his heart rate became very irregular (ventricular fibrillation). He underwent CPR. The ECG indicated a myocardial infarct of the inferior heart wall and chest x-ray revealed bilateral infiltrates. During an attempted recompression treatment, the patient's blood pressure dropped further and could not be stabilized by medications. The recompression was aborted and the patient was returned to the intensive care unit where he expired the next day. The role of asthma in this case was not clear. The patient may have first experienced acute myocardial infarction at depth and got barotrauma secondary to a rapid ascent that followed, or he may have made a rapid ascent for whatever reason first, got asthma-induced barotrauma which caused secondary myocardial infarction and cerebral arterial gas embolism. The autopsy finding did not show the infarction of the lower wall that was diagnosed based on ECG. This illustrates how acute life-threatening events may leave no trace to be found during autopsy. Read more about asthma and diving at the DAN website: http://www.diversalertnetwork.org/medical/articles/article.asp?articleid=22

One diver in his fifties, who died in a cave, reportedly used seizure medication and was a recreational cannabis user. Neither drug was implicated as a cause of death.

Information about lifestyle and physical fitness of decedents is typically extremely limited so little interpretation is possible.

4.4 Diving Certification and Experience

Eighty-three of the victims (77 percent of all cases) were known to be certified but information on the certification level was available in only 48 cases. Two victims did not have any certification and five were students. The cases with known certification included 11 open water, 18 with advanced or specialty, five divemasters or assistant instructors, three instructors, 12 technical and one each with commercial, scientific and military (note: the last three each died while diving recreationally).

Figure 4.4-1 shows the number of years since initial certification. It is based on 48 cases with known information (44 percent of total). Fifty-five percent of those with known history had been certified six years or more, and 35 percent two years or less. There were at least three divers that had had a hiatus from diving of more than one year. The distribution of experience varies substantially from year to year due to the small numbers. The primary lesson to learn is that every diver, regardless of experience, must maintain vigilance and adhere to safe diving practices.

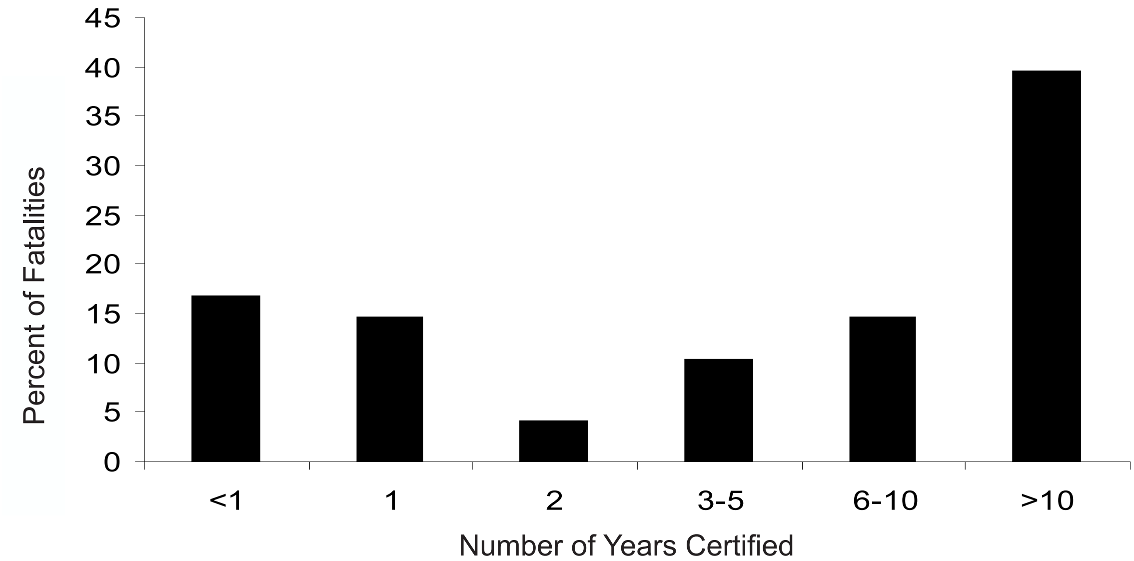

Figure 4.4-1 Number of years since initial certification of divers who died (n=48)

4.5 Characteristics of Dives

Figure 4.5-1 shows the month of death for fatalities in 2007 and fatalities in 2004-2006. The data show that the fatality rate tends to be highest in summer months (June through August). In 2007, July presented a singular peak with 20 cases (18 percent).

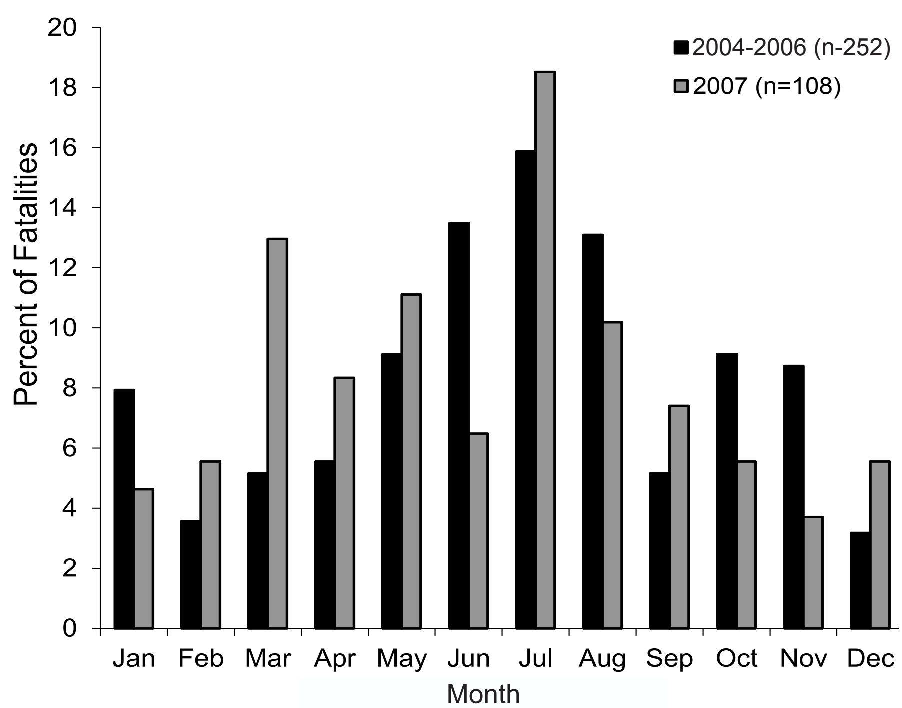

Figure 4.5-1 Fatalities by month for 2007 and 2004-2006

Figure 4.5-2 shows the type of diving activity during the accident. Information was available for 102 cases. Seventy-three (74 percent of known cases) of the fatal dives involved pleasure or sightseeing, 12 cases (12 percent of known cases) involved spear fishing, hunting or collecting game, ten (10 percent of known cases) involved training and two photography, one instructing and three were described as personal tasks.

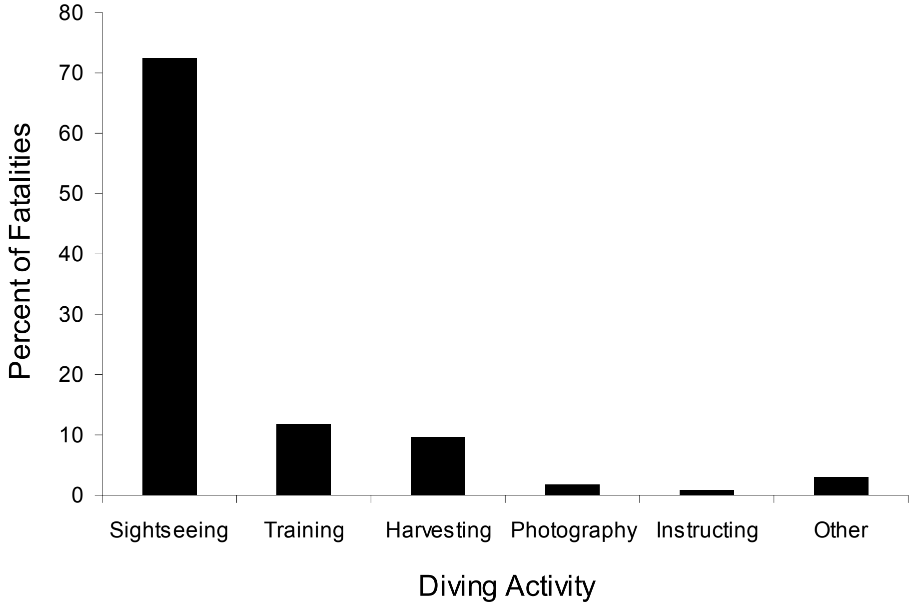

Figure 4.5-2 Diving activity (n=102)

Figure 4.5-3 shows the platform from which the fatal dives began. Data were available in 104 cases (96 percent). In most cases the dive began from a charter boat or private vessel (n=58; 58 percent of known cases), consistent with previous reports. Dives began from shore in 38 cases (n=37 percent of known cases) and from a pier or a liveaboard in four cases each.

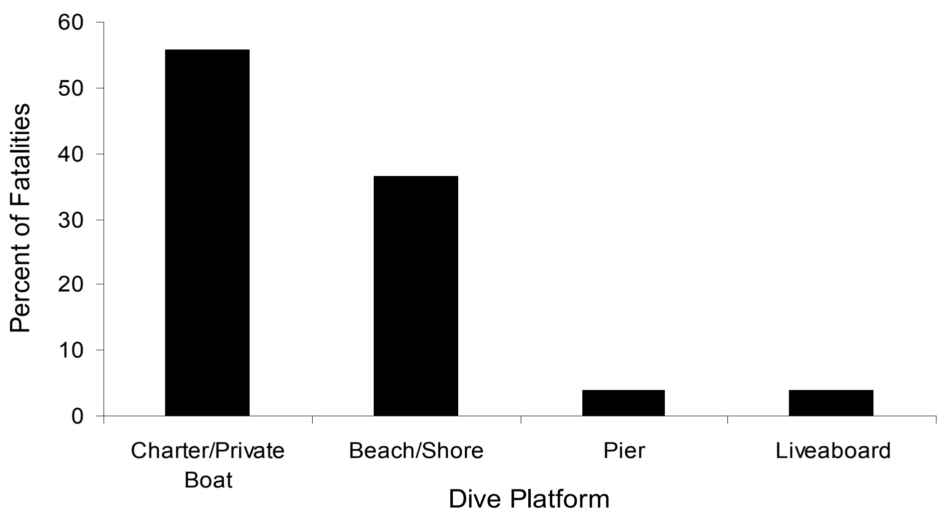

Figure 4.5-3 Dive platform (n=104)

Water condition (sea state) was reported in 43 cases (57 percent of total). Rough seas were reported in 13 cases (23 percent of known cases). Information about current was available in 31 cases (41 percent of total). Currents were described as strong in 10 cases (32 percent of known).

Information about protective suits worn by divers was available in 41 cases (55 percent of total). Twenty-eight of the victims (55 percent of known) wore wetsuits and 13 (32 percent of known) wore drysuits.

Figure 4.5-4 shows the maximum dive depth reported for known cases (n=79; 74 percent of total). The median reported depth of underwater accidents was 65 ft (20 m). Forty cases (52 percent of known) occurred in 30-120 ft (9-37 m) of water, 10 cases (14 percent) in greater than 120 ft (37 m) and 29 cases (37 percent of known) in less than 30 ft (9 m). In addition to technical dives deeper than 200 ft (61 m) on scuba shown here, two of the rebreather deaths not included in this figure occurred at 300 ft (91 m) and 375 ft (114 m).

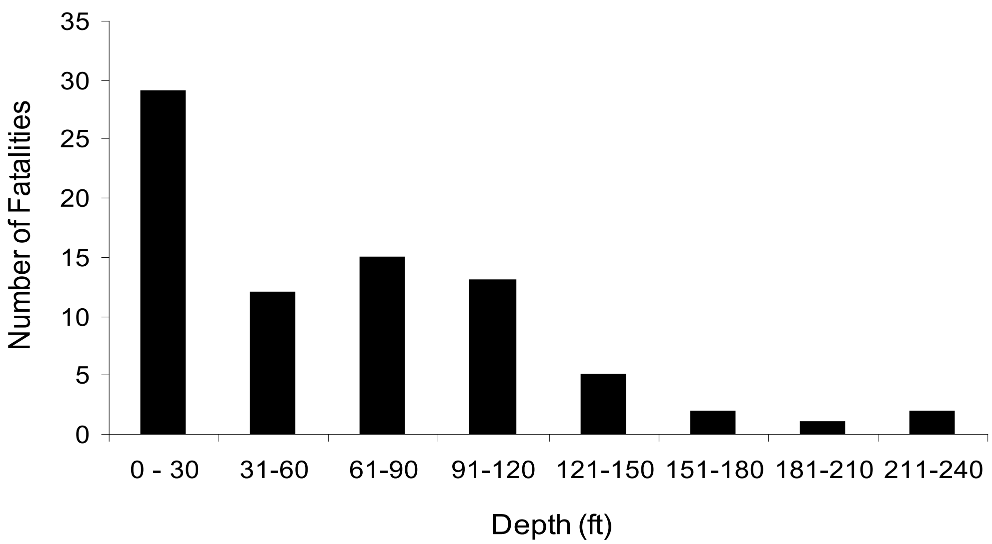

Figure 4.5-4 Maximum depth of accident dive (n=79)

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.

Open-circuit scuba was used in 103 cases, rebreathers in four and surface-supply in one case. Enriched air nitrox was used with scuba in one case and with rebreathers in two cases. Trimix was used with open-circuit in one case and with rebreathers in two cases.

4.6 Analysis of Situations and Hazards

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

4.6.1 Fatalities by dive phase

Dive phases included: a) on the surface before diving, b) descent, c) on the bottom, d) ascent, and, e) on the surface after diving. We included all fatalities in this analysis that occurred from the moment when a scuba-equipped diver entered the water. Figure 4.6.1-1 shows the distribution of fatalities by dive phase when the problem became apparent.

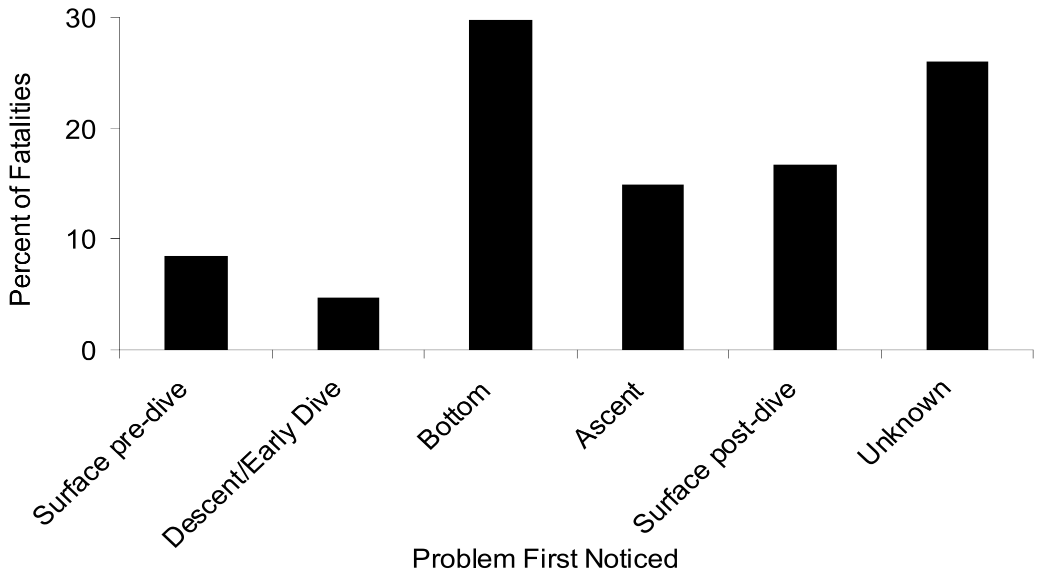

Figure 4.6.1-1 Dive phase when it became obvious that the diver had a problem (n=108)

The accident description was available in 80 cases (74 percent of total). Problems developed prior to descent in nine cases (11 percent of known), during descent in five cases (6 percent of known), on the bottom in 32 cases (40 percent of known), during ascent in 16 cases (20 percent of known), and at the surface post-dive in 18 cases (23 percent of known).

Figure 4.6.1-2 shows the distribution of fatalities by the phase in which the diver apparently lost consciousness.

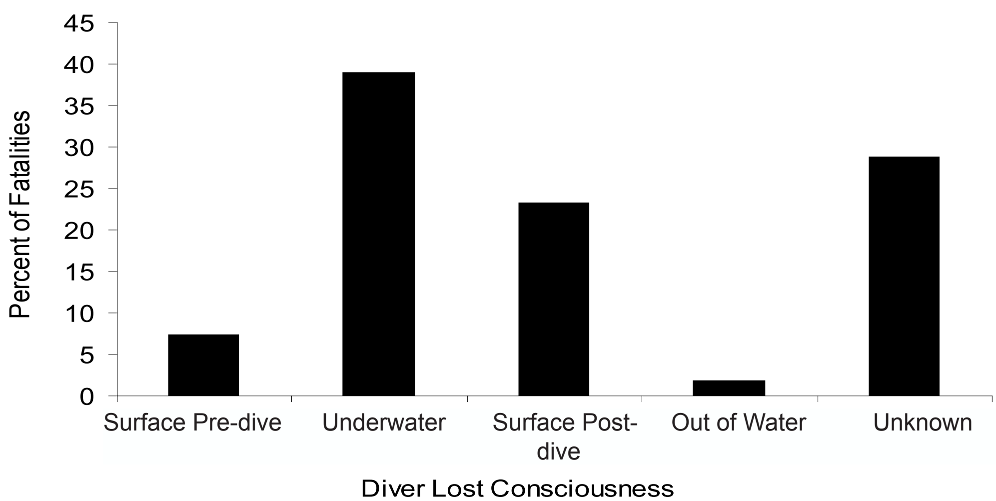

Figure 4.6.1-2 Dive phase when diver lost consciousness (n=108)

The point at which the victim lost consciousness was reported in 77 cases (69 percent of total). Most victims (n=42; 55 percent of known) lost consciousness underwater. The victims were reported to have lost consciousness at the surface post-dive in 25 cases (32 percent of known), at the surface before they submerged in eight cases (10 percent of known), and after exiting the water post-dive in two cases.

Out of eight cases that occurred pre-dive, six victims were diving from shore and went into distress during the surface swim. Rough seas contributed to three of those cases. Only one diver was over 60 years of age and had a known history of chronic disease. Most of the decedents were infrequent divers. Buoyancy was a factor in two cases. One diver struggled because she was overweighted and another because she was too buoyant and could not descend below the surface.

Twenty-five decedents lost consciousness at the surface after the dive. Six of them suffered AGE and 11 most likely suffered acute heart problems. Swimming at the surface is more strenuous than swimming underwater and it can provoke heart problems in physically unfit divers. Fortunately, fitness for swimming at the surface could be easily improved by training in the safety of swimming pools. Divers should be encouraged to avail themselves of this kind of opportunity.

4.6.2 Cause of Death (COD)

Cause of death (COD) as determined by medical examiners and coroners is shown in Figure 4.6.2-1. COD was assigned in 91 cases (84 percent of total), not reported in nine cases (8 percent of total) and the body not found in six cases (5 percent of total). Sixty-eight cases (74 percent of known) were designated as drowning, 14 (16 percent of known) as acute heart condition, eight (9 percent) as AGE and one as DCS. In one case a diver succumbed after being struck by lightning.

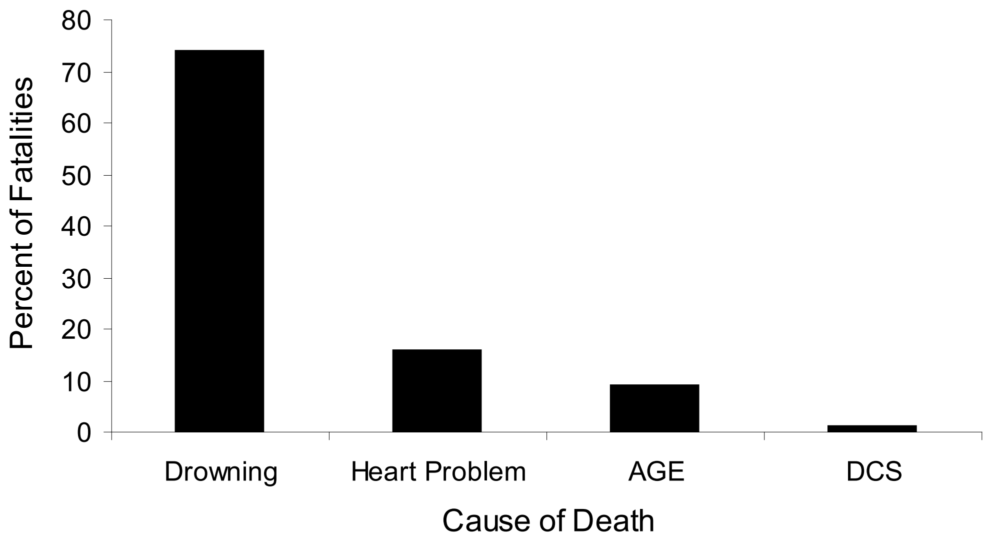

Figure 4.6.2-1. Cause of death (n=88)

4.6.3 Disabling Injury

Determination of the disabling injury 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 (Vann, 2007).

Figure 4.6.3-1 shows the distribution of the disabling injuries established in 86 (80 percent of all) cases. The three most common disabling injuries, drowning (n=37; 43 percent of known), heart problems (n=26; 30 percent of known) and AGE (n=13; 15 percent of known data) contributed to 88 percent of cases with identified causes or to 70 percent of all cases.

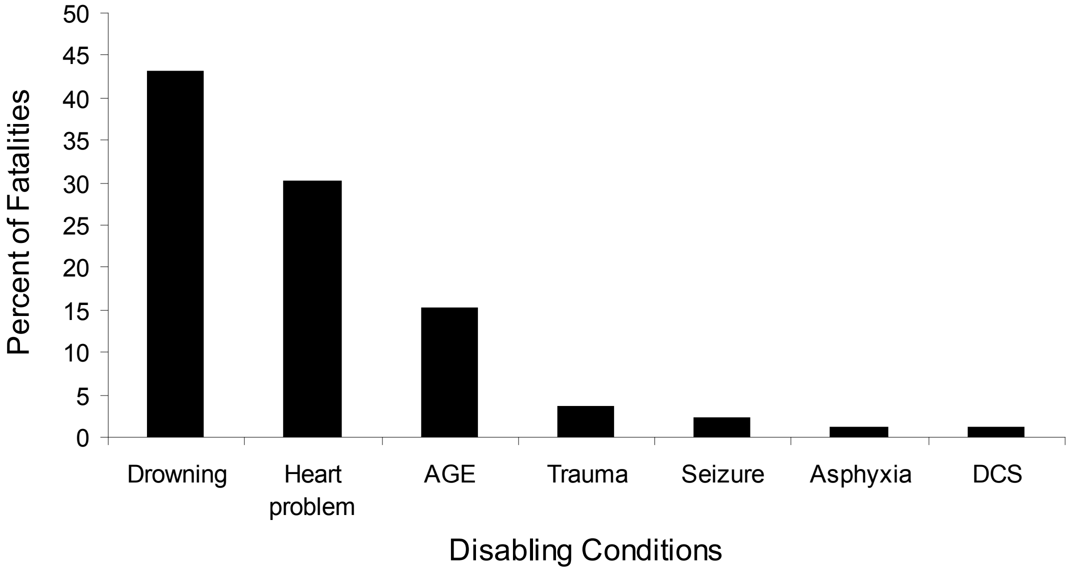

Figure 4.6.3-1. The distribution of the disabling injuries (n=86)

The diagnosis of drowning was reserved for the cases without indication of any disabling condition preceding asphyxia due to submersion and lack of breathing gas. Drowning as a disabling condition was assigned to 37 cases (43 percent of known). A typical drowning case is described below.

This 43-year-old male had an open water certification but had not dived for several years. He and a buddy were making a shore entry when the diver lost a fin and struggled to recover it. He panicked and aspirated water in the process. He was pulled back to shore by his buddy and was unconscious on the beach. Resuscitation efforts were unsuccessful. The autopsy report was not made available but the cause of death was reported to be drowning.

Another diver in his sixties was on his first dive in a discover dive class. After an uneventful dive to 38 fsw (12 msw) for 15 minutes he was swimming towards shore when a small wave caused him to inhale (aspirate) water. He started choking and panicked. The instructor inflated the diver's buoyancy compensator and towed him towards shore. About three minutes from shore, the victim lost consciousness. Subsequent attempts at resuscitation were unsuccessful.

Aspiration while swimming at the surface is fairly common but a fatal outcome following aspiration is not. Poor fitness and an inability to control breathing in the face of oncoming waves may have contributed to these deaths. Speculating further, the aspiration may have happened (if at all) after the diver became disabled by exertion-affected heart compromise.

A triple fatality resulted from a group of four divers diving to a wreck at 135 fsw (41 msw). They went into an off limits passage, kicked up silt and became lost. Only one diver made it to the surface. The other three divers ran out of gas and drowned inside the wreck.

One young female attempted her first open water dive with a friend who was teaching her. Prior to this, she had only one pool dive two months previously. After about five minutes she panicked. Her buddy tried to help her but could not. They struggled to stay at the surface but the victim sank below the surface and drowned.
Heart problems as a cause of death were established based on the description of an accident, medical findings at autopsy and the expert opinion of the reviewers.

The certification status and experience level of this 45-year-old female is unknown. She had been hospitalized a few months earlier for “exertional pulmonary edema” but upon discharge was told she could return to diving. After entering the water she complained of difficulty breathing prior to descent. She lost consciousness before submerging. An autopsy was performed but the findings were not made available. The medical examiner ruled the death as a drowning, but based on a credible witness description of the accident, recurrent pulmonary edema could not be excluded.

In this case the victim was a female in her sixties with known problems of morbid obesity, mitral valve prolapse, hypertension, and hypothyroidism. The dive was part of a resort course or a familiarization dive. She was apprehensive before entering the water from a boat. After descending to 20 fsw (6 msw) she signaled to the instructor that she wanted to ascend. On the surface she complained of shortness of breath, then lost consciousness while climbing the ladder to get back into the boat and died. The medical examiner described changes associated with drowning, mild coronary artery disease and confirmed the diagnosis of mitral valve prolapse. The timing of the onset of loss of consciousness is classic for an air embolism but the pathologist found no corroborating evidence of barotrauma at autopsy. The death was ruled as a drowning. Another speculation is that diver felt heart-related problems while at the bottom, continued having chest discomfort which she reported as difficulty breathing and was pushed into serious trouble by the effort of climbing the ladder.

A female diver in her fifties was an experienced diver with advanced open water certification. She stayed behind when a group ventured deeper into a quarry. After the other divers returned to the pier it was noticed that she had failed to return and a search was initiated. She was found on the bottom at approximately 65 ft (20 m) a few minutes later. An autopsy disclosed changes consistent with drowning as well as irregularities in the myocardium. The equipment appeared to be in good working order and her tank was nearly full. She drowned, probably after losing consciousness, possibly as a consequence of a cardiac dysrhythmia due to cardiomyopathy.

AGE was established as a disabling injury based on witnessed rapid ascent, loss of consciousness immediately upon surfacing and autopsy findings of lung barotrauma or gas in arterial circulation. The most reliable evidence is the presence of gas in arteries at the base of the brain, but in some cases gas bubbles may have passed through before the damage they afflicted resulted in death. Lung injury may sometimes be minimal and escape diagnosis. Thus, in a few instances, AGE was proposed based on reliable witness reports.

This student apparently ascended rather rapidly while holding his breath during an equipment ditching drill. He lost consciousness immediately after ascending. Autopsy details were not released but the medical examiner ruled it AGE.

In another case, a male diver in his fifties, with one year of experience, dived a wreck at 90 fsw (27 msw) for 30 minutes with four other divers. The diver wore a drysuit which he did not appear comfortable with according to witnesses. When the group decided to ascend, the diver made an extremely rapid ascent and broke the surface with a splash and in a cloud of bubbles according to witnesses. His drysuit was overinflated and he lost consciousness immediately. The autopsy report was not released but the case was ruled as air embolism due to a rapid ascent. The rapid ascent was confirmed by the victim’s dive computer record which showed that he ascended from 90 fsw (27 msw) to the surface in six seconds.

This diver in his sixties was a student in an advanced open water certification class. At depth of 60 fsw (18 msw) he wrote to the instructor on his slate that there was water in his regulator. After the instructor indicated to the other two students that he was going to ascend with the diver he turned back and the diver was nowhere in sight. The victim was found approximately one hour later, unresponsive with his regulator out of his mouth. The autopsy disclosed changes associated with drowning as well as abundant subcutaneous, intravascular, and intracardiac gas. The death was signed out as a drowning secondary to an air embolism. Cardiomegaly and moderate coronary artery disease were also noted during the autopsy. Regulator test results were not available.

Seizures were observed in two cases. In one case the observation was by experienced buddies during a cave dive at 160 fsw (49 msw) breathing 24 percent nitrox for 25 minutes. The estimated partial pressure of inspired oxygen (PIO2) was 1.4 ATA, a commonly recommended limit for oxygen partial pressure to avoid seizures. In another case a cave diver was seen to seize at 100 fsw (30 msw) while breathing nitrox with 32 percent oxygen. The estimated PIO2 was 1.2 ATA, well below the typically expected seizure threshold.

4.7 Rebreather Fatalities

In 2007 we learned about 21 fatalities involving rebreathers. The distribution of rebreather fatalities by country is shown in Table 4.7-1.

Table 4.7-1 Number of rebreather fatalities by countries

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

In 2006, rebreather fatalities peaked with 22 cases. In 2007 there were 21 fatalities. Fourteen cases occurred in Europe, four in North America, two in Africa and one in Japan. Factors that can hinder investigation of scuba accidents are even more prevalent in rebreather fatalities. Due to the complexity of equipment, the poorly evidenced nature of potentially fatal conditions that may occur, and the limited availability of technical laboratories that evaluate rebreathers, comprehensive investigations are conducted in few cases. In addition, concerns over liability and litigation keeps much available information from being made available to the public. We rarely receive any data for accidents that occurred in other countries and thus we will present only cases that occurred in the US.

One case occurred in a quarry. The victim was an older male, experienced dive instructor. His medical history included previous coronary bypass surgery. On the first dive, his rebreather leaked and he aborted the dive. All other divers in the group returned with him to the surface. Once he thought he had repaired his rebreather, they all set out on a second attempt to make a dive. After reaching the bottom, the diver again had a problem with his rebreather and signaled that he was aborting the dive. This time the others stayed down and watched him until he reached the surface. They continued on with the dive and surfaced approximately 50 minutes later. They found the diver unresponsive next to the stairs that led up to the pier. He was floating on his back with the mouthpiece still in place. The autopsy disclosed severe coronary artery disease with occlusion of one of the grafts and severe narrowing of another. He also had an enlarged heart, and evidence of prior myocardial infarcts. The medical examiner determined that the cause of death was a cardiac event. There was no information available as to whether or how the equipment was tested or to its condition. If the autopsy findings were not available in this case, the equipment would probably be suspected as a most likely root cause. In fact, a report of previous equipment malfunction does not necessarily mean that equipment failure was the cause of the accident. On the other hand, autopsy findings of major structural changes do not necessarily prove that an acute health problem was the cause of death, either. Both hazards, hypoxia on ascent and acute heart event in a diver with this medical history compete for the most likely cause of death. The autopsy was inconclusive and information from an equipment investigation that could implicate or exclude hypoxia was not available.

In another accident the victim was an experienced, middle-aged, grossly obese male diver with technical certification. With a group of several divers, including a designated buddy, he did a deep dive using a rebreather with nitrox as the breathing gas. The diver had completed only six or seven previous dives with a rebreather. On this dive, the group reported to have descended to 161 fsw (49 msw) for 105 minutes (this was most likely the total run time). There were no other details about the dive profile and decompression stops. This diver may have been as deep as 215 fsw (66 msw). He was reportedly seen at 20 fsw (6 msw) making a safety stop before surfacing. The diver returned to the boat, complained of fatigue and collapsed on the deck. He lost consciousness and could not be resuscitated. One witness claimed that the diver had a skin rash that was consistent with DCS. There was no report on equipment examination. To complicate matters, the body was embalmed before the medical examiner was able to perform an autopsy, rendering the autopsy findings suboptimal. In this case, it seemed likely that the death was not caused by malfunction of the breathing gear. The cause of death remained unresolved although one could speculate that the diver may have suffered Type III DCS, thus succumbing to the combined effects of DCS and AGE. One of the reasons for the use of rebreathers is to do deeper or longer dives. The safety of extreme dives relies on limited empirical evidence and a range of assumptions, and thus may involve more risk than divers take into account.

The third case was apparently unwitnessed. A male diver in his forties went solo diving. Thirty minutes later he was found by two other divers at the surface, entangled in a buoy line. His body was submerged in an inverted vertical position with only his fins sticking out of the water. It was not clear whether he became entangled before or after he lost consciousness. The cause of death was determined to have been drowning. There was no information about the equipment having been tested.

The fourth case was of an expert diver who died during cave diving. The only information we were able to gather came through an internet forum. The participants stopped inquiring about other possible causes after one person provided information that the medical examiner found advanced cancer with lung metastases. Without official investigatory findings, any conclusion in this case would be speculation.

Although lung metastases may contribute to death in diving in various ways, it is unknown if they played a causative role in this case.

Root cause analysis in rebreather accidents is typically based on a combination of witness reports, expert technical analysis and medical examination. The best data are usually acquired if there is a formal legal investigation. In contrast, most of the reports that reach DAN consist of incomplete reports and a variety of interpreting opinions in the absence of any equipment testing or medical examination results. The detailed narrative of an accident, including pre-dive, dive and post-dive details, helps an investigation. However, a true expert will never establish causality exclusively on what it looked like to the participants in the event or to bystanders. Equipment investigation and medical examination may provide an explanation not hinted at by appearance of the accident alone.

Consider, for example, a case of death at the surface before descent. One of the critical moments in using the rebreather is the very beginning when a diver starts breathing the loop while still at the surface. The greatest and most common hazard in this stage is hypoxia. It can occur in response to single or combined errors including failure to switch on the electronics, failure to open the oxygen supply, breathing the wrong gas, oxygen sensor malfunction, battery failure, and/or any other factors affecting the loop. The smaller the breathing bag, the smaller the safety margin. If for any reason oxygen is not added as needed, the gas will become hypoxic and the diver may lose consciousness.

While hazard analysis identifies potential threats, it is best combined with direct investigation of individual cases to complete root cause analysis. Even open-circuit diving deaths can occur on the surface before descent. In 2007, six out of eight deaths were associated with surface swimming. There can be strain even in relatively calm seas to precipitate medical crisis. In previous years, there were reports of sudden cardiac death at the surface before descent, even in conditions that did not seem to demand substantial swimming effort. Undue strain and sudden cardiac death could also be a factor for rebreather divers, particularly since the nature of the system has the loop serving for buoyancy control. A sudden loss of loop gas can create dramatic sudden demands on a diver. Death on the surface is rare, but either hypoxia or sudden cardiac issues could be factors for incidents involving rebreather divers.

There were only two cases where it appeared to be straightforward that equipment malfunction contributed to the event. In the first, the victim's alarm began to go off during descent at 164 fsw (50 msw). The diver continued to descend and at 230 fsw (70 msw) he appeared to lose consciousness, drop his mouthpiece and began to shake all over, presumably having a seizure. Strong current and difficulty with the victim's buoyancy made it impossible for the other divers to surface the body, which was never found. In the other case, an experienced diver diving solo made a rapid ascent to the surface in 130 seconds from the depth of 320 fsw (98 msw). He surfaced cyanotic, coughing and spitting caustic cocktail. He suffered a massive lung barotrauma and died onsite from AGE and DCS. His scrubber was found flooded and caustic cocktail was in the loop. His friends said that the decedent had recently completed some do-it-yourself modifications on his rig.

Many hazards with rebreathers are increased during depth changes. However, in some cases divers lost consciousness while at a stable depth, without any obvious indication of unit malfunction. In such cases one must consider the possibility of a sudden intrinsic health failure like malignant arrhythmia or epileptic seizure, and specific effects of extreme environment such as extreme work of breathing.

Knowing the stage of the dive when the diver lost consciousness, bailed out, or a warning went off, may help in an investigation. Unfortunately, such information was not publicly available in half of all cases reported. To improve the quality of the available information, DAN has posted guidelines on the web to help preserve rebreather equipment for investigation and a generic form for reporting diving accidents. Using these tools may help increase the insight into rebreather fatalities.

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

4.8 Conclusion

The causes of accidents could not be unequivocally established in all cases, but most accidents were associated with neglect of hazards or breach of safety practices due to lack of training, fitness or discipline.

Health issues played causative or contributive roles in one third of fatalities.

Equipment failures were reported, but their contribution to fatalities was difficult to establish due to the lack of proper equipment investigation.

Individual divers are responsible for their own safety but to evaluate their risks, they need help from dive medicine specialists, dive instructors and dive operators. The diving industry serving the needs of recreational divers should aim for technologies and procedures that will mitigate human errors and increase the margin of safety.

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BREATH-HOLD DIVE INCIDENTS

Neal W. Pollock, PhD

5.1 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 generated substantial public interest. 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 5.1-1. These records are not shown to promote competition, only to demonstrate that breath-hold diving can be quite different from the classic view of such activity.

Table 5.1-1 AIDA-Recognized Competitive Freediving Disciplines and Record Performance (current June 2013)

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 (m [ft])	Horizontal swim in controlled water	922 (281)	768 (234)
Dynamic Apnea - no fins (ft [m])	Horizontal swim in controlled water	715 (218)	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	466 (142)	417 (127)
Constant Weight - with fins (ft [m])	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	413 (126)	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)	223 (68)
Free Immersion (ft [m])	Vertical excursion propelled by pulling on the rope during descent and ascent; no fins.	397 (121)	289 (88)

Extensive safety and disqualification protocols have kept the incidence 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 lack of equipment definitely 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 2004 cases (those reported to DAN and those 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). The annual case intake from 2004 through 2006 was 48±14 (mean±standard deviation), with a range of 30-59 cases. 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 the DAN annual diving report since 2005. Electronic copies of these reports are available for download from the DAN website at no cost (http://www.diversalertnetwork.org/medical/report/index.asp).

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. The case summaries found in Appendix C provide brief descriptions of representative cases.

5.2 Cases in 2007

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

A total of 58 cases were captured in 2007, 42 fatal (72 percent) and 16 non-fatal. These numbers are very similar to the previous year.

Incidents were reported from 22 different countries. Almost half (n=25; 46 percent) occurred in the US, distributed between seven states or territories. Multiple events occurred in three states: Hawaii (eight cases; 32 percent), California (seven cases; 28 percent) and Florida (five cases; 20 percent). This concentration likely reflects the popularity of related activities and certainly some reporting bias. It is highly unlikely that our fatal case capture reflects true total numbers. It is certain that many fatal events that could have involved specific breath-holding hazards are classified as drowning and 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 known incidents occurred in the ocean (n=51; 91 percent). Two cases occurred in a lake or quarry, and one each in a swimming pool, a golf course water trap, and a tuna enclosure (ocean-based but not counted under the simple ‘ocean’ category).

The primary activity of incident victims was most commonly described as snorkeling (48 percent), then spearfishing (20 percent), collecting (17 percent) and freediving (15 percent). 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.

Figure 5.2-2 presents the gender and age breakdown for the 2007 cases. The majority of victims were male (84 percent). The mean age (±standard deviation) was 42±15 years, ranging from 14 to 71 years (in cases with known age; n=52). This was very similar to the pattern in the previous year, (41±16 [6-77] years of age).

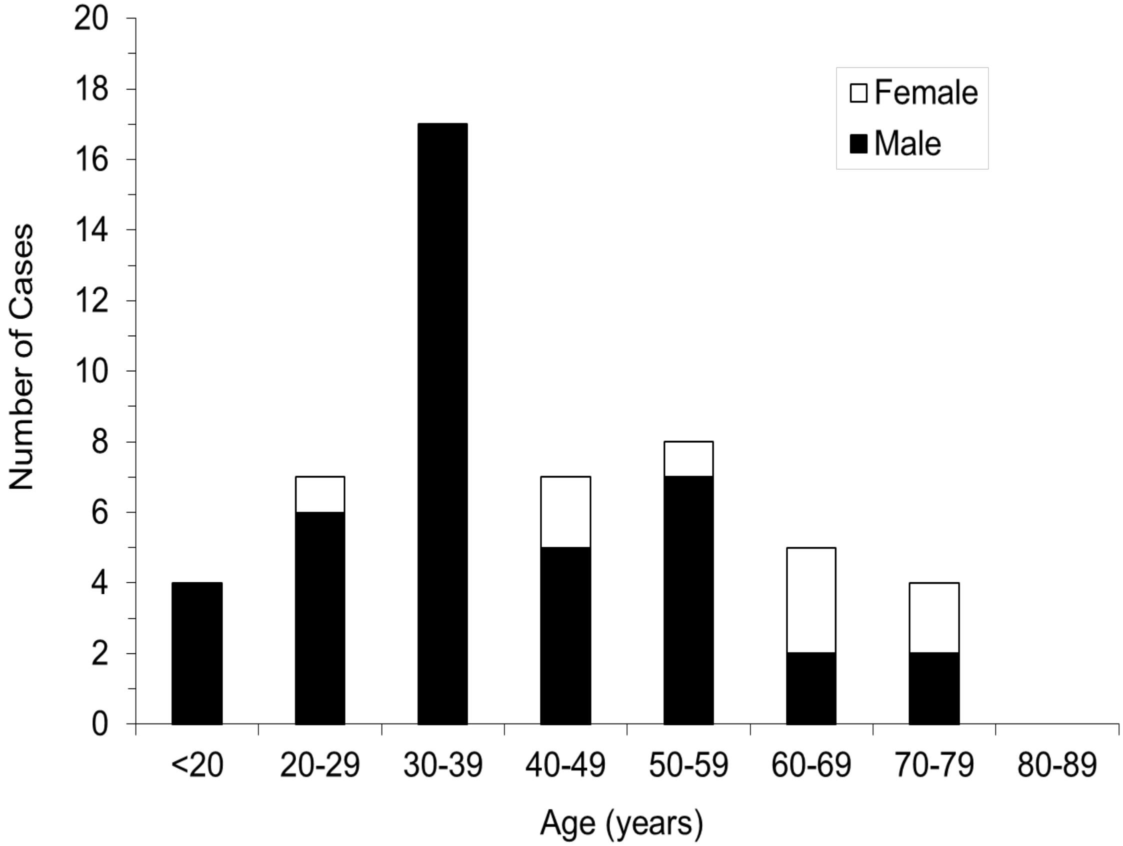

Figure 5.2-2: Age and gender distribution of breath-hold incident victims in 2007 (n=52)

Information regarding the support available to divers was captured in over half (n=32; 55 percent) of the cases. The most common patterns were group diving (n=13; 41 percent of known), solo or with no support (n=11; 34 percent of known), and partner diving (n=8; 25 percent of known).

The presence of one or more witnesses to the event was established in half of the captured cases, with witnesses present in 59 percent of these. Problematically, many of the acts that may contribute directly to accidents are difficult to fully appreciate by 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, but 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 may receive insufficient consideration.

The casualty’s level of experience in the breath-hold activity, familiarity with the incident site, and health history were rarely confirmed.

5.3 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 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.

Very few records for the 2007 cases were considered complete. This is especially so for international incidents. Medical examination documentation, for example, was rarely procured. Case details, however, were often sufficient to allow reasonable speculation as to the trigger or disabling agent. The cases are categorized into primary hazard clusters in Table 5.3-1.

Table 5.3-1 Primary trigger or disabling agent ascribed to 2007 breath-hold incidents

Hazard Cluster	Count	Percent
Animal-involved injury	13	22
Hypoxic blackout	12	21
Medical health	9	16
Boat strikes	6	10
Environmental conditions	5	9
Entanglement	1	2
Unclear or unknown	12	21
Total	**58**	**100**

Animal-Involved Injury

There were 13 cases of animal interaction ending in injury, none fatal. This was an increase from five in the previous year, four fatal and one non-fatal. Ten of the new injuries were caused by sharks, one each by an alligator and a crocodile, and one by a humpback whale. Six of the shark injuries were experienced by spearfishermen and four by snorkelers. Injuries caused by sharks, alligators or crocodiles are likely to draw media attention and may be overrepresented in our database. It is certain that many animal-involved injuries, particularly minor ones, would not be captured.

Hypoxic blackout

Twelve cases were attributed to practice-induced blackout; all but two fatal. It is possible that some of the cases classified as ‘medical health’ and likely that some of the unknown cases would properly fall into this category, but this cannot be confirmed by the available facts.

Many breath-hold divers will employ strategies to extend breath-hold time. The risk of blackout during breath-hold is increased by excessive hyperventilation.

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 continues to be a major life threat to healthy and often extremely capable breath-hold divers. The 12 cases identified in 2007 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 due to a lack of understanding or irrational optimism.

Medical Health and Environmental Conditions

There were nine fatal cases captured in 2007 where medical health issues appeared to have played a significant role. This classification was largely made because of advancing age, potentially poor physical and/or medical fitness and witness reports. It is possible that hypoxic blackout played a role in some, but cardiorespiratory problems were highly suspected.

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. There were five fatal cases classified as 'environmental conditions' due to current and wave conditions. It is possible that the poor outcome for these cases was influenced by medical health status.

Boat Strikes

There were six cases put in the category of physical trauma associated with boat strikes. Four involved propeller strikes (three fatal), one involved a jetski strike (non-fatal), and one unusual case of a snorkeler in the water being struck by something coming off a boat - a person traveling at speed off a slide from the upper deck (fatal). It is possible that boat strikes are overrepresented in the database as one of the patterns of injury with the greatest physical evidence (along with animal-involved injuries).

Entanglement

There was only one fatal case attributed directly to entanglement. This was also the only case involving confirmed freediving training activity. This individual's ascent from a deep dive was impaired when the line being used to bring the diver to the surface became entangled.

Unknown

There were 12 fatal cases that could not be classified since sufficient details were not available.

5.4 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 generally extremely effective for the population served. 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 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, longer for deeper dives. A group of three, diving in series, facilitates this schedule and ensures that one 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.

The presence of an appropriate support network is critical when problems do arise. Close support protocols that have divers shadowed during the final portion of their ascent and the first 30 seconds of the post-dive period can address the majority of issues. The risk of loss of consciousness continues post-breath-hold until the oxygen in an inspired breath reaches the brain to counter hypoxia.

The dedicated solo hunter presents a difficult case. He or she may understand the risks of incautious diving and the safety provided by direct supervision but may still want to operate unfettered. The sense of self-confidence, if not invincibility, often stands in the way of smart decision-making. The idea that blackout could 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 limit 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.

The risk of a bad outcome following loss of consciousness increases when negative buoyancy is an issue. Wearing weight to achieve negative buoyancy makes it easier to descend but this benefit is overshadowed by the undesirable effects. If a wetsuit is worn and loses buoyancy under pressure, a significant degree of negative buoyancy may exist at depth. This will increase the effort required to ascend, increasing the risk of blackout due to the increased oxygen consumption rate. A negatively buoyant diver will also tend to descend more rapidly if consciousness is lost. This will make it difficult, or in some cases impossible, for immediate rescue to be completed. For safety reasons, it is recommended that breath-hold divers weight themselves to be neutrally buoyant at a depth no less than 15 ft (4.6 m). Some advocate weighting for neutral buoyancy at 30 ft (9 m), particularly for those planning to dive deeper than 60 ft (18 m).

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

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

All divers need to be aware of the hazards they face and strategies to reduce their risk. Receiving initial training by qualified persons makes the transition into any activity smoother and safer. Ongoing education, which includes learning from the mistakes of others, is important to ensure that the risk of participation remains low.

5.5 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.

5.6 Conclusion

A total of 58 breath-hold diving incidents occurring in 2007 were collected by DAN; 47 (84 percent) involving males and 42 (72 percent) fatal. Animal interactions, hypoxic blackout, and compromised medical health, respectively, were the most common problems. 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.

5.7 References

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APPENDIX A. DIVE INJURY CASE REPORTS

DAN Medics

65548

This was a 49-year-old male recreational diver, considered to be in good health and on no regular medications. He denied any history of dive related illness or injury. He completed a single dive on 28 percent enriched air nitrox to 130 fsw (40 msw) with a total bottom time of 15 minutes and total dive time of 30 minutes. The dive was uneventful and he reported no problems. Five minutes following his dive, he complained of right sided abdominal discomfort that radiated as pain around his right side and towards his lower back. This was accompanied by an ascending paresthesia and motor weakness in his right leg with difficulty walking across the deck of the boat.

He was immediately administered a high concentration of surface level oxygen until the boat reached the shore. After 45 minutes, he reported complete symptom resolution and was transferred to a local hospital where he was again placed on oxygen and evaluated for a variety of possible illnesses, including stroke and cardiac events. There were no unusual findings upon exam. He remained asymptomatic and was subsequently discharged from the hospital later that day. During his drive home, he developed pain in his right shoulder, radiating toward his neck. He also complained of a mild positional pain in his right arm. He was referred by DAN to a local hyperbaric facility.

71981

This diver was a 52-year-old male with a history of cardiovascular disease and current medication for treatment of hypertension. While lobster fishing in Florida, he completed a series of two dives in one day: Dive #1 - 70 fsw (21 msw) for 60 minutes, followed by a 62 minute surface interval time, then Dive #2 - 87 fsw (27 msw) for 41 minutes. He reported that he overexerted himself during the second dive, twisting the right side of his back. He also felt that he may have experienced a rapid ascent at the end of his dive. Five minutes after surfacing from the second dive, he noticed a sudden onset of right back spasms that radiated to his left side. He also complained of right leg numbness and tingling that included his right foot, as well as left foot numbness as if it were asleep, and abdominal tightness and tingling.

During the boat ride back to shore, his buddies administered a massage to the affected areas to ease the discomfort and his symptoms gradually subsided. He reported that the tightness, numbness, and tingling continued throughout the balance of the day. He awoke the following day still experiencing the same symptoms and boarded his flight to return home, 22 hours after the final dive. He reported no change in symptoms during his flight. The diver returned to work on a construction site the next day while still complaining of right leg numbness from his groin to his toes and abdominal discomfort. The diver presented to a local emergency department for evaluation. The attending emergency physician arranged for transfer to a hyperbaric facility, where the diver was treated with three USN TT6 hyperbaric oxygen schedules over a three day period. He successfully recovered with full symptom resolution.

71938

This was a 34-year-old male diver, no medical history was available. He completed a series of two dives on nitrox in a single day at an unknown location in Florida using a computer to calculate bottom time. Dive #1 - 75 fsw (23 msw) for 25 minutes on 34 percent nitrox followed by a 120 minute surface interval time, then Dive #2 - 90 fsw (27 msw) for 20 minutes. The dives were uneventful with the exception of a brief period of dizziness during the surface interval. Fifteen minutes following the second dive he began complaining of dizziness, vertigo, nausea and vomiting, as well as a crackling sound in his right ear, although no hearing loss was noted. He was placed on surface level oxygen but had no relief.

The diver presented to a local emergency department for evaluation. CT scan, ECG, and x-ray were all unremarkable. His blood work did show that he was slightly dehydrated. The evaluating doctor's initial diagnosis was inner ear DCS since the symptoms were consistent with that diagnosis, even though the dive profiles were not. He was then transferred to another hospital for hyperbaric care and was treated with a USN TT6 hyperbaric oxygen schedule with two extensions. This produced no apparent change in his clinical picture. An ENT consult revealed nothing unusual, no inflammation in middle ear, or tympanic membrane rupture. The patient was prescribed medication for nausea and dizziness and subsequently discharged.

The following day he was able to return to work but was unable to drive due to the persistent dizziness. The consensus opinion among the hyperbaric doctors was that he did not suffer inner ear decompression sickness for the following reasons: 1) the non-provocative nature of the dives, and 2) no apparent change in his clinical picture as a result of hyperbaric oxygen treatment.

Eight days following this incident he was contacted by DAN for follow up. He indicated that he was healing well with about 90 percent of the dizziness resolved. A follow-up appointment with an ENT physician resulted in a working diagnosis of inner ear barotrauma resulting in the rupture to the round or oval window. The ENT physician recommended that the diver wait four to six weeks prior to diving again. The diver returned to diving and three years after the injury reported having no further incident.

71057

This 50-year-old female recreational diver, with a history of 87 lifetime dives, completed a series of four dives in a two-day period using compressed air. The profiles for her initial day of diving were a series of two multi-level dives to maximum depths of 130 fsw (40 msw) each for total dive times of approximately 30 minutes each. She denied problems or complications with these dives and described experiencing a mild headache that night, thought to be allergy induced, which she treated with aspirin. On day two her profiles were Dive #1 - 45 fsw (14 msw) for 30 minutes, followed by a surface interval time of 45 minutes. Dive #2 - 45 fsw (14 msw) for 30 minutes. Upon reaching the surface she experienced involuntary spasms of her right arm and became unresponsive while climbing the boat ladder, falling back into the water. She was rescued to the boat where she was revived and placed on surface level oxygen. The US Coast Guard was summoned and provided transport to a local hospital. She presented as alert and oriented, but on exam was discovered to have involuntary spasms of the right arm, be unsteady on her feet with a wide ataxic gait, have short-term memory loss, slurred speech, and a history of missed decompression the day before. She was also found to be hyperglycemic with a blood glucose level of 479 $mg \cdot dL^{-1}$ (26.6 $mmol \cdot L^{-1}$).

The patient was transported via ambulance on oxygen and intravenous fluids to a hyperbaric center where she received a series of three hyperbaric oxygen treatments over a period of three days. With the exception of persistent and mild right arm spasms, she resolved all signs and symptoms following her third hyperbaric oxygen session. She was discharged home where her right arm spasms gradually resolved over the next eight month period, during which time she tested positive for a patent foramen ovale (PFO) which was subsequently closed. This patient returned to recreational diving 20 months post-incident and at follow up had completed approximately 30 dives without any problem.

65632

The diver was a 52-year-old female on a liveaboard dive boat that plied remote islands in the Indian Ocean. She completed a series of 10 dives over four days. All were using air and her greatest maximum depth was to 96 fsw (29 msw). After her last dive on the fourth day she developed a headache, nausea and bilateral hip pain. The pain was described as being in the muscle and soft tissues, not in the joints. She did not report her symptoms to the boat crew. However, she was observed having greater than expected difficulty while walking.

She was evaluated by the leader of the dive group. The evaluation suggested neurological involvement. At this point the dive leader contacted DAN to discuss the findings. Decompression sickness could not be ruled out so the recommendation was for the diver to be provided as high a concentration of surface level oxygen as was available and be transported to the nearest medical facility. The group leader relayed the results of the evaluation and the recommendations from DAN to the crew. After some difficulty with assembling the equipment the diver was provided with oxygen.

After four hours on oxygen the diver reported that her headache and nausea had resolved and the bilateral hip pain was greatly reduced. The boat crew contacted a local dive physician who recommended that they continue to observe the diver overnight and if symptom remained by the morning she should be transported to his facility. When the diver was re-evaluated in the morning the hip pain was still present. The headache and nausea had not returned. The diver was transported by speed boat to the physician's clinic. She was treated with a USN TT6 and experienced complete resolution of the hip pain. The diver did not return to diving for the rest of the trip.

66880

The diver was a 61-year-old female diving at a popular land-based Caribbean resort. She had participated in a series of six dives over a three day period (two dives per day). The deepest depth she achieved in the series was 100 fsw (30 msw). Routinely, her breathing gas for the first dive of the day was 32 percent nitrox and for the second dive air. The first four dives were uneventful. After her fourth dive she napped for three hours. When she awoke she complained of pain around her hips which she described as muscular. Further investigation revealed soreness to touch with not only the muscle layer but deep tissues as well. There was no itching or observable skin discoloration. By the next morning the pain had completely resolved.

Her dives on the third day were to a maximum of 88 fsw (27 msw) for 38 minutes using 32 percent nitrox; the second dive was to a maximum of 73 fsw (22 msw) for 52 minutes using compressed air. The diver did not recall her exact surface interval time between the two dives but reported it as at least 30 minutes. Within a few minutes the hip pain returned. She reported it as more intense than the day before. Again there was no itching or skin discoloration. Her travel companion contacted DAN to discuss the situation. The possibility of skin bends could not be ruled out. The diver was referred to the local hyperbaric facility for evaluation.

Upon arrival at the facility the diver was examined and no other signs or symptoms were uncovered. The evaluating physician recommended treatment in the chamber. The diver was treated with a USN TT6 and experienced a great reduction in the pain. She was asked to return to the facility the next morning for a follow up evaluation. The evaluation the following morning noted that she was still experiencing discomfort around her hips. She was treated with a USN TT5 and had full resolution of all discomfort. She returned to the facility the following morning. There was no return of any discomfort and she was discharged with no further treatment.

66339

An emergency room nurse in the Midwest called regarding a 41-year-old male who did a single dive on a single day of diving, to a maximum depth of 116 ft (35 msw) that morning. While ascending, he felt “some crackling and some girdling” in his chest. Upon surfacing, diver said he felt some tightness in his chest, too. At the ER the diver had no shortness of breath, and denied ever experiencing any breathing difficulty after the dive. He did report, however, having “coughed some pink sputum.”

Upon examination, the diver’s hemoglobin saturation was 97 percent on room air, the chest x-ray, PTT, D-Dimer, CBC, ECG and blood gases all normal. His PO_2 was 95 mm Hg and blood pH 7.4. The rest of the clinical findings were within normal limits. A CT scan was conducted to rule out any form of extra-alveolar air, including subcutaneous emphysema. An ENT consultation was arranged to look for evidence of sinus barotrauma that could explain some traces of blood dripping from the patient’s rhinopharynx, a common source of blood often misconstrued and reported as “coughing up blood”. All was negative and patient was discharged after hours of observation.

During a follow-up call with the patient, he confirmed that he had coughed a solid and consolidated pink foamy sputum, denied experiencing any equalization problems, and stated this was not dripping from his throat because he could feel and hear some cracking in his lungs while exhaling during his ascent. Further interrogation revealed that he had been diving in a wetsuit on 38°F (3.3°C) water.

Immersion pulmonary edema (IPE) was discussed with the patient. He was advised to gather all the tests and results and to make an appointment with a physician with experience in dive medicine.

IPE has been well described with aquatic exposures as a multifactorial problem. Preexisting cardiovascular disease is a known contributing factor, as is a relative hyperhydration, immersion, cold exposure, physical exertion and high breathing resistance.

APPENDIX B. DIVE FATALITY CASE REPORTS

James L. Caruso, MD

Proximate Cause: Air Embolism

07-11 Diver recently open water certified, recent complaint of cold symptoms, buddy was son, returned to boat for additional weight, made dive to wreck, made rapid ascent, lost consciousness after surfacing.

Cause of Death: Air Embolism due to Rapid Ascent due to Scuba Diving

This was this 50-year-old female's first dive after receiving initial open water certification two days earlier. She had been complaining of cold symptoms as well as some chest pain from coughing for a few days and was taking ibuprofen for pain relief. Her only other apparent medical problem was obesity. The diver and her 14-year-old son were buddies on dive from a boat using air as a breathing gas. The diver initially returned to the boat for additional weight as she felt she was too buoyant. The two divers then descended to view a wreck at approximately 35 fsw (11 msw) for 25 minutes before ascending. The diver made a witnessed rapid ascent and swam over to the boat but she lost consciousness after removing her fins. The stricken diver was brought onboard the boat and resuscitation efforts were initiated. She was transferred to a faster boat and brought to shore but she died without regaining consciousness. The medical examiner determined the cause of death to be an air embolism secondary to a rapid ascent.
BMI = 32.4 $kg \cdot m^{-2}$

07-13 Certified, experienced diver, multiple serious medical problems, on medications, made dive with buddy at high altitude using nitrox, had ear squeeze on descent, signaled to surface, buddy had mask problem and lost sight of diver, both surfaced, lost consciousness while buddy towed diver back to shore, computer showed rapid ascent.

Cause of Death: Air Embolism due to Rapid Ascent due to Scuba Diving

This 56-year-old male had rescue diver certification, having made approximately 100 lifetime dives. He had multiple serious medical problems including obesity, sleep apnea, hypertension, elevated serum cholesterol, chronic obstructive pulmonary disease, and coronary artery disease. He had also undergone a total hip replacement in the past for which he still experienced chronic pain and took narcotics. The diver and a buddy made a dive at an altitude of 5000 ft (1523 m) using nitrox as a breathing gas. They planned to descend to 90 ft (27 m), but during the descent the diver had an ear squeeze and signaled to his buddy that he wanted to surface. The buddy had trouble with his own mask fogging and lost sight of the diver during the ascent, though he reported seeing part of what he described as a rapid ascent. The diver was initially conscious on the surface but could not swim back to shore on his own and his buddy towed him to the beach. The diver lost consciousness during the swim back to shore and could not be resuscitated. An interrogation of the diver's computer revealed two rapid ascents during the dive, including a very rapid ascent from 71 ft (22 m) to the surface. An autopsy demonstrated evidence of the multiple natural disease processes previously noted. Toxicological studies revealed antihistamines and a muscle relaxant onboard, but no narcotics. The medical examiner signed the case out with an unknown cause of death but this was most likely an air embolism caused by a rapid ascent.
BMI = 30.4 $kg \cdot m^{-2}$

07-28 Certified and experienced technical diver, medical history positive for asthma with inhaler use and obesity, made a solo dive to spearfish on trimix near wreck, made rapid ascent early in the dive, complained of weakness and lost consciousness, had hyperbaric treatment with no improvement.

Cause of Death: Air Embolism due to Rapid Ascent due to Scuba Diving

This 59-year-old male was an experienced diver with technical diving certification. His medical problems included asthma for which he used an inhaler and obesity (BMI = 37.0 $kg \cdot m^{-2}$). The diver made a solo dive to 200 fsw (61 msw) using trimix to spearfish near a wreck. After 12 minutes of bottom time he surfaced and immediately complained of weakness. The diver then collapsed and resuscitation efforts were initiated. He was somewhat stabilized and transferred to the closest hospital before being moved to a hospital that had a recompression chamber. There was no improvement in his condition with hyperbaric oxygen treatment and the diver died the next day. An autopsy disclosed moderate coronary artery disease. During the course of the investigation one witness mentioned that he saw the diver ascend rapidly. The cause of death was determined to be an air embolism.
BMI = 37.0 $kg \cdot m^{-2}$

07-73 Advanced open water certified diver, made dive with group on wreck using nitrox, wore drysuit, strong current, after dive on ascent, diver made extremely rapid ascent, broke surface in a cloud of bubbles, drysuit was overinflated, lost consciousness.

Cause of Death: Air Embolism due to Rapid Ascent due to Scuba Diving

This 53-year-old male had advanced open water certification and had been diving for one year. He and four other divers planned two dives on a wreck to approximately 90 ft (27 m) using nitrox 32 percent. The diver employed a drysuit which he did not appear comfortable with according to witnesses. The dive site was a river and the current was typically strong. After entering the water from a boat there was an initial delay in descending as one of the other divers had a computer issue. After descent the divers spend 30 minutes on the bottom they began their ascent. The diver made an extremely rapid ascent and broke the surface with a splash and in a cloud of bubbles according to witnesses. His drysuit was overinflated and he lost consciousness immediately. The diver's buddy quickly brought him to the boat and the boat then headed for shore, leaving the divers who remained in the water swim to the beach on their own. The diver was pronounced dead upon arrival at a medical care facility. The autopsy report was not released but the case was signed out as an air embolism due to a rapid ascent. An evaluation of the diver's computer showed that he ascended from 90 ft (27 m) to the surface in six seconds.
BMI = na

07-93 advanced open water certified diver with moderate experience, medical problems positive for extreme obesity and depression, made dive with buddy in lake to view wreck, cold water and poor visibility, descended to depth, diver began rapid ascent, buddy slowed diver down, but kept ascending too fast, lost consciousness at surface.

Cause of Death: Air Embolism due to Rapid Ascent due to Scuba Diving

This 47-year-old female possessed advanced open water certification and a moderate amount of diving experience. Her medical problems included extreme obesity and depression. The diver made a dive into a lake with a buddy in order to view a wreck. The dive platform was a boat and the water was cold, with poor visibility. The two divers descended to 83 ft (25 m) and approximately 10 minutes into the dive the diver went to the line and began a rapid ascent to the surface. At the 60-foot mark the diver's buddy successfully slowed the diver down, but her ascent was again very rapid from approximately 15 ft (5 m) to the surface. Upon surfacing, the diver spit out her regulator and was coughing up frothy, bloody fluid. The divemaster advised her to put her regulator back into her mouth which she did for a

short period before spitting it out again and subsequently losing consciousness. She was pulled into the boat and resuscitation efforts were initiated though ultimately unsuccessful. The autopsy revealed evidence of pulmonary barotrauma, cardiomegaly, moderate- to focally-severe coronary artery disease, lymphocytic thyroiditis and toxicology positive for an antidepressant medication. The cause of death was determined to be an air embolism secondary to a rapid ascent.
BMI = 38.7 kg·m^{-2}

07-107 Certified open water diver, inexperienced, medical history included chest pain attributed to indigestion, borderline obese, made second dive of day, diver was cold and uncomfortable, panicked, rapid ascent to surface, lost consciousness.

Cause of Death: Air Embolism due to Rapid Ascent due to Scuba Diving

This 42-year-old male obtained his open water diving certification 14 years earlier but had only made approximately 35 lifetime dives. Medical conditions included chest pain that he attributed to indigestion for the past six to eight weeks and he was also borderline obese. The diver was making a set of dives on the first day of a multiple day dive trip. The first dive was to 27 fsw (8 msw) for 58 minutes and was reported to have been uneventful. During the second dive the diver and his buddy descended to a maximum depth of 87 fsw (26 msw). The diver reportedly was cold and uncomfortable and started to panic. He signaled to his buddy to head to the surface and the two divers ascended to 30 fsw (9 msw). At that point the diver headed to the surface, ascending 30 fsw (9 msw) in 18 seconds according to his computer. The diver signaled that he was okay on the surface, at least initially. He then stated that something was wrong before losing consciousness. Resuscitation efforts were unsuccessful. An autopsy was performed and the medical examiner determined the cause of the death to be an air embolism.
BMI = 30.6 kg·m^{-2}

07-109 Certified open water, inexperienced diver, medical problems included obesity and gastrointestinal problems night before dive, made dive with group and buddy, ascended multiple times looking for boat, on third ascent, was helped into boat, collapsed and struck head on ladder.

Cause of Death: Air Embolism due to Insufficient Air due to Scuba Diving

This 50-year-old male had open water certification but had only made seven lifetime dives including those made during training. His medical problems included obesity and he also had experienced gastrointestinal problems the night before this diving mishap. The diver made two uneventful dives the day before and was making this first dive of the second day of diving as part of a large group but with a dedicated buddy. The buddy pair lost their bearings and surfaced a couple of times looking for their boat. They ascended a third time after locating a boat and made a safety stop on the way. The diver then surfaced ahead of his buddy and called for assistance. A divemaster from the boat entered the water, inflated the diver's buoyancy compensator, and helped the diver up the ladder. The diver collapsed while being assisted up the ladder and struck his head on it. Resuscitation efforts were unsuccessful. The autopsy demonstrated marked cardiomegaly with mild coronary artery disease, pulmonary emphysema, and pulmonary adhesions. There was also evidence of pulmonary barotrauma with gas present in both sides of the heart. The cause of death was determined to be air embolism. The diver's equipment was determined to be functioning adequately, though his tank was empty.
BMI = 40.5 kg·m^{-2}

Proximate Cause: Drowning/Air Embolism

07-16 Certified diver with unknown experience level, medical history of obesity and diabetes, on second dive of day with no designated buddy, on ascent, did safety stop, surfaced unconscious with regulator out of mouth.

Cause of Death: Drowning due to Air Embolism due to Scuba Diving

This was the second dive of the day for this 50-year-old male who was a certified diver with an unknown amount of diving experience. His medical problems included obesity and diabetes. The diver was on a liveaboard trip and reportedly had felt ill the day before. Details of the event are incomplete because it does not appear that the diver had a designated buddy and the diver's computer failed to auto-activate upon descending. According to one witness, who was at least a loosely associated dive buddy, the first dive was to approximately 115 fsw (35 msw) for a total dive time of 25 minutes. For the second dive the diver again descended to a depth in excess of 115 fsw (35 msw) and ascended to a stop at 20 fsw (6 msw) after a dive time of approximately 18 minutes. The diver surfaced after a two-and-a half minute stop and subsequently was noted to be unconscious with his regulator out of his mouth. He was brought into the boat and resuscitative efforts were initiated but were without success. An autopsy demonstrated moderate coronary artery disease, left ventricular hypertrophy, and diabetic nephropathy in addition to extensive intravascular and intracardiac gas and changes associated with drowning. The death was ruled to be a drowning secondary to an air embolism. Coincidentally, the diver that was identified as a buddy was treated with hyperbaric oxygen for decompression sickness.
BMI = 29.2 $kg \cdot m^{-2}$

07-55 Student in advanced open water class, inexperienced, made shore entry dive with instructor and students, trouble with regulator and signaled to ascend, disappeared from group, found later, unconscious, regulator out of mouth.

Cause of Death: Drowning due to Air Embolism due to Scuba Diving

This 56-year-old male was a student in an advanced open water certification class. According to the investigation reports he was a weak student and likely had little diving experience. He made a shore entry with two other students and the instructor. They went to a maximum depth of 85 fsw (26 msw) but at around 60 fsw (18 msw) the diver signaled to the instructor that he was having some trouble and wanted to ascend. He had written on his slate that there was water in his regulator. After the instructor indicated to the other two students that he was going to ascend with the diver he turned back and the diver was nowhere in sight. A search was subsequently initiative from the surface. Two other divers found the missing student approximately one hour later, unconscious and with his regulator out of his mouth. Cardiopulmonary resuscitation was attempted but he was pronounced dead on arrival at a local hospital. The autopsy disclosed changes associated with drowning as well as abundant subcutaneous, intravascular, and intracardiac gas. The death was signed out as a drowning secondary to an air embolism. Cardiomegaly and moderate coronary artery disease were also noted at autopsy. An equipment check revealed 1000 psi (69 bar) remaining in the diver's tank.
BMI = na

07-59 Certified, experienced diver, solo dive to retrieve equipment, topside support noticed bubble pattern change, found unconscious with mask on his forehead, air still flowing.

Cause of Death: Drowning due to Air Embolism due to Scuba Diving

This 46-year-old male was an experienced, certified diver who entered the water alone to retrieve a piece of scientific equipment. He descended to 104 fsw (32 msw) while topside support watched his

bubbles. After 10-12 minutes the bubble pattern changed enough that the personnel in the boat were concerned and a safety diver descended to check on the situation. The divers were wearing full face masks but the second diver found the initial diver unconscious and with the mask on his forehead with air still flowing. After some difficulty the rescue diver was able to bring the unconscious diver to the surface after cutting away his dive gear. The dive gear was not fully recovered for examination. The autopsy disclosed no evidence of significant natural disease processes with abundant subcutaneous, intravascular, and intracardiac gas. The medical examiner signed the case out as an air embolism, which likely resulted in drowning though there is no way of confirming that the diver attempted to ascend prior to the time he was pulled from the bottom.
BMI = na

07-112 Certified, infrequent diver, multiple medical problems, made shore entry dive with buddy using unfamiliar drysuit, on ascent had difficulty venting the drysuit, made rapid ascent, feet first, breaking surface and lost consciousness, drysuit was inflated only from the waist down.

Cause of Death: Drowning due to Air Embolism due to Rapid Ascent due to Scuba Diving

This 59-year-old male had multiple medical problems including hypertension, asthma, diabetes, bilateral knee replacements, obesity, mitral valve prolapse, and multiple back surgeries for scoliosis. He had been a certified diver for over 30 years but infrequently active so he took a recertification course one year before this incident. The diver made a shore entry dive with a buddy using a drysuit that he was not very familiar with. He and his buddy descended to 66 ft (20 m) and spent approximately 25 minutes on the bottom before deciding to ascend. The divers ascended a short distance and the buddy related that he noticed the diver had difficulty venting the drysuit. The diver then made a rapid ascent, feet first, breaking the surface with his feet initially and losing conscious shortly after that. Witnesses on the surface stated that the diver's drysuit was only inflated from the waist down. Resuscitation efforts were unsuccessful. The autopsy disclosed changes associated with drowning as well as mild coronary artery disease and steatosis (fatty degeneration) of the liver. The death was signed out as a drowning, which was likely a result of an air embolism due to a rapid ascent.
BMI = 36.2 $kg \cdot m^{-2}$

07-50 Certified, experienced diver, made shore entry solo dive to 211 fsw (64 msw) depth using nitrox, found unconscious and floating on surface by kayakers, tank was out of air, computer showed rapid ascent from 179 fsw (55 msw).

Cause of Death: Drowning due to Air Embolism due to Rapid Ascent due to Insufficient Air due to Scuba Diving

This 48-year-old male was an experienced diver who had been certified for 10 years. He made a shore entry dive, alone, to a maximum depth of 211 fsw (64 msw) using nitrox. The diver was found unconscious and floating on the surface by a group of kayakers. The autopsy demonstrated changes consistent with drowning as well as abundant intravascular gas. He also had mild coronary atherosclerosis. An evaluation of his equipment revealed an empty tank and a dive profile that consisted of a very rapid ascent from 179 fsw (55 msw) to the surface as well as omitted decompression. The death was ruled a drowning due to probable air embolism. It should also be pointed out that nitrox can be dangerous to use on dives as deep as this one due to the high risk of oxygen toxicity.
BMI = na

07-114 Certified advanced open water diver, made deep dive in cold water quarry, with two buddies, two divers had problem with free flowing regulators, shared air, this diver was found on the bottom one hour later, out of air, buddy was found on the surface, unconscious. [see case 07-113]

Cause of Death: Drowning due to Air Embolism due to Insufficient Air due to Scuba Diving

This was a double fatality case involving three experienced divers making deep dives in a quarry. The water was cold, which may have had a direct effect on the diving equipment and therefore the outcome of this mishap. This 21-year-old male had advanced open water certification. He and two divers with divemaster certification made a shore entry dive into a quarry. They first descended to 70 ft (21 m) then went to a depth in excess of 100 ft (30 m). This diver had a free-flow problem with his regulator and went over to one buddy for assistance. That buddy offered him his octopus but he did not take it and went over to the third diver, who was female. This diver and the female diver were seen by the surviving buddy to possibly begin to buddy breath and head to the surface. On the surface the surviving buddy saw the unconscious female diver being brought to shore by other divers. This male diver remained at depth until his body was pulled to the surface approximately one hour later. His tank was empty as was the tank of the female buddy who also died. The autopsy of this diver disclosed gas in both sides of the heart and cerebral blood vessels. An incidental finding was an arteriovenous malformation in the brain. There were also changes consistent with drowning. The cause of death was a drowning due to an air embolism.
BMI = na

Proximate Cause: Cardiac

07-01 Certified diver, unknown experience, last dive two years prior, medical history of severe heart disease, diving with buddy from boat to gather lobster, surfaced, pointed to his chest and lost consciousness.

Cause of Death: Acute Myocardial Infarction due to Severe Coronary Artery Disease

This 58-year-old male was a certified diver with an unknown amount of diving experience. His last dive before this incident was apparently two years earlier. Medical problems included previous heart attacks and severe coronary artery disease. The diver also had sustained a subdural hemorrhage many years earlier, with no sequelae from the event. The diver had complained of three days of vague abdominal discomfort prior to the dive but went into the water anyway. After a boat entry, the diver and his buddy spent approximately fifteen minutes at depth to gather lobster before they returned to the surface. The diver gasped for breath on the surface and pointed to his chest. He was helped into the boat but lost consciousness and could not be resuscitated. The autopsy disclosed severe coronary artery disease, marked hypertrophy of the left ventricle of the heart, scarring from previous myocardial infarcts and mild atherosclerosis of the arteries at the base of the brain. The medical examiner also noted that the deceased diver was “morbidly obese” but his weight was not available in the autopsy report. This death is correctly classified as a cardiac death while diving.
BMI = na

07-06 Experienced instructor-level diver, made dive to record video underwater in kelp bed, collapsed while climbing pier ladder.

Cause of Death: Acute Myocardial Infarction due to Severe Coronary Atherosclerosis

This 77-year-old male was an experienced diver with instructor level certification. He made a series of dives to take underwater video in a kelp bed and collapsed while climbing the ladder to get back on the pier. He fell back into the water and first responders pulled him out and administered

cardiopulmonary resuscitation. Their efforts were unsuccessful. The autopsy findings included severe calcific atherosclerosis of the coronary arteries, an abdominal aortic aneurysm, pulmonary emphysema, cardiomegaly, and atherosclerosis of the arteries at the base of the brain. He also had undergone surgical procedures to the abdomen and one of his hips in the past. The medical examiner determined the cause of death to be an acute cardiac event.
BMI = 24.9 $kg \cdot m^{-2}$

07-44 Diver with unknown certification and experience, collapsed after dive, limited information available.

Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

There is very little information available on the death of this 64-year-old male. His certification status and dive experience are unknown. According to the minimal information available he was making an ocean dive when he collapsed from a cardiac event. An autopsy was not performed.
BMI = na

07-48 Certified diver, unknown experience, medical history positive for hypertension and diabetes, made shore entry dive with two buddies, had buoyancy problem, unable to submerge, divemaster assisted back to dock, collapsed while removing his gear.

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. The diver's medical history was significant for hypertension and diabetes. He and two other divers made a shore entry dive as part of a cruise ship excursion. The diver had difficulty with his buoyancy and was unable to submerge. The divemaster assisted the diver back to the dock where he collapsed while removing his dive gear. Resuscitation efforts were employed but the diver did not respond. An autopsy was not performed and the death was attributed to cardiovascular disease.
BMI = na

07-51 Certified diver, unknown experience, made dive from liveaboard with buddy, difficulty breathing at depth, surfaced, lost consciousness.

Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

There is little information available on the death of this 62-year-old male. He was a certified diver with an unknown amount of experience who was on a liveaboard boat. He and a buddy were making a dive to 40 fsw (12 msw) when he complained of difficulty with breathing while at depth. The divers surfaced together and the stricken diver continued to have trouble breathing. He eventually lost consciousness and could not be resuscitated. An autopsy was not performed but the death was attributed to a cardiac event.
BMI = na

07-108 Certified advanced open water and nitrox, inexperienced, student in specialty class, medical history positive for heart disease and seizures, on multiple medications, made second dive of day on nitrox, while removing his fins on ladder, seized and lost consciousness, recompressed at chamber, never regained consciousness.

Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 55-year-old male had only been certified for one year but had already completed advanced open

water and nitrox certifications, even though his logbook only documented 19 lifetime dives. He was a student in another specialty diving class making a series of dives from a boat. The diver had answered negative to all health problems on the health screening intake form for this class. However, the diver had undergone previous coronary artery bypass surgery and also had a seizure disorder. He was taking multiple prescription medications. The first dive was to a maximum depth of 104 fsw (32 msw) for 26 minutes on air and was uneventful. After completing a second dive to 45 fsw (14 msw) for 32 minutes on nitrox the diver lost consciousness while removing his fins on the ladder and seized. The diver was taken to a local hospital where he was recompressed with hyperbaric oxygen but he never regained consciousness. The autopsy demonstrated severe ischemic heart disease with atherosclerosis involving native vessels and grafts. He also had diffuse myocardial fibrosis, aortic stenosis, marked atherosclerosis of the aorta, obesity, cardiomegaly, and evidence of a remote cerebrovascular accident. The death was attributed to a cardiac event.
BMI = 32.5 $kg \cdot m^{-2}$

07-61 Certified divemaster, made uneventful dive with buddy and group, lost consciousness on surface swim back to boat.

Cause of Death: Cardiac Dysrhythmia due to Coronary Artery Disease

This 52-year-old male was a certified diver with divemaster status. He and a buddy made a dive from a boat as part of a dive group off a cruise ship. After completing a 35 minute dive to an unknown depth the diver lost consciousness during the surface swim back to the boat. Cardiopulmonary resuscitation was initiated by other divers in the group but the diver could not be resuscitated. An autopsy was performed but the report was not made available. The death was determined to be due to a cardiac event.
BMI = na

07-62 Open water student, on open-ocean dive, limited information.

Cause of Death: Cardiac Dysrhythmia due to Coronary Artery Disease

This 48-year-old male was a student in an initial open water certification class. There is little information available regarding this diving-related death except that it was during an open ocean check-out dive and the death was determined to be due to a cardiac event.
BMI = na

07-64 Certified diver, unknown experience, made uneventful dive with group to wreck, collapsed during surface swim back to boat.

Cause of Death: Cardiac Dysrhythmia due to Coronary Artery Disease

There is minimal information on the death of this 59-year-old male. He was reportedly a certified diver with an unknown amount of diving experience in a group of six divers that included a dive instructor. The dive was reported to have been uneventful and included an excursion to 60 fsw (18 msw) to view a wreck. The diver collapsed during the surface swim back to the boat and could not be resuscitated. The cause of death was reported to have been a cardiac event.
BMI = na

07-76 Experienced diver and underwater photographer, made dive with buddy, lost consciousness, minimal information.

Cause of Death: Cardiac Dysrhythmia due to Coronary Artery Disease

This 59-year-old male was an experienced diver and underwater photographer. According to the minimal information available he lost consciousness at 40 fsw (12 msw) while with his buddy. Resuscitation efforts were unsuccessful. The most likely cause of death in this case is a cardiac event.
BMI = 27.4 kg·m^{-2}

07-87 Unknown certification and experience, medical history positive for colitis, made dive, surfaced gasping for air and descended again, pulled from water, equipment test found both regulators free flowed and tank was empty, toxicology positive for antidepressants, seizure and bipolar medication.

Cause of Death: Cardiac Dysrhythmia due to Coronary Artery Disease

The certification status and experience level of this 58-year-old male is unknown. His medical history is significant for colitis. He made a dive to 50 fsw (15 msw), came up gasping for air and then descended back down. He was pulled from the water and had a pulse but was not breathing on his own. Resuscitation efforts were unsuccessful and the diver was pronounced dead at a local hospital. An equipment evaluation revealed that both regulators free flowed and the diver's tank was empty. An autopsy was performed with a focus on any evidence of a decompression accident being present but none was found. The autopsy revealed atherosclerotic cardiovascular disease, cardiomegaly, patchy myocardial fibrosis, and steatosis of the liver. Toxicology was positive for two antidepressant medications as well as a drug that is used to treat partial seizures and bipolar disease. The death was ruled to have been due to a cardiac event.
BMI = na

07-95 Unknown certification and experience, made uneventful dive, surfaced, boarded boat, complained of chest pain that began during ascent, lost consciousness.

Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

There is no information on the dive profile, dive certification, or experience level of the diver in this case. He was a 50-year-old male with an unknown medical history making a deep dive from a boat into the ocean. According to the investigative report this diver surfaced from an uneventful dive that was to a maximum depth of 113 fsw (34 msw). On the boat he complained of chest pain that began during the ascent and persisted. He lost consciousness and could not be resuscitated. An autopsy was performed that demonstrated moderate coronary artery disease and cardiomegaly as well as steatosis of the liver. The death was attributed to a cardiac event, though the possibility of an air embolism was apparently not considered by the pathologist who did the autopsy. It cannot be completely excluded given the history.
BMI = 33.3 kg·m^{-2}

07-99 Certified open water diver, unknown experience, made dive with group into freshwater lake, disoriented, cardiac arrest before submerging.

Cause of Death: Cardiac Dysrhythmia due to Coronary Artery Disease

This 49-year-old male obtained his initial open water certification three years earlier but the amount of diving experience he possessed is unknown. He was making a dive from a boat into a freshwater lake as part of a group of six divers but as they entered the water the diver appeared to be disoriented. He

went into cardiac arrest before submerging for the dive and resuscitation efforts were unsuccessful. The death was ruled to have been due to a cardiac event.
BMI = na

07-100 Student in open water certification class, made dive with group of students and instructor, lost consciousness on ascent.

Cause of Death: Cardiac Air Embolism due to Scuba Diving

This 64-year-old male was under instruction for initial open water certification. There is limited information on this death but it was reported that the diver was among a group of students and an instructor making a dive from a boat. He apparently lost consciousness on ascent and was taken to a local hospital where he was pronounced dead. The mishap report states that he had a “cardiac event due to an air embolism.” The history is good for an air embolism but his age makes a cardiac event difficult to exclude. An air embolism can often lead to cardiac arrest so distinguishing between the two clinical entities, especially without an autopsy report or any knowledge of the diver’s medical history, is very difficult.
BMI = na

Proximate Cause: Drowning/Cardiac

07-02 Diver completed open water class day before, in advanced open water class, family medical history of heart disease, medical history included obesity and smoking, second dive of day with buddy, on ascent, lost consciousness, brought to surface.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Severe Coronary Artery Disease

This 51-year-old male had completed his initial open water certification course the day before and was a student in an advanced open water course. He had a positive family history for heart disease but no known significant health problems other than obesity and cigarette smoking. The diver was making his second dive of the day using a shore entry into a freshwater spring. After nearly 20 minutes at a maximum depth of 72 ft (22 m), he began an ascent. The diver’s buddy noticed that he was drifting downward instead of ascending and when he went to render assistance the buddy realized that the diver had lost consciousness. The stricken diver was brought to the surface but resuscitation efforts were unsuccessful. The autopsy disclosed changes consistent with drowning as well as focally severe atherosclerosis of the coronary arteries and aorta. A pneumothorax and multiple rib fractures were also present, likely as a consequence of cardiopulmonary resuscitation efforts. The death was certified as a drowning, likely due to a cardiac event. The deceased diver had a strong family history of heart disease.
BMI = 33.3 $kg \cdot m^{-2}$

07-19 Certified, experienced diver, no health issues known, made dive with group, ascended to surface early dive, ditched equipment, found on surface floating face down, unconscious.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Marked Cardiomegaly

This 59-year-old male was an experienced, certified diver with no known health problems. He was making a dive with a group of divers from a boat and was witnessed to first descend, before heading to the surface within the first five minutes of the dive. According to witnesses, the diver was in charge of the float line so his early surfacing did not alarm the other divers. He was then seen on the surface, unconscious and face down in the water. It was discovered that the diver had ditched his regulator, buoyancy compensator and mask. Resuscitation efforts were unsuccessful. An autopsy disclosed a

markedly enlarged heart, which is a potential source of a fatal dysrhythmia. The diver's equipment was examined and found to be in good repair. The air in his tank contained excess hydrocarbons and carbon dioxide, but not at levels that would have clearly posed a hazard. The diver typically filled his own tanks from a compressor in a body shop, which would not have filtered out many of the impurities. This death likely represents a drowning due to a cardiac event sustained while diving.
BMI = na

07-20 Experienced advanced open water certified diver, anxiety and depression medications, made dive with buddy/husband and group in quarry, buddy swam away with group, diver lost consciousness at depth, found at bottom.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Cardiomyopathy

This 54-year-old female was an experienced diver with advanced open water certification. Her medications included Prozac for anxiety and depression. She was diving with her husband in a large group in a local quarry. Her husband decided to head to deeper water with other divers. For no apparent reason the diver lost consciousness at depth and when an instructor swam by her he was busy with his students and did not recognize that she was in need of assistance. After all of the divers returned to the pier, it was noticed that this diver had failed to return and a search was initiated. The diver was found on the bottom at approximately 65 ft (20 m) a few minutes later. Resuscitation efforts were unsuccessful. An autopsy disclosed changes consistent with drowning as well as irregularities in the myocardium. The equipment appeared to be in good working order and her tank was nearly full. This was likely a drowning as a consequence of a cardiac dysrhythmia due to cardiomyopathy.
BMI = na

07-47 Certified and experienced diver, made dive in freshwater cave system with buddy, diving nitrox, turned back to exit, lost consciousness, buddy exited cave for help, diver pulled from cave.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis, Focally Severe

This 51-year-old male was a certified, experienced diver who was in a freshwater cave system with a buddy. Both divers were cave certified. Visibility was poor and they were using nitrox as a breathing gas. This diver signaled that it was time to turn back after approximately one-third of his gas source had been utilized. The divers were approximately 20 ft (6 m) apart, going through the cave in single file when this diver lost consciousness. The divers were at a depth of 60 ft (18 m) at that point. The stricken diver's buddy could not get a response from him and exited the cave to get assistance. After the diver was pulled from the cave, resuscitation efforts were unsuccessful. The local Medical Examiner erroneously declared the cause of death to be air embolism. Since the loss of consciousness occurred at a depth of 60 ft (18 m), an air embolism would be extremely unlikely. Other autopsy findings included focally severe coronary artery disease, which is a much more likely trigger in this case. The pathologist misinterpreted intravascular and intracardiac gas from the diving and this death was likely a drowning secondary to a cardiac event.
BMI = na

07-89 Certified diver with moderate experience, infrequent diver, medical problems include smoking, obesity, hypertension and elevated serum cholesterol, made solo shore entry dive into lake, found floating with head submerged and feet above the surface.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 51-year-old male was a certified diver with a moderate amount of experience, but he was an

infrequent diver. His medical problems included obesity, tobacco abuse, hypertension, and an elevated serum cholesterol level. He made a shore entry, solo dive into a lake and was found floating with his head submerged and feet above the surface by two other divers just entering the water. The medical examiner determined the death to be a “dry drowning due to a cardiac event” though an autopsy was not performed. It would be very difficult to make that call without an autopsy and in this case the medical examiner only did an external examination on the body. In all likelihood, however, this probably was a cardiac event that resulted in a drowning. The diver’s tank had 2700 psi (186 bar) of air remaining in it. According to his friends, this diver “always went diving alone” so there are no witnesses to any event that may have occurred in the water.
BMI = 32.6 kg·m^{-2}

07-52 Unknown certification or experience, medical history positive for knee, chest, and neck surgeries and obesity, observed to act unusual on first dive, during second dive was found floating unconscious on surface.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Dilated Cardiomyopathy

There little information available on this fatality. This 52-year-old female was likely uncertified and probably had little or no diving experience. She most likely was participating in a resort course according to the sparse information available. Her medical problems included prior unspecified surgeries on both knees, chest, and neck. She was also obese. During her first dive she had to be assisted back to the boat because of “unusual actions” according to the instructor. During the second dive she was found floating unconscious on the surface. The diver was eventually taken to a hospital emergency room where she was pronounced dead on arrival. The death was ruled to have been a drowning due to a cardiac event.
BMI = na

07-106 Unknown certification and experience, no known health problems other than obesity, made dive with three other divers, attempted to remove gear at depth, buddies brought to surface, lost consciousness.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Artery Disease, Focally Severe

The certification status and diving experience of this 45-year-old male is unknown. The diver had no known health problems except for obesity. He was making a dive from a boat in a group of three divers and while at depth he was seen attempting to remove his gear. His dive buddies brought him to the surface and got him back into the boat, but he could not be resuscitated. The autopsy demonstrated severe coronary artery disease in one of the main coronary arteries as well as minor trauma to the scalp and face and changes associated with drowning. The death was signed out as a drowning secondary to a cardiac event. Toxicology was positive for diphenhydramine (Benadryl).
BMI = 30.0 kg·m^{-2}

Proximate Cause: Drowning/Insufficient Air

07-07 Experienced advanced open water diver, made solo dive to spearfish using nitrox, friends on boat became concerned when he did not surface, found on bottom, out of air.

Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 60-year-old male was an experienced diver with advanced open water certification. He made a solo dive from a boat to spearfish while three others waited on the surface. The diver used nitrox 40 as

a breathing gas and went to a maximum depth of 90 fsw (27 msw). After nearly an hour had elapsed the individuals in the boat began to worry and one entered the water to search for the diver. He found the diver on the bottom, unconscious and without his regulator in his mouth. The stricken diver was brought to the surface but no one on the boat attempted cardiopulmonary resuscitation. An autopsy was performed and the medical examiner determined the cause of death to be drowning. An equipment evaluation revealed that the deceased diver's primary gas source had been exhausted. His spare gas was full but had possibly been closed during the dive. At a depth of 90 fsw (27 msw) it is possible to experience oxygen toxicity with enriched air containing 40 percent oxygen (PIO2 1.49 atm) but it is unlikely that the primary gas source would have coincidentally been exhausted. The death was most likely due to drowning secondary to an exhausted gas supply.
BMI = na

07-113 Certified divemaster, made deep dive in cold water quarry, with two buddies, two divers had problem with free flowing regulators, shared air, this diver was found at the surface unconscious, second buddy was found on bottom one hour later. [see case 07-114]

Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 43-year-old female was one of two divers who died in a double fatality mishap. This diver had divemaster certification and one of her buddies had advanced open water certification while the other was a fellow divemaster. The three divers made a deep dive in a quarry in very cold water. They first descended to 70 ft (21 m) and then down to 100 ft (30 m). They may have even exceeded 120 ft (37 m) for a maximum depth. It appears the divers made it to slightly shallower water before they encountered problems. One diver went over to one of his buddies and showed him that the regulator he was using was free flowing. The buddy offered him his octopus regulator but then that diver went over to this diver. This diver apparently also had a regulator free flow problem. They appeared to be buddy breathing and the first buddy prepared to ascend after he lost sight of the other divers. This diver was found by the surviving buddy, unconscious and on the surface. Other divers rendered aid and brought this diver to the beach but she did not survive. The autopsy showed changes consistent with drowning as well as cardiomegaly. The tanks of both decedents were empty and the surviving buddy was treated with hyperbaric oxygen at a local hospital.
BMI = na

07-10 Experienced technical diver, history of seizure medication, made solo dive in complex cave system on mixed gas, did not return, body found next day, out of air.

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Cave) due to Scuba Diving

This 53-year-old male was a technical diver with cave diving experience. He mixed his own gas and maintained his own gear. The diver made a habit of surveying caves alone using mixed gas. The medical history states that the diver was on "seizure medicine" but none was found on toxicological testing. The diver entered a complex cave system alone using a reel line and breathing 27 percent nitrox. When he did not return a search was conducted and his body was found the next day, 300 ft (91 m) from the cave entrance and at a depth of 46 ft (14 m). The diver's gas supply was exhausted and his reel line was caught on a fin, though the recovery team felt that the line was not contributory to his death. The autopsy findings were consistent with drowning and additionally the diver had mild coronary atherosclerosis. Toxicological studies were positive for caffeine metabolites and an antidepressant medication. The death was ruled an accidental drowning.
BMI = na

07-18 Experienced dive instructor, teaching advanced open water class, second dive of day, same tank as first dive, left students alone, they surfaced, instructor was found next day in cave shaft, no safety lines, out of air.

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Cave) due to Scuba Diving

This 40-year-old male was a dive instructor teaching an advanced open water certification course. One of the students had open water certification while the other student possessed no dive certification whatsoever. The instructor and his two students were making their second dive of the day; the first was to 110 ft (34 m) and was reported to have been uneventful, though it included an excursion into a cavern. The students had changed tanks for the second dive but apparently the instructor descended using the same tank as he did for the first dive. They descended deeper than planned and silt made visibility difficult. The instructor had the students stay in one place while he went on. The students believed they were being tested so they obediently remained in place but the instructor did not return. After one of the students descended briefly to look for the instructor, the students then ascended to a decompression stop followed by an exit from the water. Recovery divers found the instructor's body the next day within a cave shaft and between some rocks. His had no lines with him, his gas source had been exhausted and his flashlight battery was dead. Other than changes associated with drowning the autopsy indicated that the instructor was significantly obese.
BMI = 38.8 $kg \cdot m^{-2}$

07-24 Certified, experienced instructor, medical history positive for asthma with inhaler, made repetitive dives under ice with student, poor visibility, student had line, but instructor did not, using same tank as previous dive, separated, found next day, weights still in place and out of air.

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Ice) due to Scuba Diving

This 41-year-old male was a certified dive instructor with significant diving experience. His medical problems included asthma for which he used an inhaler. The instructor was making repetitive dives under ice with a student. They both began this dive with approximately 600 psi (41 bar) of air, having used the same tanks on a previous dive. The student was attached to a line leading back to an exit point through the ice; the instructor was diving without the aid of a line. Visibility was poor and when the student was down to 200 psi (14 bar) remaining he signaled to the instructor to go up. The two divers became separated and the student went to the exit point, descended back down to look for the instructor, and finally exited the water. A tender then went below the ice to search for the instructor as did rescue divers but his body was not recovered until the next day. When his body was recovered it was noted that the instructor's weights were in place and he was out of air. The autopsy report was not made available but the cause of death was reported to be drowning.
BMI = na

07-70 Experienced technical diver, made shore entry dive with buddy, in ice-covered river to wreck, on trimix, experienced regulator free flow and problem with secondary, signaled out of air, shared air until just under ice, left behind in strong current, body recovered next day.

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Ice) due to Scuba Diving

This 57-year-old male was an experienced diver with technical certification. He and a buddy made a shore entry dive into a river covered with ice in order to check out a shipwreck. The divers used trimix as a breathing gas and the maximum depth was planned to be 85 ft (26 m). Approximately 12 minutes into the dive and 700 ft (213 m) from the entry point in the ice this diver experienced a regulator free flow. He also had problems with his secondary regulator and signaled to his buddy that he was out of air. The buddy tried to render assistance and provided his alternate air source to the diver as they ascended

up to the ice. Just beneath the ice surface the diver dropped his buddy's regulator from his mouth and would not take it back. The current was strong and the dive buddy had to leave the diver behind and head to the point where they entered the water through the ice. The diver's body was recovered the next day. An autopsy was performed but the report was not made available. The cause of death was determined to be drowning due to entrapment under the ice.
BMI = na

07-83 advanced open water certified diver (no cave), planned dive in cave in freshwater spring system, first buddy ran low on air and they shared air, diver behaved erratically and went farther into cave, became entangled in line, buddies did not have knives and surfaced for help, police recovered diver at bottom.

Cause of Death: Drowning due to Insufficient Air due to Entangled (Line) due to Scuba Diving

This 19-year-old male held advanced open water certification but had no formal training in cave diving. He and two other divers, one a divemaster and the other an instructor, intended to make a series of dives in a freshwater spring. None of the divers were cave trained but they misrepresented themselves at the check-in office in order to bring lights along on their dive. They also brought lines and reels with them and likely planned on entering the cave. The trio descended to 90 ft (27 m) and entered the mouth of the cavern. One of the divers ran low on air and initially shared air with this diver but then switched to sharing air with the other buddy. According to the two other divers, this diver behaved erratically at this point and appeared to go farther into the cavern, toward the cave entrance. He became entangled in one of the safety lines and none of the divers had a knife to use to cut him free. The two buddies surfaced and one called for assistance while the other went back down to assist the entangled diver. Police divers arrived on the scene within minutes and the diver was cut loose and brought to the surface. Resuscitation efforts were unsuccessful and the diver was pronounced dead at a local hospital. The autopsy findings were consistent with drowning. The diver's tank was empty. The deceased diver's buddies thought that perhaps the diver's erratic behavior was due to the effects of nitrogen narcosis. In any event this death was due to divers going beyond their level of training and experience.
BMI = na

07-98 Experienced technical diver, medical history of surgical repair of patent foramen ovale, made dive with buddy to penetrate wreck, using nitrox and a drysuit, entered wreck and stirred up silt to zero visibility, became separated, body found 12 days later inside wreck.

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Wreck) due to Scuba Diving

This 32-year-old male was an experienced technical diver making a wreck penetration dive to 120 fsw (37 msw) using twin nitrox tanks and a drysuit. The diver had explored this wreck several times previously. He and his buddy entered the wreck and found their way to a small room where the silt was stirred up and visibility went to zero. The diver and his buddy became separated and the dive buddy surfaced to call for help. An immediate search was unfruitful and the diver's body was not recovered until 12 days later. His body was located in the same room where he and his buddy became separated. The diver's tanks were empty and as part of his dive gear there was a reel with 250 ft (76 m) of line that had not been deployed during the dive. The cause of death was determined to be drowning. Coincidentally the diver had a surgical repair of a patent foramen ovale five months earlier.
BMI = na

07-101 Experienced technical dive, made dive with three others to penetrate wreck, using nitrox, entered areas of wreck that were off limits, one diver exited but three did not follow, this diver was found in wreck and pulled to surface, other two divers recovered next day. [See cases 07-102 and 07-105]

Cause of Death: Drowning due to Insufficient Air due to Entrapment in Wreck due to Scuba Diving
This 51-year-old male was one of three divers who died in a single incident involving a wreck penetration dive. He was a very experienced technical diver with no known health problems. This diver was among a group of four divers who were making a series of deep wreck penetration dives using nitrox. The divers had made two uneventful dives on the wreck one day earlier and descended for the first dive of the second day of diving. The depths of all of the dives was approximately 140 fsw (43 msw) and on this dive the divers entered areas of the wreck that were known to be off limits due to narrow passageways and very confined spaces. The divers entered a small room within the lower decks of the ship and three of the divers headed down a passageway leading from the room. The fourth diver stayed back and was getting low on his breathing gas. Silt stirred up by the divers reduced visibility considerably. When the three divers were returning to the room the fourth diver exited but he was not followed by his dive buddies. The fourth diver surfaced to get help before descending again for a decompression stop. Other divers on the surface descended to the wreck and pulled this diver out of the wreck and up to the surface. The bodies of the other two divers were located later that day but could not be recovered until the next day. This diver was taken to a nearby hospital where he was pronounced dead. An autopsy was performed and the cause of death was determined to have been drowning. An examination of the diving equipment revealed that all of the tanks the divers had with them inside of the wreck were empty. They had lines and reels with them but did not deploy them to explore the wreck. Apparently over the few years preceding this event, divers had removed some of the chains and welds that restricted access to areas of the wreck that were considered off limits.
BMI = 24.7 $kg \cdot m^{-2}$

07-102 Experienced technical dive instructor, medical history positive for obesity, made dive with three others to penetrate wreck, using nitrox, entered areas of wreck that were off limits, one diver exited but three did not follow, one diver was found and pulled to surface, this diver and fourth diver were recovered the next day in wreck. [See cases 07-101 and 07-103]

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Wreck) due to Scuba Diving
This 38-year-old male was one of three divers who died in a single incident involving a wreck penetration dive. He was a very experienced dive instructor with no known health problems except obesity. This diver was among a group of four divers who were making a series of deep wreck penetration dives using nitrox. The divers had made two uneventful dives on the wreck one day earlier and descended for the first dive of the second day of diving. The depth of all of the dives was approximately 140 fsw (43 msw) and on this dive the divers entered areas of the wreck that were known to be off limits due to narrow passageways and very confined spaces. The divers entered a small room within the lower decks of the ship and three of the divers headed down a passageway leading from the room. The fourth diver stayed back and was getting low on his breathing gas. Silt stirred up by the divers reduced visibility considerably. When the three divers were returning to the room the fourth diver exited but he was not followed by his dive buddies. The fourth diver surfaced to get help before descending again for a decompression stop. Other divers on the surface descended to the wreck and pulled one of the divers out of the wreck and up to the surface. The bodies of this diver and the third diver were located later that day but could not be recovered until the next day. An autopsy was performed and the cause of death was determined to have been drowning. An examination of the diving equipment revealed that all of the tanks the divers had with them inside of the wreck were empty. They had lines and reels with them but did not deploy them to explore the wreck. Apparently over the few years preceding this event, divers had removed some of the chains and welds that restricted access to areas of the wreck that were considered off limits.
BMI = na

07-103 Experienced technical dive instructor, made dive with three others to penetrate wreck, using nitrox, entered areas of wreck that were off limits, one diver exited but three did not follow, one diver was found and pulled to surface, this diver and third diver were recovered the next day in wreck. [See cases 07-101 and 07-102]

Cause of Death: Drowning due to Insufficient Air due to Entrapment (Wreck) due to Scuba Diving

This 55-year-old male was one of three divers who died in a single incident involving a wreck penetration dive. He was a very experienced dive instructor with no known health problems except mild obesity. This diver was among a group of four divers who were making a series of deep wreck penetration dives using nitrox. The divers had made two uneventful dives on the wreck one day earlier and descended for the first dive of the second day of diving. The depth of all of the dives was approximately 140 fsw (43 msw) and on this dive the divers entered areas of the wreck that were known to be off limits due to narrow passageways and very confined spaces. The divers entered a small room within the lower decks of the ship and three of the divers headed down a passageway leading from the room. The fourth diver stayed back and was getting low on his breathing gas. Silt stirred up by the divers reduced visibility considerably. When the three divers were returning to the room the fourth diver exited but he was not followed by his dive buddies. The fourth diver surfaced to get help before descending again for a decompression stop. Other divers on the surface descended to the wreck and pulled one of the divers out of the wreck and up to the surface. The bodies of this diver and the third diver were located later that day but could not be recovered until the next day. An autopsy was performed and the cause of death was determined to have been drowning. An additional finding at autopsy was moderate cardiovascular disease. An examination of the diving equipment revealed that all of the tanks the divers had with them inside of the wreck were empty. They had lines and reels with them but did not deploy them to explore the wreck. Apparently over the few years preceding this event, divers had removed some of the chains and welds that restricted access to areas of the wreck that were considered off limits.
BMI = 32.9 $kg \cdot m^{-2}$

07-27 Certified diver with moderate experience, made multiple dives from liveaboard, buddy ran low on air, began ascent, poor visibility, became separated, found next day on bottom, regulator out of mouth and out of air.

Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 64-year-old male was a certified diver with a moderate amount of diving experience who was on a liveaboard doing multiple days of diving. On the first dive of the third day of diving he and two dive buddies entered the water as part of a large group. The diver had trouble with one fin early in the dive but otherwise the dive was uneventful until one of the buddies ran low on air. This was at approximately 75 fsw (23 msw) and the divers agreed to head back to the boat and surface. Visibility was poor and the divers became separated during the ascent. The buddy who was low on air went directly to the surface and the other buddy made a safety stop during his ascent. Neither saw the third member of the group during ascent and upon returning to the boat they initiated a search for the missing diver. The missing diver's body was recovered the next day at 80 fsw (24 msw). His regulator was out of his mouth and his tank was empty. The autopsy revealed changes consistent with drowning as well as mild coronary artery disease.
BMI = 23.5 $kg \cdot m^{-2}$

07-30 Certified, inexperienced diver, medical history positive for high cholesterol and esophageal reflux, on medications including antimalarial, made shore entry night dive with group, daughter was buddy, moderately rough seas, separated, found floating face down on the surface, regulator out of mouth.

Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 59-year-old female was a certified diver with approximately 15-20 lifetime dives. Her medical history included prescription medications for elevated cholesterol and esophageal reflux. She was also taking an antimalarial medication at the time of this dive trip. The diver made a shore entry night dive with three other divers, including her daughter as a dive buddy. The sea state was moderately rough and initially the divers in each buddy pair were able to stay together but eventually all divers became separated. The diver's daughter searched briefly then surfaced from the dive. An observer on shore saw the diver floating face down, unconscious and with her regulator out of her mouth. Resuscitation efforts were unsuccessful. The cause of death was determined to be drowning though it is not clear that an autopsy was performed. The diver was low on air according to one report and an air embolism cannot be excluded.
BMI = na

07-41 Experienced, certified diver, tropical fish collector, made solo dive, strong current and rough seas, topside support tried to locate him when overdue, body found next day, out of air.

Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 46-year-old male was an experienced, certified diver who collected tropical fish to sell to local pet stores. He entered the water alone for a dive and planned to go to 90-130 fsw (27-40 msw) to gather fish. The diver had topside support back in the boat. After his tender thought the diver had been below the surface too long he went down to check on the diver and could not locate him. The sea state was rough and there was a strong current so the second diver had to abort the search and call the Coast Guard. The Coast Guard search was also unsuccessful that day but the following day the diver's body was recovered at a depth of 115 fsw (35 msw). The diver's tank was noted to be empty. An autopsy disclosed changes associated with drowning as well as an enlarged heart. Toxicology was positive for hydrocodone, diazepam, and their metabolites.
BMI = 26.9 $kg \cdot m^{-2}$

07-42 Experienced, certified diver, made scientific certification dive with instructor from shore, signaled out of air to surface, buoyancy trouble at safety stop, instructor shoved alternate air into mouth and towed to shore, removed weight belt and attempted to remove divers' belt, he sank underwater, body found later.

Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 44-year-old male was an experienced, certified diver who was diving with an instructor in order to earn qualifications to join a scientific diving team. The instructor stated that, in retrospect, the diver behaved a bit erratically for an experienced diver but there were no complaints or pre-dive medical issues discussed. The only medical problem the diver had, according to the investigative report, was obesity. The two divers entered the water from shore for a planned dive to 120 fsw (37 msw). Approximately 15 minutes into the dive the diver signaled to the instructor that he was out of air and needed to surface. They ascended to a safety stop but the diver could not maintain a consistent depth and struggled in the water. The instructor offered his alternate air source to the diver but he would not take it. The instructor stated that at one point he forced one of his regulators into the diver's mouth and began to tow him toward shore. The instructor removed his own weights and then attempted to remove the other diver's

weights but he was unsuccessful at the latter task. The instructor lost control of the stricken diver's body and without a weight belt he could not submerge after him. The instructor returned to shore to get help and the Coast Guard pulled the diver's body from the water approximately 90 minutes later and he was pronounced dead at a local hospital. Autopsy information was not made available but the cause of death was reportedly determined to be drowning. There is conflicting information regarding how much air remained in the deceased diver's tank and the exact circumstances leading to the aborted dive are still largely unknown.
BMI = 32.4 $kg \cdot m^{-2}$

Proximate Cause: Drowning/Various Causes

07-03 Certified diver for one year, unknown experience, medical history included hypertension and recent leukemia treatment, made dive with two buddies (one being his son), surfaced in distress, sank below surface, found on bottom.

Cause of Death: Drowning due to Scuba Diving

This 55-year-old male was certified as an open water diver one year earlier but his experience level is unknown. The diver's past medical history is significant for hypertension and recent treatment for leukemia. In fact, he still had a vascular access device in place for chemotherapy at the time of his death. The diver and two buddies, including his son, entered the water and descended for a dive. The diver's son surfaced for more weight and the diver came to the surface a short time later in obvious distress. He sank back below the surface and was found unconscious and on the bottom, with his regulator out of his mouth. The divers rendering assistance removed the stricken diver's weight belt but it became entangled around his fin straps. The diver was brought to the surface where resuscitation efforts were started but he was pronounced dead at a local hospital. The autopsy demonstrated changes associated with drowning, hypertrophy of the left ventricle of the heart, a calcified granuloma in the right lung, and evidence of a recent splenectomy.
BMI = na

07-04 Certified diver, advanced certification and experience, medical history of hypertension, obesity and past history of smoking, spearfishing dive with two buddies, planned separation at bottom, buddies surfaced, diver found four hours later on bottom.

Cause of Death: Drowning due to Scuba Diving

This 47-year-old male held advanced open water certification with approximately 60 dives during the two years that had elapsed since initial certification. His medical history included hypertension, obesity, and cigarette smoking, though he had managed to quit smoking. The diver and two buddies descended together to spearfish but they separated shortly after reaching the bottom. When his buddies surfaced without him a search was initiated. The Coast Guard found the diver four hours later on the bottom, without his buoyancy compensator and tank. In addition to changes associated with drowning, the autopsy disclosed moderate coronary atherosclerosis, cholesterolosis of the gallbladder, and marked obesity. There were also superficial abrasions and contusions present on the body, likely a result from being dragged along the bottom. A cardiac event cannot be excluded from having a role in this death.
BMI = 36.2 $kg \cdot m^{-2}$

07-05 Experienced diver, medical history included amputation of finger portions, made dive with buddy (son) to spearfish in strong current, buddy helped diver to surface, surfaced 100 ft (30 m) from boat, disappeared while being helped onto the boat, body found eight days later.

Cause of Death: Drowning due to Scuba Diving

This 53-year-old male was an experienced, certified diver who made frequent dives. The diver had no known health problems and the only significant note in his medical history was traumatic amputation of the distal portions of the fourth and fifth fingers of his left hand. He and his 14-year-old son entered the water to spearfish on a planned dive to 70 fsw (21 msw). The current was strong and the son had some trouble early in the dive but was able to correct any problems and descend. Both divers surfaced approximately 100 ft (30 m) from the boat and they called for help. The diver's son was pulled into the boat but the diver was unable to be pulled from the water. His body was recovered eight days later with most of the diving gear still in place. An evaluation of the diver's equipment revealed that his buoyancy compensator would not hold air. The victim's dive buddy said that there was some sort of problem on the bottom and that he assisted the diver to the surface before they became separated.
BMI = na

07-09 Experienced technical diver, spearfishing dive on wreck with two buddies, planned decompression dive with 80/20 nitrox, buddies found him unconscious on the wreck.

Cause of Death: Drowning due to Scuba Diving

This 23-year-old male was an experienced diver with technical certification. He was making his second dive of the day after an uneventful first dive and descended to 150 fsw (46 msw) with two buddies. The diver's past history is significant for an episode of oxygen toxicity with little information about the event. The divers were spearfishing near a wreck with planned decompression (air for the dive and 20 percent nitrox for decompression). Approximately 20 minutes into the dive, the two buddies noticed that the diver was sitting motionless on the top surface of the wreck and further inspection revealed that he was unconscious. The stricken diver was brought to the surface and resuscitation efforts were initiated but were unsuccessful. The medical examiner signed the case out as an air embolism but loss of consciousness occurred at depth and without an ascent air embolism is not likely. The divers were using air as a bottom mix which is unlikely to cause seizures at a maximum depth of 162 fsw (49 msw). The decompression mix in the pony bottle was 80 percent oxygen which could cause oxygen toxicity (PIO2 4.73 atm) but there is no evidence that the diver accidentally breathed his deco mix at depth. There is much conflicting information regarding this case including the possibility that the diver was out of air or that his primary tank may have contained nitrox. The intravascular gas observed by the medical examiner was likely an artifact of the dive profiles and the loss of consciousness went unwitnessed. Other findings at autopsy included changes associated with drowning and a scalp contusion that is consistent with rescue/resuscitation efforts. The exact details resulting in this death remain unknown.
BMI = 21.3 $kg \cdot m^{-2}$

07-14 Uncertified and inexperienced diver, only medical history was obesity, made dive on surface supplied gas to collect artifacts, multiple descents and ascents, panicked and grabbed buddy's regulator, lost consciousness, assisted to surface.

Cause of Death: Drowning due to Scuba Diving

This 24-year-old male was not a certified diver and had no known previous diving experience. His only known medical problem was obesity. The diver was using a surface supplied gas source with four other divers to make excursions to approximately 12 ft (4 m) in order to recover artifacts from the bottom. After multiple excursions up and down over a period of 45 to 90 minutes the diver appeared to be

having some difficulties and he signaled to his buddy that he wanted to surface. The buddy came over to render aid, but the diver panicked and grabbed his buddy's regulator out of his mouth. The buddy surfaced and another diver entered the water and assisted the first diver to the surface. At this point the diver was unconscious. Resuscitation efforts were initiated and the diver was transported to a local hospital where he was pronounced dead. The autopsy revealed changes consistent with drowning as well as the presence of diazepam on toxicological testing.
BMI = 31.8 kg·m^{-2}

07-15 Certified diver, unknown experience, smoker, made dive with buddy group of four, overweighted, buddy tried to dump weight and inflate buoyancy compensator, panicked and lost consciousness.

Cause of Death: Drowning due to Scuba Diving

This 36-year-old female had been certified as a basic open water diver four years earlier but her level of experience is unknown. Her only medical issue was that she smoked cigarettes. She was in a buddy group of four, including children ages 13 and 10, making a dive from a charter boat with a large group of divers. The diver entered the water and felt she was wearing too much weight. Her adult buddy attempted to assist her in jettisoning some of the weight, but she panicked and struggled on the surface. The buddy attempted to inflate the diver's buoyancy compensator and at the same time he called for assistance. By the time the divers were pulled back into the boat the diver who initially needed assistance had lost consciousness. Resuscitation efforts were unsuccessful. The autopsy revealed changes associated with drowning as well as cholelithiasis and the presence of an antihistamine on toxicological testing. The cause of death was determined to be drowning.
BMI = 17.6 kg·m^{-2}

07-21 Certified diver with unknown experience level, made shore entry dive with buddy in rough conditions, surfaced and began surface swim to shore, separated from buddy and slammed into rocks, lost consciousness, buddy pulled him to shore.

Cause of Death: Drowning due to Scuba Diving

This 45-year-old male obtained his open water certification approximately two years earlier but his experience level is unknown. He made a shore entry dive with a buddy into rough seas and after spending approximately 20 minutes at 40 fsw (12 msw) they decided to surface. The sea state had worsened and they began a surface swim toward shore. The diver and his buddy became separated and the buddy saw a large wave slam the diver into some rocks. The diver remained below the surface and was pulled from the water by his buddy and another individual who stopped to help. Resuscitation efforts were unsuccessful. The autopsy demonstrated changes associated with drowning as well as lacerations and abrasions of the scalp. There was no skeletal trauma but the head injuries would have been sufficient to render the diver unconscious.
BMI = 25.4 kg·m^{-2}

07-22 Recently certified diver, history of asthma with inhaler use, made dive with an inexperienced diver, both had buoyancy problems, descended, lost consciousness, buddy panicked and could not bring diver to surface, divemaster recovered victim, faulty regulator, overweighted.

Cause of Death: Drowning due to Scuba Diving

This 25-year-old female earned her initial open water certification two months earlier and she was making her first dive outside of a student status. The diver paired up with another inexperienced diver at the dive site. Notably the diver had a history of asthma for which she regularly used an inhaler. The two

divers entered the water and both immediately had buoyancy problems. They eventually descended to approximately 65 fsw (20 msw) and initially both signaled that they were okay. Visibility was reported to be poor. About 10 minutes into the dive, the diver's buddy noticed that she had lost consciousness. The buddy panicked and could not bring the stricken diver to the surface as he failed to remove her weights. He surfaced and called for help. The divemaster went down and brought the diver to the surface where medical care was rendered and she was transported to a local hospital. The diver died after a brief admission to the intensive care unit. An autopsy report was not made available but the cause of death was reported to be drowning. An evaluation of the deceased diver's regulator revealed that it was improperly adjusted, which would have made breathing at depth more difficult. The diver was also over-weighted, including weights in the buoyancy compensator pockets.
BMI = na

07-26 Certified, experienced cave diver, exploring flooded mine shafts in cold water with poor visibility, found unconscious with dislodged regulator and flooded mask, found to have malignant masses in one lung and liver.

Cause of Death: Drowning due to Scuba Diving

This 51-year-old male was a certified, experienced cave diver on an expedition to explore and document flooded mine shafts. The water was very cold and visibility was poor. The diver made an excursion to a 50 ft (15 m) maximum depth but was found unconscious at 30 ft (9 m) by a fellow diver. The diver was brought to the surface where resuscitation efforts were unsuccessful. When the stricken diver was found it was noted that the second stage of his primary regulator had become dislodged and his mask was flooded with water. The autopsy report was not made available for review but a medical statement describes likely malignant masses in one of the diver's lungs and in his liver. The pathologist who performed the autopsy concluded that the diver suffered an air embolism due to air trapping from the lung mass. This conclusion was likely based on the presence of intravascular and intracardiac gas which was most likely a consequence of the dive itself. Even with potential air trapping due to a lung mass, it is very unlikely that the diver would have sustained a pulmonary over-expansion injury by going from 50 to 30 ft (15 to 9 m) in depth within this cave system. The ambient pressure would have still been nearly two atmospheres at that point. It is more likely that the diver drowned with the regulator malfunction being the trigger in this case.
BMI = na

07-29 Diver just completed open water course earlier in the day, made first open water dive with father as buddy, shore entry dive into lake, panicked and spit out regulator, buddy tried to offer regulator and did not accept, found on bottom.

Cause of Death: Drowning due to Scuba Diving

This 16-year-old female had just completed her initial open water certification course earlier in the morning and was making her first open water dive after certification. With her father as a dive buddy the diver made a shore entry into a lake and descended to a platform that was at a depth of 20 ft (6 m). As the diver left the platform to continue on the dive she panicked and spit her regulator out. Her father then tried to offer his second regulator to her but she did not take it and he panicked as well. Her father surfaced and called for assistance. The dive instructor entered the water, found the diver at an approximate depth of 45 ft (14 m), and brought her to the surface. She was transported to a medical treatment facility where it was determined that she had irreversible hypoxic brain injuries and the family agreed to organ donation. A small subdural hemorrhage associated with a scalp contusion was noted at autopsy, likely a consequence of trauma when she was pulled from the water. The cause of death was determined to be drowning.
BMI = 13.2 $kg \cdot m^{-2}$

07-31 Certified but inactive diver, made a dive from shore with buddy, lost fin, panicked, pulled back to shore, unconscious on beach.

Cause of Death: Drowning due to Scuba Diving

This 43-year-old male had open water certification but had not been an active diver for several years. He and a buddy were making a shore entry when the diver lost a fin and struggled to recover it. The diver panicked and aspirated water in the process. He was pulled back to shore by his buddy and was unconscious on the beach. Resuscitation efforts were unsuccessful. The autopsy report was not made available but the cause of death was reported to be drowning.
BMI = na

07-36 Unknown certification and experience level, made solo dive to work on boat mooring, body was found five days later, toxicology positive for ethanol and cocaine.

Cause of Death: Drowning due to Scuba Diving

This 43-year-old male had an unknown dive certification and experience status. He was making a dive by himself off his boat to work on a boat mooring. The diver's body was recovered five days later, approximately 100 ft (30 m) from shore and 90 ft (27 m) from the boat. The autopsy demonstrated changes associated with drowning. Toxicology revealed the presence of significant concentrations of ethanol and cocaine in the decedent's blood. The death was ruled to have been an accidental drowning.
BMI = na

07-37 Open water certified, but infrequent diver, made shore entry dive with buddy, separated when surfaced, could not keep up on swim to boat, divemaster assisted, found unconscious, brought to shore.

Cause of Death: Drowning due to Scuba Diving

This 54-year-old male possessed open water certification but had only completed 30 dives over a several year period and was a very infrequent diver. He made a shore entry dive with a buddy to 60 fsw (18 m) for 30 minutes. At the 30 minute mark the diver and his buddy ascended but became separated from each other on the surface. The buddy noticed the diver was not keeping up with him during a surface swim toward shore and a divemaster swam out to assist. The diver was noted to be unconscious and was brought back to shore. Resuscitation efforts were unsuccessful. The autopsy report was not made available but it was reported that the death was signed out as a drowning. The pathologist who performed the autopsy stated that the diver had severe coronary artery disease and also that there was "foam drainage from one ear that indicated a rapid ascent was made". If the diver truly sustained a perforated tympanic membrane it might indicate barotrauma had occurred and make air embolism a possibility. Bloody fluid in the ear canal would be an indication of that and a pathologist could examine the tympanic membranes to see if they are intact. It is impossible to discern exactly what the pathologist meant by "foam drainage". This may have been a drowning secondary to a cardiac event or to an air embolism.
BMI = na

07-38 Unknown certification and experience level, medical problems positive for hypertension, diabetes, obesity and heart disease, made shore entry dive with group, buddy was wife, on surface swim to dive, disappeared, found floating face down on surface, never submerged.

Cause of Death: Drowning due to Scuba Diving

The certification status and experience level of this 57-year-old male is unknown. The diver's medical problems included hypertension, diabetes, obesity, and heart disease. He was making a shore entry dive as part of a group of divers with his wife as a dive buddy. His wife was uncomfortable during the surface swim and decided to turn back. At first the diver planned on continuing the dive but then he signaled to the others that he was also turning back. When all the divers had returned to shore it was determined that the diver was missing and a search found him floating face down on the surface. He had never descended below the surface. An autopsy confirmed severe coronary artery disease and the cause of death was determined to be drowning, likely secondary to a cardiac event.
BMI = na

07-43 Uncertified and no experience, made first open water dive with instructor, signaled to surface, hit by large wave at surface, choked and panicked, instructor inflated buoyancy compensator and towed him back to shore, lost consciousness.

Cause of Death: Drowning due to Scuba Diving

This 62-year-old male was not a certified diver and had no known prior experience with diving. He was making his first ever open water dive as part of a "discover scuba" experience. The diver and an instructor descended to 38 fsw (12 msw) and after 15 minutes the diver signaled that he was ready to surface. On the surface the diver initially did well until a large wave hit him and he aspirated some water. The diver choked and then panicked as the instructor rendered assistance. The instructor inflated the diver's buoyancy compensator and began to tow him back to shore. The diver lost consciousness during the transit. Resuscitation efforts, including cardiopulmonary resuscitation, were attempted but the diver was pronounced dead at a local hospital. In addition to changes consistent with drowning the autopsy demonstrated significant coronary artery disease, cardiomegaly, and evidence of a previous inferior wall myocardial infarction.
BMI = 27.1 $kg \cdot m^{-2}$

07-45 Certified diver with unknown experience level, made shore entry dive with buddy and group, drift dive in river, buddy and diver became separated from group, stuck in a hydroelectric plant intake, bodies were recovered the next day. [See case 07-46]

Cause of Death: Drowning due to Scuba Diving

This 38-year-old male was a certified diver with an unknown amount of diving experience who was involved in a double diving fatality. The diver and his buddy made a shore entry dive into a river as part of a group of divers. It was a drift dive and the group of five divers became separated into two pairs and a solo diver. This diver and his buddy swam or drifted out of the feeder creek and into the river where they became stuck in the intake for a hydroelectric plant. The bodies of both divers were recovered the next day. The other three divers in the group surfaced and were rescued. Autopsy reports were not made available but the cause of death was determined to be drowning. Apparently there had been a recent change in the intake system that resulted in different times and flow rates for the water intake.
BMI = na

07-46 Certified, experienced diver, made shore entry dive with buddy and group, drift dive in river, buddy and diver became separated from the group, stuck in a hydroelectric plant intake, bodies were recovered the next day. [See case 07-45]

Cause of Death: Drowning due to Scuba Diving

This 66-year-old male was a certified, experienced diver who was involved in a double diving fatality. The diver and his buddy made a shore entry dive into a river as part of a group of five divers. It was a drift dive to a maximum depth of 30 ft (9 m) and the divers became separated into two pairs of divers and a solo diver. This diver and his buddy swam or drifted out of the feeder creek and into the river where they became stuck in the intake for a hydroelectric plant. The bodies of both divers were recovered the next day. The other three divers in the group surfaced and were rescued. Autopsy reports were not made available but the cause of death was determined to be drowning. Apparently there had been a recent change in the intake system that resulted in different times and flow rates for the water intake.
BMI = na

07-56 Uncertified diver, learning to dive with buddy who was certified but not an instructor, made shore entry dive, panicked early in dive, buddy tried to assist, could not release weight belt, sank to bottom, found later, regulator out of mouth and mask off, toxicology positive for multiple drugs.

Cause of Death: Drowning due to Scuba Diving

This 23-year-old female was not a certified diver and her only experience with diving equipment was trying it out in a swimming pool two months earlier. Her boyfriend was a certified diver but not an instructor and offered to teach her how to scuba dive. His diving experience level also appeared to be minimal. The two divers made a shore entry and approximately five minutes into the dive the untrained diver panicked. Her buddy tried to render assistance and struggled to put provide his second regulator as an alternate air source while pulling her toward the surface. The dive buddy was unsuccessful in getting her weight belt to release. His buoyancy compensator inflated and she sank while he headed to the surface alone. The diver was found an hour later on the bottom with the regulator out of her mouth and her mask off. The autopsy disclosed changes associated with drowning as well as positive toxicology for codeine, morphine, antidepressants, and cannabis.
BMI = na

07-60 Certified diver, moderate amount of experience, made shore dive with buddy in rough seas, separated during surface swim, buddy found tank, then unconscious diver.

Cause of Death: Drowning due to Scuba Diving

This 34-year-old male was a certified diver with moderate experience who decided to make a shore entry dive with a buddy in a very rough sea state. During the surface swim from shore the two divers separated and the buddy first came upon the other diver’s tank then found the unconscious diver. The buddy towed the diver to shore where resuscitation efforts proved unsuccessful. The autopsy disclosed changes consistent with drowning along with blunt force injuries of the scalp and extremities. He also had mild to moderate coronary artery disease.
BMI = na

07-65 Diver with basic open water certification, inexperienced, smoker, medical problems with sinuses and ears, made dive with buddy and group, experienced problem at depth, unresponsive, brought to surface, lost consciousness.

Cause of Death: Drowning due to Scuba Diving

This 32-year-old male possessed basic open water certification and had made 40 lifetime dives. His only known medical problems included tobacco abuse and occasional problems with his sinuses and his ears. The diver and a buddy made a dive as part of a large group. The dive profile included an excursion to a maximum depth of 130 fsw (40 msw) using air as a breathing gas. The diver was fine at first but then experienced an unclear problem at depth. He would not respond to the divemaster's prompting and was brought to the surface. On the surface the diver was unconscious and he was transported to a medical treatment facility where he was pronounced dead on arrival. The autopsy report was not available for review but the cause of death was determined to be drowning. A clear trigger event could not be identified; nitrogen narcosis may have played a role in this death.
BMI = na

07-68 Certified diver, minimal experience, made dive with two buddies, surfaced with one buddy missing, second buddy went to search for him, they surfaced and diver had disappeared, body found next day.

Cause of Death: Drowning due to Scuba Diving

This 53-year-old male had been a certified diver for three years but had minimal overall diving experience and had not been diving recently. He and two other divers entered the water from a boat, leaving an empty boat on the surface. This diver and one buddy surfaced but the second buddy was not with them. This diver's buddy then submerged to look for the third diver but when he returned to the surface with the third diver the first diver was nowhere in sight. The missing diver's body was recovered the next day and had evidence of shark predation, thought to be postmortem. The investigative report states that the diver drowned but does not identify a trigger and if an autopsy was performed the results were not made available.
BMI = na

07-69 Unknown certification and experience, medical history positive for recent hospitalization for exertional pulmonary edema, told safe to dive, entered water to dive, difficulty breathing before descent, struggled at surface, then lost consciousness.

Cause of Death: Drowning due to Scuba Diving

The certification status and experience level of this 45-year-old female is unknown. She had been hospitalized a few months earlier for "exertional pulmonary edema" but upon discharge was told she could return to diving. After entering the water the diver complained of difficulty breathing prior to descent. The dive was aborted and the captain jumped in to the water to render assistance. For a short period of time the diver was still conscious on the surface but struggling. She eventually lost consciousness and after being transported to a medical treatment facility she was pronounced dead. An autopsy was performed but the findings were not made available. The death was ruled to have been a drowning but one cannot exclude recurrent pulmonary edema as at least a trigger, even with a complete autopsy.
BMI = na

07-72 Unknown certification and experience level, made a dive from boat, difficulties at depth, assisted back to boat, pronounced dead at hospital.

Cause of Death: Drowning due to Scuba Diving

The certification status and experience level of this 41-year-old male is unknown. All that is known is that he was making a dive from a boat and developed some difficulties at depth. He was assisted back to the boat and taken to a medical treatment facility where he was pronounced dead on arrival. An autopsy was performed but the report was not made available. According to the investigative report and the death certificate the cause of death was determined to be drowning.
BMI = na

07-75 Experienced advanced open water diver, made dive with group, surfaced from second dive, boat had drifted away, dumped weights and inflated buoyancy compensators, swam back to shore, diver lost consciousness, towed to shore by buddy.

Cause of Death: Drowning due to Scuba Diving

This 58-year-old female was an experienced diver with advanced open water certification. She and three other divers were making a second dive from a boat to approximately 25 fsw (8 msw). After surfacing from the second dive, the divers realized that their boat, which they had left unattended, had broken free from its mooring and drifted away. The divers dumped their weights, inflated their buoyancy compensators, and began the two-mile surface swim back to land. Fatigued and distressed, at some point during the transit this diver lost consciousness and was towed to the beach by her buddy. She was pronounced dead on shore. There is no autopsy report available. The diver most likely drowned, though a cardiac event cannot be excluded completely.
BMI = na

07-80 Certified and experienced divemaster, medical problem included obesity, made shore entry dive with two buddies in rough sea state, first buddy had trouble and while second buddy assisted him, diver fell face down into water, buddies found him unconscious.

Cause of Death: Drowning due to Scuba Diving

This 38-year-old male was a certified divemaster and experienced diver. His medical problems included morbid obesity. This diver and two others attempted to make a shore entry dive in a very rough sea state where swells were in excess of 11 ft (3 m). One of the diver's buddies fell over in the surf zone and needed help removing equipment and standing up. The other buddy rendered assistance and while they walked back to the beach this diver fell face down into the water and could not raise himself back up. The diver's buddies were already fatigued and could not respond very quickly. By the time they assisted the fallen diver out of the water he was unconscious and resuscitation efforts were unsuccessful. The autopsy findings were consistent with drowning. In this case obesity likely played a greater role than usual in this diving-related death.
BMI = 42.8 $kg \cdot m^{-2}$

07-81 Certified open water diver, made three uneventful dives day before, shore entry dive into cold lake with poor visibility, unknown problem at depth, surfaced in distress, submerged again and found unconscious on the bottom.

Cause of Death: Drowning due to Scuba Diving

This 52-year-old male received his open water certification one year earlier and had completed 50 divers during that time. He had made three dives the day before, which were reported to have been uneventful. The dive was made using a shore entry into a cold lake where visibility was poor. The maximum depth was approximately 60 ft (18 m). The diver experienced an unknown problem at depth, surfaced in distress and appeared disoriented. He then submerged again and was pulled unconscious from the bottom. Resuscitation efforts were unsuccessful. An autopsy was performed but the report was not made available. The cause of death was reported out as a drowning with possibly a cardiac event as a contributing cause.
BMI = na

07-85 Certified diver, unknown experience level, made dive in river to collect fossils, separated from buddy, found floating unconscious on surface.

Cause of Death: Drowning due to Scuba Diving

This 45-year-old female was a certified diver with an unknown amount of experience who was diving in a river to collect fossils. She became separated from her buddy shortly after entering the water and was found floating unconscious on the surface. An autopsy was performed and the cause of death appears to have been drowning but the report was not made available.
BMI = na

07-88 Unknown certification or experience, numerous health issues, including obesity, mitral valve prolapse, hypertension, hypothyroidism, and gastric band in place for weight loss, apprehensive before dive, entered water with instructor, at shallow depth signaled to ascend, surfaced short of breath and lost consciousness.

Cause of Death: Drowning due to Scuba Diving

This 61-year-old female had numerous health issues including morbid obesity, mitral valve prolapse, hypertension, and hypothyroidism. She had a gastric band in place for weight loss. The investigative report does not indicate this diver's certification status but from reading the investigative report it appears that this dive was part of a resort course or a familiarization dive. The diver was reported to have been very apprehensive the day before and the morning of the dive. She entered the water from a boat and was accompanied by an instructor. After descending to 20 fsw (6 msw) the diver signaled to the instructor that she wanted to ascend. On the surface she complained of shortness of breath and she lost consciousness while climbing the ladder to get back into the boat. Resuscitation efforts were unsuccessful and the diver was pronounced dead at a local hospital. In addition to changes associated with drowning the autopsy demonstrated the presence of mild coronary artery disease and confirmed the diagnosis of mitral valve prolapse. The history is classic for an air embolism but the pathologist found no corroborating evidence of barotrauma at autopsy. The death was signed out as a drowning.
BMI = na

07-90 Unknown diver certification and experience, planned night dive with buddy to video their dives, went back to shore for more weight, large swell crashed over him, buddy lost sight of him and after 40 minutes of searching, called for help, body was recovered in 6 fsw (2 msw).

Cause of Death: Drowning due to Scuba Diving

The certification status and diving experience of this 48-year-old male are unknown. He and a buddy planned to do a night dive and take video of each other while diving. The diver weighed approximately 165 lb (75 kg) and was using 30 lb (14 kg) of lead on his belt, with an additional 10 lb (5 kg) in his buoyancy compensator. Despite that, he stated that he needed more weight as the diver and his buddy waded out through the surf for a shore entry. He turned back to swim toward shore with his regulator out of his mouth as a large swell from a passing ship went over him. The diver's buddy lost sight of him and presumed he had submerged to dive. After forty minutes of searching the diver's buddy called for help. Fire department divers recovered the body 50 ft (17 m) from shore in 6 fsw (2 msw) and the diver was pronounced dead. There was 2500 psi (172 bar) of air in his tank. The configuration of the hoses on the diver's tank was atypical, calling into question his amount of diving experience. An autopsy was performed and the cause of death was determined to be drowning.
BMI = na

07-91 Unknown diver certification and experience, made shore entry dive to spearfish with two freedivers, rough seas, freedivers witnessed diver surface in distress, tried to pull him to safety but lost him, found trapped between rocks.

Cause of Death: Drowning due to Scuba Diving

The certification status and diving experience of this 51-year-old male are unknown. He made a shore entry solo dive to spearfish while two other individuals who accompanied him were free-diving for abalone. The sea state was fairly rough and after approximately 30 minutes the free-divers saw the diver surface in distress. They tried to render assistance and pull the diver to safety but lost sight of him and called for assistance. A helicopter with rescue divers onboard arrived at the scene within minutes and located the diver who was trapped between some rocks with his head submerged. The diver's body was recovered and he was pronounced dead on the beach. The cause of death was determined to be drowning.
BMI = na

07-94 Certified technical diver, made solo dive with rebreather, diver was found entangled in buoy line with head submerged and fins above water, unconscious.

Cause of Death: Drowning due to Scuba Diving

This 43-year-old male was a certified technical diver making a solo dive with a rebreather. There are few details available about the circumstances but two students in an initial open water certification class discovered the unconscious diver entangled in a buoy line with his head submerged and his fins above the surface of the water. Resuscitation efforts were unsuccessful and the cause of death was determined to have been a drowning. It is not known for certain if the entanglement occurred before or after the diver lost consciousness.
BMI = na

07-96 Open water certification, unknown amount of experience, made dive with group, no buddy, taking underwater photos, found unconscious by a fellow diver, toxicology positive for cocaine metabolites.

Cause of Death: Drowning due to Scuba Diving

This 56-year-old male had open water certification and an unknown amount of diving experience. He made a dive from a boat along with a group of seven other divers. The diver did not have a buddy and was performing a solo dive to take underwater photos. The diver was found unconscious below the surface by one of the other divers. Resuscitation efforts were unsuccessful. An autopsy was performed and the cause of death was determined to be drowning. Toxicology was positive for cocaine metabolites.
BMI = na

07-97 Open water and specialty (nitrox and drysuit) certification, inexperienced, made dive with buddy on wreck, unknown problem with regulator at depth and began ascent, became separated, instructor found diver on bottom, unconscious.

Cause of Death: Drowning due to Scuba Diving

This 32-year-old male had open water certification as well as nitrox certification and training in a drysuit. According to the investigation report he was not a very experienced diver, however. He and a buddy were diving on a wreck and the depth was at least 120 fsw (37 msw) but perhaps as deep as 140 fsw (43 msw). The diver had some unknown problem with his regulator on the bottom and wanted to ascend. As the diver and his buddy made their ascent they became separated. The diver's buddy surfaced and could not locate the diver. A dive instructor found the diver on the bottom and unconscious. The autopsy report was not made available but the cause of death was determined to have been drowning.
BMI = na

07-110 Certified, infrequent diver, made dive with buddy to collect lobster, surfaced after dive, swam back to boat through kelp bed, buddy looked back and the diver was gone, divemaster found diver on bottom, unconscious, regulator out of mouth, mask on head.

Cause of Death: Drowning due to Scuba Diving

This 38-year-old male received his open water certification 14 years earlier but had only completed 12 lifetime dives over the intervening period. His last dive prior to this mishap was eight months earlier. The diver and a buddy were making their first dive on a multiple dive trip in order to collect lobster. There was an initial excursion to 44 fsw (13 msw) but most of the dive took place at 25 fsw (8 msw). The two divers surfaced and decided to return to the boat. The transit required getting through a dense kelp field so the diver's buddy swam ahead of him. When the buddy looked back he no longer saw the diver, so the buddy returned to the boat to see if the diver had done the same thing. The diver had not returned so a divemaster dressed out and entered the water. He found the diver unconscious and on the bottom at 25 fsw (8 msw). The diver's regulator was out of his mouth and his mask was on his forehead. The diver was brought back to the boat where cardiopulmonary resuscitation was ineffective. The autopsy findings were consistent with drowning. Additionally, the diver had focally severe coronary artery disease. An evaluation of the diver's equipment revealed that the power inflator mechanism could not function, and there were weights zippered into the pockets of the buoyancy compensator. The diver had 30-36 lb (14-16 kg) of weights in the pockets of his buoyancy compensator, which precluded any efforts to increase his buoyancy.
BMI = 27.1 $kg \cdot m^{-2}$

07-111 Specialty certified, experienced diver, medical history positive for elevated serum cholesterol and obesity, made dive with group to collect lobster, buddy witnessed diver grab lobster, turned, then turned back and diver was gone, found later unconscious on the bottom, equipment evaluation revealed faulty buoyancy compensator, could not release weight.

Cause of Death: Drowning due to Scuba Diving

This 54-year-old male was an experienced diver with specialty certifications. His medical problems included elevated serum cholesterol and obesity. The diver was collecting lobster in a group of five divers and with an identified buddy. They entered the water from a boat and descended to a maximum depth of 110 fsw (34 msw). At one point the diver's buddy saw the diver grabbing a lobster but then the buddy turned away and worked on collecting one for himself. When he looked back the diver was not in sight and eventually the buddy surfaced. After a period of time had elapsed, other divers descended to search for the missing diver. He was found unconscious on the bottom two hours later. The autopsy findings were consistent with drowning with the added diagnoses of mild cardiomegaly and mild coronary artery disease. An evaluation of the diver's equipment revealed that his buoyancy compensator was nonfunctional and he had a significant amount of weight that could not be jettisoned during the dive.
BMI = na

07-57 Certified open water diver, not cave certified, medical problems included obesity, depression and anxiety, made dive in cave with buddy on nitrox, 600 ft (183 m) into the cave diver became trapped, removed his gear, recovered by rescue divers later that day.

Cause of Death: Drowning due to Entrapment (Cave) due to Scuba Diving

This 48-year-old male was not a certified cave diver and had only basic open water certification which he had obtained 20 years earlier. His medical problems included obesity as well as depression and anxiety for which he took prescription medication. He and a buddy who was certified in cave diving entered a freshwater cave system using dual tanks filled with nitrox. At a depth of approximately 95 ft (29 m) and a distance of 600 ft (183 m) into the cave the diver became stuck and could not extract himself. His buddy surfaced for help and it was not until later in the day that rescue divers removed the diver's body from the cave. He had removed his equipment in an attempt to get out of the tight area of the cave but without success. There was still 2000 psi (138 bar) of gas remaining in the tanks. The death was ruled a drowning secondary to entrapment in a cave. Other autopsy findings included mild coronary artery disease, cardiomegaly, and atherosclerosis of the aorta. Toxicology was positive for an antidepressant medication as well as a benzodiazepine.
BMI = na

07-53 Experienced technical cave diver, made dive in freshwater cave system with buddies, using nitrox, showed erratic behavior and signaled to ascend, had seizure, buddies offered alternate air and did not accept, unable to bring out of cave, recovered later by other divers.

Cause of Death: Drowning due to Seizure due to Oxygen Toxicity due to Scuba Diving

This 46-year-old male was a very experienced technical diver with cave diving certification. He was making a dive in a freshwater cave system using 32 percent nitrox and the event occurred during his first dive of the day. At a depth of approximately 100 ft (30 m) the diver first demonstrated "erratic behavior" and then gave the signal to ascend, according to his dive buddies. He followed that with a witnessed seizure and one of his buddies attempted to render assistance by providing an alternate air regulator to use. The diver did not take the regulator and rapidly lost consciousness. The dive buddies were unable to bring the diver out of the cave system and surfaced after appropriate decompression.

Two other divers recovered the body of the stricken diver and he was pronounced dead. The local medical examiner erroneously signed the case out as an air embolism because of large amounts of intracardiac and intravascular gas noted at autopsy. Since the diver never ascended during his dive profile, an air embolism is unlikely. The diver seized at depth, most likely as a result of breathing gases with high partial pressures of oxygen. This was a modest depth for a seizure (PIO2 1.29 atm) but the event was witnessed by two dive buddies. Toxicology was positive for codeine.
BMI = 25.7 $kg \cdot m^{-2}$

07-54 Certified, experienced cave diver, physically fit and healthy, diving in freshwater cave using trimix, uneventful first dive, second dive, signaled to buddies to turn back, seizure during ascent, buddy offered alternate air source, wouldn't take, continued to seize during attempt to ascend and at surface.

Cause of Death: Drowning due to Seizure due to Oxygen Toxicity due to Scuba Diving

This 28-year-old female was an experienced, certified cave diver making a set of dives into a freshwater cave system. According to the investigative report she was healthy and physically fit. The diver was using trimix with a reported oxygen component of 24 percent. The first dive was to a maximum depth of 102 ffw (31 mfw) and was reported to have been uneventful. The second dive was to a depth of 160 ffw (49 mfw) and at the 25 minute mark the diver signaled to her two buddies that she wanted to turn back. During the ascent the diver suffered a witnessed seizure at approximately 147 ffw (45 mfw). At that point the divers were 200 ft (61 m) into the cave. The diver's buddies attempted to render assistance including providing an alternate gas source but she would not hold it in her mouth as the seizure continued. The diver lost consciousness and it took 45 minutes to get her to the surface. Resuscitation efforts were unsuccessful. The autopsy disclosed changes associated with drowning as well as abundant intravascular and intracardiac gas. The death was signed out as a drowning secondary to a seizure from oxygen toxicity. An air embolism was mentioned by the medical examiner, but the dive profile does not support the occurrence of an air embolism. The intravascular gas was most likely a consequence of the time spent at depth breathing compressed gas with the remote possibility that an air embolism occurred during the attempt to bring the diver to the surface. It does not appear that the diver had breathed a high oxygen-containing decompression mix as has happened in similar cave diving fatalities. More likely she was overly sensitive to the effects of hyperbaric oxygen and a seizure was triggered (PIO2 of 1.28 atm at 147 ffw; 1.37 atm at 160 ffw). The investigative report mentions this diver had experienced some mild symptoms of oxygen toxicity in the past.
BMI = na

Proximate Cause: Unspecified or Body Not Recovered

07-08 Experienced technical diver, diving on rebreather with two buddies to explore wreck at planned depth of 375 fsw (114 msw), alarms sounded at 150 fsw (46 msw), buddy attempted help but he continued descent, observed to lose consciousness at 200 fsw (61 msw), body never found.

Cause of Death: Unknown, Body not Recovered

This 42-year-old male was an experienced diver with technical diving certification. He was using a rebreather rig with two buddies to explore a shipwreck. During a planned descent to 375 fsw (114 msw) alarms on the rig went off at approximately 150 fsw (46 msw). One of the buddies attempted to assist him with switching of the breathing gas, but the diver continued his descent anyway. The diver appeared to lose control of his descent and his buddies tried to render aid. He was observed to lose consciousness at 200 fsw (61 msw). His two buddies attempted to inflate his buoyancy compensator and ditch his weight belt but they were unsuccessful in making the diver buoyant enough for ascent.

The dive buddies had to eventually abandon the diver at depth and head to the surface. The diver's body was never recovered.
BMI = na

07-17 Certified, experienced diver, made solo dive for lobster, friends topside saw that bubbles stopped, searched, but body never found.

Cause of Death: Unknown, Body not Recovered

This 61-year-old male was a certified, experienced diver making a dive to gather lobster. He entered the water alone while others waited in the boat and watched his bubbles. The topside personnel felt that he was ascending based on changes in his bubbles but then the bubbles stopped completely. Some of the topside personnel entered to water to search for the diver but all that was found was some drifting lobster collecting gear. The diver's body was never recovered.
BMI = na

07-25 Certified and experienced divemaster, smoker, medications included decongestant for recent congestion, made second dive of day with buddy to collect lobster and spearfish, using 32 percent nitrox, separated at bottom, buddy surfaced, search done but diver never found.

Cause of Death: Unknown, Body not Recovered

This 38-year-old female was a very experienced diver and certified divemaster. She was making the second dive of the day with a buddy in order to collect lobster and spearfish. The diver was using 32 percent nitrox as a breathing gas. The diver was a cigarette smoker and she reportedly was using decongestants for recent nasal congestion. The first dive was reported to be uneventful and went to a maximum depth of 85 fsw (26 msw). After a surface interval the divers descended for the second dive and arrived on the bottom at 105 fsw (32 msw). The dive buddies became separated and the diver's buddy returned to the boat without her. Extensive searches were conducted over the next several days but the lost diver's body was not recovered. Her speargun was recovered from the bottom three days after she went missing and her dive buoy was found another two days after that.
BMI = na

07-32 Certified, experienced diver, made dive with group, separated and never found.

Cause of Death: Unknown, Body not Recovered

This 43-year-old female was an experienced, certified diver who entered the water with four other divers, a divemaster, and two snorkelers. She was supposed to buddy up with at least one other diver but she went off on her own. The diver was never seen again; her body unrecovered.
BMI = na

07-33 Certified, experienced diver, photographer, made solo dive in strong current, boat found next day, body never found.

Cause of Death: Unknown, Body not Recovered

This 32-year-old male was a certified diver with extensive experience, particularly with underwater photography. He entered the water from a boat to perform a solo dive in a strong current. The Coast Guard found the diver's boat the next day but his body was never recovered. The diver had frequently gone diving without a buddy in the past.
BMI = na

07-35 Unknown certification and experience level, made dive with group, trouble equalizing, and surfaced, buddy continued dive and victim not seen again.

Cause of Death: Unknown, Body not Recovered

There is little information available regarding the death of this 59-year-old male. His certification status and diving experience are unknown. He was diving from a charter boat with a group of divers and he had a designated buddy. It appears that on descent he indicated that he was having trouble equalizing and wanted to head back to the surface. The buddy continued on the dive and victim was never seen again. His body was not recovered.
BMI = na

07-63 Certified divemaster, on liveaboard trip, made solo night dive, possibly overweighted and with inoperable computer, seen on wall at 92 fsw (28 msw), did not return to the boat, body never recovered.

Cause of Death: Unknown, Body not Recovered

This 35-year-old male was a certified divemaster with two years of diving experience. He was on a liveaboard dive trip when he entered the water for a solo dive at night. The investigative report states that the diver likely had an inoperable dive computer and no gauges. He may also have been overweighted and was not wearing any thermal protection. His light may have been seen at 92 fsw (28 msw) by another solo diver who was on the wall. The diver never returned to the boat and his body was never recovered.
BMI = na

07-66 Unknown dive certification and experience, entered water with buddy, became separated, body never recovered.

Cause of Death: Unknown, Body not Recovered

There is little information available regarding the circumstances of the death of this 36-year-old male. His dive certification status and experience level are unknown. He and a buddy entered the water from a boat and became separated during the dive. The diver's buddy was rescued later the same day but the diver's body was never recovered.
BMI = na

07-34 Certified, experienced diver, medical problems includes diabetes mellitus, made dive with group, separated and disappeared, found floating unconscious on surface.

Cause of Death: Unknown Cause of Death

This 71-year-old male was a certified, experienced diver. The diver's medical problems included diabetes mellitus; it is unclear if he was aware of any heart or blood pressure problems prior to the dive. He was diving with a group for a planned excursion to 100 fsw (30 msw) when he went missing. He was found shortly thereafter, floating unconscious on the surface. The local coroner reported that he felt the diver had sustained an air embolism due to an uncontrolled rapid ascent but there is absolutely nothing that documents his ascent and this conclusion seems to be complete speculation. The autopsy disclosed hypertensive heart disease and coronary atherosclerosis.
BMI = na

07-67 Unknown certification and experience, made ocean dive, limited information.

Cause of Death: Unknown Cause of Death

There is virtually no information available regarding the circumstances of the death of this 56-year-old male. His dive certification status and experience level are unknown. The dive took place in the ocean but other than that nothing is known about the dive profile or what problem may have occurred. If an autopsy was performed, the findings were not made available.
BMI = na

07-77 Unknown certification and experience, on liveaboard with husband, entered water for a dive, lost consciousness at shallow depth, limited case information.

Cause of Death: Unknown Cause of Death

There is little information regarding the death of this 53-year-old female. She and her husband were on a liveaboard trip and she lost consciousness at a depth of approximately 10-15 fsw (3-5 msw) shortly after entering the water for a dive. This case may have involved a cardiac event but there is not enough information available to make that determination.
BMI = na

07-78 Unknown certification and experience, made dive from boat, limited case information.

Cause of Death: Unknown Cause of Death

This diving related death involved a 50-year-old male with an unknown training and certification status. He died during an open ocean dive from a boat. No other information is available.
BMI = na

07-79 Unknown certification and experience, made shore entry dive with buddy into freshwater canal system, became separated at depth, buddy surfaced and submerged again to search for diver, found later by recovery divers.

Cause of Death: Unknown Cause of Death

The certification status and dive experience of this 49-year-old male is unknown. He did a shore entry into a freshwater canal system and began the dive with a buddy but they separated while submerged. The diver's buddy surfaced and did not see the diver so he descended but still could not locate him. Rescue divers recovered the diver's body shortly after arriving on the scene. The cause of death and any information from an autopsy, if one was performed, are unknown.
BMI = na

07-82 Unknown certification and experience level, made ocean dive with group to a wreck, unknown problem at depth, unconsciousness at surface.

Cause of Death: Unknown Cause of Death

The information on this male involved in a diving-related death is scant. His name, age, certification status, experience level, and most of the circumstances of the case are all unknown. He dived from a boat into the ocean with a number of other divers to view a wreck. He experienced an unknown problem at depth and was unconscious on the surface. His buddies helped him into the boat and it was reported that the diver was declared dead upon arrival at a local hospital.
BMI = na

07-86 Student in open water class, on third of four check-out dives, with instructor and buddy, practicing compass skills, buddy got ahead of diver, reached shore and he had disappeared, instructor found diver unconscious, weight belt around his ankles, regulator out of mouth.

Cause of Death: Unknown Cause of Death

This 43-year-old male was a student in an initial open water certification class making the third of four required check-out dives. He made the first pair of dives one week earlier. The dive was from a boat and made with a designated buddy under the supervision of an instructor. After descending to 18 fsw (5 msw) the diver and his buddy were practicing compass skills. The diver's buddy got ahead of him and when the buddy reached shore the diver was no longer behind him. The instructor found the diver unconscious, with his regulator out of his mouth and his weight belt around his ankles. The diver was taken to a local hospital and pronounced dead. An autopsy was apparently performed but the findings and a cause of death were never released.
BMI = 25.2 $kg \cdot m^{-2}$

07-84 Open water certified diver, making drysuit training dive with instructor and buddies, surfaced with one buddy, planned to join two other buddies, they surfaced later and diver was missing, found at bottom.

Cause of Death: Unknown Cause of Death

This 43-year-old male had been open water certified for approximately one year and was making a training dive with two other divers and an instructor. The diver was learning how to dive with a drysuit and this was his first dive of the season. The diver and his buddy headed toward shore after an excursion to a maximum depth of 90 ft (27 m) and then the diver was supposed to join the other two divers while his buddy exited the water. The diver indicated that he would join the other divers after he picked up the dive flag. When the other divers surfaced, all realized they were missing one diver and they began a search. The diver was found unconscious on the bottom. He was brought up and provided emergency medical services but without success. An autopsy was performed but the results and report were not made available. There is not enough information available to determine the cause of death with any certainty in this case.
BMI = na

07-104 Experienced, certified diver, made solo dive to gather lobster, three others topside in boat, no longer saw diver's bubbles, pulled on line, not attached, body found two weeks later, washed ashore.

Cause of Death: Unknown Cause of Death

This 29-year-old male was an experienced, certified diver making a solo dive to gather lobster while three other individuals waited in the boat. According to friends it was not unusual for this diver to dive alone. There is little information available on this fatality but the report states that the depth of the dive was about 20 fsw (6 msw). The tenders on the boat became concerned when they could no longer follow the diver's bubbles. They pulled in the safety line but it was no longer attached to the diver's body. The diver's body was recovered two weeks later when it washed ashore. An autopsy was performed but the report and findings were not made available. In this age group death due to natural causes is less likely but still a possibility. This probably represents an accidental drowning but without more information it is impossible to categorize this death.
BMI = na

Proximate Cause: Other

07-12 Student in open water class, husband was instructor, made dive in rough sea state, surfaced struggling in choppy water, lost consciousness during surface swim, died four days later in hospital.

Cause of Death: Hypoxic Encephalopathy due to Near Drowning due to Scuba Diving

This was this 40-year-old female's first open water dive as a student in an initial certification class with her husband as the instructor. She had already completed two dives in a canal for instruction on basic skills. The dive was to 25 fsw (8 msw) in a rough sea state. Upon surfacing, the diver switched to a snorkel but struggled in the choppy water. They surfaced approximately 300 ft (90 m) from the boat and the diver lost consciousness during the surface swim. She was brought onboard the boat where cardiopulmonary resuscitation and oxygen administration were initiated. The diver was transferred to a hospital where she died four days later. The cause of death was complications of near-drowning, which included hypoxic encephalopathy and pneumonia. As an aside it was noted that a dive shop employee was arrested for obstructing law enforcement's ability to take custody of the dive gear. The equipment should always be impounded by law enforcement for inspection in diving-related deaths.
BMI = na

07-49 Experienced, certified diver, made shore entry dive in lake with buddy, shallow depth, buddy surfaced, diver did not surface immediately, panicked at surface, buddy tried to assist but could not hold him up, sank underwater, nearby boat stopped and assisted buddy, diver survived on life support for eight days.

Cause of Death: Anoxic Brain Injury due to Near Drowning due to Scuba Diving

This 44-year-old male was an experienced, certified diver making a shore entry dive into a lake with a buddy. They went down to a depth of 15 ft (5 m) for approximately 30 minutes. At that point the buddy wanted to surface and went up. The diver did not immediately surface with his buddy but when he did surface he acted peculiarly according to the buddy and then began to thrash about before losing consciousness. The buddy swam to the stricken diver to render assistance. He tried to hold the unconscious diver on the surface but eventually he lost his grip. A passing boat stopped and helped bring the diver into the boat. The diver was taken to a local hospital where he remained on life support for eight days before being pronounced dead. An autopsy was performed but only showed the effects of multiple organ system failure. This was likely an air embolism but the trigger remains unknown.
BMI = na

07-58 Certified, inexperienced diver, attempting shore dive with buddy, lost regulator and panicked, aborted dive, snorkeled back to shore through heavy kelp, lost consciousness during surface swim, died next day.

Cause of Death: Anoxic Encephalopathy due to Near Drowning due to Scuba Diving

This 37-year-old male was a certified diver who seems to have had minimal diving experience. He and a buddy were attempting to make a shore entry dive. They swam out from shore breathing off their regulators but the diver lost his regulator and panicked. His buddy handed his regulator back to him but at that point the diver became distressed and they decided to abort the dive without descending. The two divers decided to use snorkels to swim back to shore through an area with heavy kelp growth. The diver lost consciousness during the surface swim to the beach and resuscitation efforts resulted in marginal benefit. The diver died of complications of a near-drowning episode the next day.
BMI = 25.0 $kg \cdot m^{-2}$

07-105 Certified diver with unknown experience, medical history positive for obesity and allergies, nausea and vomiting night before dive, made uneventful shore entry dive with buddy, struggled during surface swim and lost consciousness, on life support for two days.

Cause of Death: Anoxic Encephalopathy due to Cardiac Dysrhythmia due to Coronary Artery Disease, Focally Severe

This 39-year-old male was a certified diver with an unknown amount of diving experience. Chronic medical problems included morbid obesity and allergies. The diver skipped diving the night before because of nausea and vomiting. He and his dive buddy completed an uneventful, shore entry dive and the diver first struggled during the surface swim, then lost consciousness as his buddy rendered assistance. The diver was resuscitated and maintained on life support for two days before being pronounced dead. The autopsy demonstrated severe coronary artery disease and cardiomegaly. Toxicology was positive for fentanyl and benzodiazepines. Since the autopsy report does not mention if this was run on admission blood, it likely represents therapeutic administration. The death was attributed to a cardiac event.
BMI = 42.1 $kg \cdot m^{-2}$

07-71 Experienced technical diver, medical problem of severe obesity, made deep dive with buddy and group, using rebreather with nitrox, inexperienced on rebreather, separated from buddy but did safety stop, boarded boat and collapsed after complaining of fatigue, lost consciousness.

Cause of Death: Decompression Sickness due to Scuba Diving

This 39-year-old male was an experienced diver with technical diver certification. His medical problems included severe obesity. He was with a group of seven divers, including a specified buddy, making a deep dive using a rebreather with nitrox as a breathing gas. The diver had only completed six or seven previous dives with a rebreather. The divers descended to 161 fsw (49 msw) for 105 minutes but this diver may have been as deep as 215 fsw (66 msw). He became separated from his buddy but was reported to have made a safety stop at 20 fsw (6 msw) before surfacing. The diver returned to the boat and collapsed on the deck after complaining of fatigue. The diver lost consciousness and could not be resuscitated. One witness claimed that the diver had a skin rash that was consistent with cutaneous decompression sickness. To complicate matters the body was embalmed before the medical examiner was able to perform an autopsy so the autopsy findings were suboptimal. The medical examiner signed the case out as “barotrauma” but this case likely represents a death due to decompression sickness, most consistent with type III decompression sickness, a combined result of decompression sickness and arterial gas embolism. The presence or absence of a patent foramen ovale was not mentioned in the autopsy report.
BMI = 39.2 $kg \cdot m^{-2}$

07-74 Certified, experienced diver, made dive to 258 fsw (79 msw) on trimix, uneventful dive, lost consciousness on the boat, taken to chamber where she coded during treatment, remained in coma for 17 days, life support withdrawn.

Cause of Death: Decompression Sickness due to Scuba Diving

This 32-year-old female was an experienced, certified diver. There is little information on the dive profile but she apparently made a dive to 258 fsw (79 msw) using trimix and then returned to the boat. Once on the boat the diver lost consciousness and resuscitation efforts were employed. She was taken to a medical treatment facility that had a recompression chamber and eventually was recompressed to 60 fsw (18 msw) for a planned USN TT6. The diver coded during the treatment and hyperbaric oxygen therapy was aborted. The diver subsequently remained in a coma and on life support for the next 17 days before life support was withdrawn. If an autopsy was performed the report was not made

available. This death was most likely due to a decompression accident, either air embolism or severe decompression sickness. In an experienced diver severe decompression sickness would be more likely.
BMI = na

07-92 Unknown certification and experience, made uneventful dive with group from a boat, surfaced about 30 ft (9 m) from boat, in a severe thunderstorm, tank was struck by lightning.

Cause of Death: Electrocution by Lightning Strike

This was an unusual accident for diving but occurred in the state where this type of death is reported more often than in any other state. The certification status and diving experience of this 36-year-old male are unknown. He made a dive from a boat in a group of four divers and reportedly had an uneventful dive for a 30-minute bottom time. As the dive was concluding a severe storm rolled in with abundant thunder, lightning, and hail. The diver surfaced approximately 30 ft (9 m) from the boat and it appeared that his tank was struck by lightning. He was brought back to the boat and transported to the beach but resuscitation efforts were unsuccessful. The diver died of electrocution as a result of being struck by lightning. Toxicology done at the autopsy showed the presence of narcotics in the diver's blood that would not be used in an advanced life support setting.
BMI = 27.0 $kg \cdot m^{-2}$

APPENDIX C. BREATH-HOLD INCIDENT CASE REPORTS

Neal W. Pollock, PhD

C.1 Blackout

07-B011 - Fatal

This 36-year-old male, an experienced freediver, was with a group of snorkelers in relatively calm, high visibility open water in daylight conditions. He was freediving in waters with a depth of 100 fsw (30 msw). The group was loosely monitored from an accompanying boat. After the diver was slow to surface, witnesses observed the victim sinking at a depth of approximately 40 ft (12 m). Rescue divers brought the victim to the surface from a depth of 95 fsw (29 msw) within minutes. Efforts to resuscitate were unsuccessful. An autopsy found no evidence of injury or disease.

This was almost undoubtedly a case of hypoxia of ascent. The diver apparently exhibited no difficulties until quietly losing conscious and beginning to sink. Overweighting can cause a diver to sink; even faster if gas is expelled from the airway. Defensive weighting establishes neutral buoyancy with an empty lung at a depth significantly below the surface. Momentum established during ascent can carry the diver to the surface even if consciousness is lost. While still at very high risk when diving alone, it would be very easy for dive partners to support victims and protect their airways under these conditions until consciousness was restored. In this case the disabling injury was hypoxic loss of consciousness, possibly triggered by excessive hyperventilation.

07-D011 - Fatal

This 36-year-old male expert freediver was on a training dive for the competitive discipline of ‘no limits.’ In this case, divers descend by riding on a weighted sled and ascend by holding onto an inflated lift bag. The available information was incomplete but it is likely that atypical friction or binding interfered with the smooth action of the pulley and/or lines. The diver lost consciousness underwater and was brought to the surface by rescue divers from a depth of approximately 100 fsw (30 msw). Resuscitation efforts were unsuccessful.

‘No limits’ freediving is the most extreme of the recognized competitive disciplines. The current depth records are 702 ft (214 m) and 525 ft (160 m) for males and females, respectively. These records were set in June 2007 and August 2002, respectively. While these records may fall, it must be appreciated that the risk associated with such efforts are high. The difference between successful performance and catastrophic failure is very small at this level of performance. In this case, the disabling injury was hypoxic loss of consciousness and the trigger was likely compromise in the action of the line system.

07-G014 - Fatal

This 23-year-old male was an experienced freediver and spearfisherman in good health. He went spearfishing alone from a private vessel in daylight and calm conditions. A search was initiated when he failed to return. His body was found at rest on the bottom at 72 fsw (22 msw). There were no signs of injury or struggle.

The absence of witnesses and/or physical evidence makes case classification speculative. However, in this case, given the youth, health and experience of this diver, there is a high probability that the disabling injury was loss of consciousness and the trigger excessive hyperventilation. Loss of consciousness is the primary hazard in freediving and spearfishing. Hyperventilation is commonly employed to reduce the carbon dioxide level in the blood and prolong breath-hold time. The hazard is that excessive hyperventilation can effectively abolish any warning of impending hypoxic blackout. The motivation to catch fish and the varied physical demands that a spearfishing dive can entail can erode safety margins even if hyperventilation is limited. If buddy or team support is not possible, freedivers should wear automatic diver recovery vests so even if they do lose consciousness, they will be returned to the surface where the chance of dying is much lower.

07-I008 - Fatal

This 39-year-old male was an expert freediver. He was spearfishing with two friends when he chose to move a distance away and dive alone. His friends went to look for him when he failed to return after a reasonable period of time. His speargun, discharged with a fish on the line was found at 23 fsw (7 msw). His body was found at 100 fsw (30 msw). Information from his downloadable dive computer confirmed that he had a long surface interval prior to his final dive to 89 fsw (27 msw). After approaching the surface he sank and remained at the bottom, presumably as a result of loss of consciousness through hypoxia of ascent.

The lack of physical evidence on autopsy makes it difficult to confirm cases of hypoxic loss of consciousness or hypoxia of ascent. In this case, physical evidence from the dive computer strongly supports a determination of hypoxia of ascent. The disabling injury was loss of consciousness. The trigger was possibly the extra metabolic demand of managing the large, speared fish through the ascent. The diver may have employed pre-dive hyperventilation to delay the urge to breathe. Combining the normal metabolic cost of surfacing, the extra metabolic demand of managing the speared fish, and the decrease in oxygen partial pressure due to the falling ambient pressure, the state of hypoxia could easily become severe enough to result in loss of consciousness with no warning. Without his support network, the life hazard was extreme. The same event occurring in the presence of his companions would likely have had a positive outcome.

C.2 Trauma

07-C001 - Non-Fatal

This 50-year-old male was part of a group of snorkelers swimming around humpback whales in open water, daylight conditions. When a sleeping mother and calf were startled, the mother flipped her tail, breaking this diver’s femur. The injury was caused by surprise rather than overt aggression. The victim was treated at a land-based facility.

Animal interactions can be exciting but the risks are not negligible, particularly when the animal can weigh up to 40 tons (36,000 kg). Even those not known to threaten humans can react badly when startled, crowded or feeling protective of offspring. In this case, the disabling injury was the tail strike and the trigger was the extremely close proximity of the divers to the animals.

07-I008 - Fatal

This 62-year-old female snorkeler had just entered the water and was next to a cruise ship when an adult male slid down a slide from the ship's upper deck. He landed on top of her, causing a severe spinal cord injury. The victim was stabilized and evacuated to hospital, where she died several days later.

Trauma in breath-hold diving most typically results from animal interactions or extreme nearshore water conditions. Physical isolation between areas for surface activities and areas for extreme water entry is warranted. In this case, the disabling injury was clearly the physical trauma.

07-C003 - Fatal

This 29-year-old male was spearfishing with a partner from a boat anchored offshore in daylight conditions. When another boat passed over them, the propeller severed his leg. He died while being transported to hospital.

The disabling injury in this case was the propeller strike, a substantial hazard for open water breath-hold divers. The absence of bubbles makes it difficult for observers to ascertain the position of divers. Position can be a greater challenge with spearfisherman if their activity draws them further away from their surface platform or float. The greater time spent on the surface by breath-hold divers increases their risk over compressed gas divers. Finally, selecting of suits in dark or camouflage colors would make them easier to miss even for vigilant observers.

07-F001 - Non-Fatal

This 43-year-old male was snorkeling in daylight conditions within 60 ft (18 m) of a pier used to ferry passengers between vessels and shore. The diver was unable to avoid a boat bearing down on him. Three of his fingers were severed by the propeller.

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 are visible in all directions. Swimming or snorkeling in areas of frequent or high speed boat traffic increases the risk of interactions. In this case, the disabling injury was the propeller strike. Factors contributing to the accident included the overlap of snorkeling and boating activity, diver visibility and awareness, and boat crew awareness.

C.3 Environment

07-G013 - Fatal

This 19-year-old male was freediving with two friends in daylight conditions when the group was caught in strong current/surge/wave conditions on the exposed shore. The victim helped one of his friends out of the water onto some rocks. While trying to climb out himself, his leg became stuck between rocks underwater. He was battered by waves and swept out by a large one. He was found by firefighters approximately130 ft (40 m) offshore with major injuries. He could not be resuscitated.

The effects of waves and surge in the surf zone can create substantial risk for swimmers and divers. Crossing the surf zone is best done in a region of least turbulence, preferably passing through quickly during a set of relatively smaller waves, but these strategies may not be practicable in emergent events. In this case, the disabling injury was caused by waves, the trigger was the leg trapping, and the contributing factors were anxiety and fatigue in the group.

C.4 Medical

07-B005 - Fatal

This 53-year-old female was snorkeling from shore when caught in an outbound current during daylight conditions. Her husband saw that she was in trouble and swam out to pull her back to shore. Onsite cardiopulmonary resuscitation was unsuccessful and she was pronounced dead in hospital.

The facts are incomplete in this case, but it is possible that the physical demands of fighting the current became a trigger for medical collapse.

APPENDIX D. PUBLICATIONS

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APPENDIX E. GLOSSARY

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 commonly 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 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 (rarely fatal), 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.

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)
Air 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 pressure increases and will expand if the pressure 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."

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

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

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

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 stop.

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.

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.

Computerized 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 DCS and 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" and "Type II 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.

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

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

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 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.

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 one atmosphere, 1 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 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 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 (FAO2)
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 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.”

Hart-Kindwall Oxygen Recompression Treatment Table
A 2:30 h:min recompression protocol used to treat decompression sickness. Oxygen is breathed throughout. 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 the 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)
U.S. 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.

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

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.

Hypoxia
Condition of lower-than-normal oxygen partial pressure in the blood. See “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, that are received by the DAN Medical 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. Many 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 first noticed when breathing air at depths of 60-100 fsw (18-30 msw), depending on diver susceptibility.

Nitrox
See “EAN” and “Mixed Gas”.

No-Decompression Dive or No-Stop Dive
A dive where direct ascent to the surface at 30-60 fsw (9-18 msw) per minute is allowed at any time during the dive without a 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 $p<0.05$.

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 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.

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 semi-closed 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 6 and 5 (USN TT6 and TT5) 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 minutes at 10-20 fsw [3-6 msw]) 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."

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.

Set Point (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 set point. 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 set point.

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.

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-breathing 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; it covers medical evacuation for any medical emergency.

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). Extensions can increase the duration at either 60 fsw or 30 fsw (9 msw). Extremely similar to Royal Navy Treatment Table 62.

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 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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