ANNUAL DIVING REPORT
2008 EDITION

DAN
DIVERS ALERT NETWORK

Annual Diving Report – 2008 Edition

Table of Contents

Acknowledgments

Data for the 2008 Annual Diving Report have been collected and assembled by DAN employees and associated staff. DAN wishes to recognize the following for their important contributions:

EDITOR

Neal W. Pollock, PhD

AUTHORS

Section 1   Neal W. Pollock, PhD
Section 2   Richard G. Dunford, MS, Petar J. Denoble, MD, DSc
Section 3   Petar J. Denoble, MD, DSc
Section 4   Petar J. Denoble, MD, DSc
Section 5   Neal W. Pollock, PhD
Appendix A   Joel A. Dovenbarger, BSN
Appendix B   James L. Caruso, MD
Appendix C   Neal W. Pollock, PhD

CONTRIBUTORS

Research
   Julie E. Ellis
   Lisa Li, BS
   Jeanette P. Moore
   Katherine E. Suek, BA
   Donna M. Uguccioni, MS
   Richard D. Vann, PhD

Medicine
   John J. Freiberger, MD, MPH
   Marty C. McCafferty, EMT-P, DMT-A
   Daniel A. Nord, BFA, EMT-P, CHT

Communications
   Rick T. Melvin (Cover Design)

DAN America wishes to thank 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 wishes to thank local sheriff, police, emergency medical personnel, Coast Guard, medical examiners, coroners and members of the public who have submitted incident data.

DAN Regions and Regional Coordinators for Hyperbaric Treatment

DAN works with a network of approximately 500 hyperbaric chamber facilities in the United States and around the world, of which approximately 200 provide annual reports on decompression illness (DCI) injuries. The DAN US network is divided into eight regions, each overseen by a Regional Coordinator.

Internal Headquarters and Southeast Region – Alabama, Georgia, North Carolina, South Carolina and Tennessee
Richard Moon, MD
Center for Hyperbaric Medicine and Environmental Physiology, Box 3823, Duke University Medical Center, Durham, NC 27710.

Southwest Region – Arizona, California, Nevada and Utah
Lindell Weaver, MD, FACP, FCP, FCCM
Department of Hyperbaric Medicine, LDS Hospital, 8th Avenue and 'C' Street, Salt Lake City, UT 84143

Northeast Region – Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia and West Virginia
Cynthia Cotto-Cumba, MD and Robert Rosenthal, MD
Department of Hyperbaric Medicine, Maryland Institute for Emergency Medical Services Systems, University of Maryland, 22 S. Greene Street, Baltimore, MD 21201

Gulf Region – Arkansas, Colorado, Kansas, Louisiana, Mississippi, Missouri, New Mexico, Oklahoma and Texas
Keith Van Meter, MD and Randy Springer, CHT
St. Charles General Hospital, 3700 St. Charles Avenue, New Orleans, LA 70115

Midwest Region – Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin and Wyoming
Jeffrey Niezgoda, MD and Stephen Fabus, CHT
Department of Hyperbaric Medicine, St. Luke's Medical Center, 2900 W Oklahoma Avenue, Milwaukee, WI 53215

Northwest Region – Alaska, Idaho, Montana, Oregon and Washington
Neil Hampson, MD and Richard Dunford, MS, CHT
Hyperbaric Department, Virginia Mason Research Center, 952 Seneca Street, Seattle, WA 98101

Pacific Region – Guam, Hawaii and U.S. Territories
Richard Smerz, DO
Hyperbaric Treatment Center, University of Hawaii, John A Burns School of Medicine, 347 N Kuakini Street, Honolulu, HI 96813

Florida and Caribbean Region – Florida and Caribbean Basin
Marc R. Kaiser and Ivan Montoya, MD
Diving Medical Center Mercy Hospital, 3663 South Miami Avenue, Miami, FL 33133

International DAN Offices

DAN America - Dan Orr, MS
6 West Colony Place • Durham, NC 27705 USA
Telephone +1-919-684-2948 • Fax +1-919-490-6630
dan@DiversAlertNetwork.org • www.DiversAlertNetwork.org
Dive emergencies: +1-919-684-8111 (toll) or +1-919-684-4DAN (4326) (collect)

DAN Latin America Emergency Hotline Network - Cuauhtémoc Sánchez, MD
c/o Servicio de Medicina Hiperbarica, Hospital Angeles del Pedregal
Camino a Santa Teresa 1055 Heroes de Padierna, 10700 • Mexico DF Mexico
Daytime Office Telephone +52-55-5568-8082 • Fax +52-55-5568-8083
danmex@hotmail.com
Dive Emergencies for All of Latin America
+1-919-684-9111 (collect; assistance in Spanish and Portuguese)

DAN Europe - Alessandro Marroni, MD
P.O. Box DAN• 64026 Roseto (Te) Italy
Telephone +39-085-893-0333 • Fax +39-085-893-0050
mail@daneurope.org • www.daneurope.org/main.htm
Dive emergencies: +39-06-4211-8685

DAN Japan - Yosihiro Mano, MD
Japan Marine Recreation Association
Kowa-Ota-Machi Bldg, 2F, 47 Ota-machi 4-Chome Nakaku,
Yokohama City, Kagawa 231-0011 Japan
Telephone +81-45-228-3066 • Fax +81-45-228-3063
dan@danjapan.gr.jp • www.danjapan.gr.jp
Dive emergencies: +81-3-3812-4999

DAN Asia-Pacific - John Lippmann
PO Box 384, Ashburton, Victoria 3147 • Australia
Telephone +61-3-9886-9166 • Fax +61-3-9886-9155
info@danseap.org • www.danseap.org
Diving Emergency Services (DES)
DES Australia (within Australia) 1-800-088-200
DES Australia (from overseas) +61-8-8212-9242
DAN / DES New Zealand 0800-4DES111 (within New Zealand)
Singapore Naval Medicine & Hyperbaric Center 6758-1733 (within Singapore)
DAN Asia-Pacific - Philippines +02-632-1077
DAN Asia-Pacific - Malaysia +05-681-9485
DAN Asia-Pacific – Korean Hotline (010) 4500-9113
DAN Asia-Pacific – Pacific Chinese Hotline +852-3611-7326

DAN Southern Africa - Frans Cronjé, MD
DAN-SA Building Rosen Office Park, Cnr Invicta and Third Roads
Halfway House Midrand, South Africa
International admin numbers: Telephone +27 11 312 0512 Fax +27 11 312 0054
Local telephone numbers: Sharecall - 0860 242 242
Faxes: 086 512 9091 (Fax 2 E-mail) FAX DAN (0861 329 326)
mail@dansa.org • www.dansa.org
Dive Emergencies: (within South Africa) 0800-020-111
(outside South Africa) +27-11-254-1112 (accepts collect calls)

1. INTRODUCTION

1.1 The 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 are now available for download free of charge to anyone. It is our hope that wider 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."

Core sections of the report include reviews of Project Dive Exploration (PDE), dive injuries, dive fatalities, and breath-hold incidents. The data described in the 2008 annual report is largely based on events occurring in 2006. There are two exceptions. Summary data through 2007 are included in this introductory chapter. This provides an early snapshot of what will be detailed in the next annual report. The second exception is the dive injuries section, which presents data logged into the Medical Services Call Center (MSCC) in 2007.

Case summaries are a popular tool for reviewing operational practice. Thumbnail reviews are available for dive injuries (Appendix A), dive fatalities (Appendix B), and breath-hold incidents (Appendix C). A review of the sources of PDE data is found in Appendix D.

A list of publications and materials authored or co-authored by DAN staff and affiliated investigators in 2007 and 2006 appear in Appendix E. These include peer-reviewed research reports (primary literature), review articles (secondary literature), textbooks and book chapters (tertiary literature), editorials (opinion pieces requested by journals), papers published in 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. New for this report is the addition of abstracts from peer-reviewed research and review articles when available.

Web-based training will increase in importance as a 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 F.

1.2 Data Collection at DAN

The data discussed in this report provides a montage of events occurring in the recreational diving community, but it does not represent the complete range of activity or incidents associated with diving. The report includes only data made available to DAN and, in most cases, only data that can be followed up with a manageable effort. The majority of sections, therefore, are limited to residents or citizens of the United States or Canada. The exception to this is the breath-hold incident database, which currently captures cases from wherever they are identified worldwide. Difficulties in collecting additional data from international cases may prompt a shift in focus or a strengthening of international collaborations in the future.

Figure 1.2-1 depicts the annual record of emergency calls, information calls and e-mail requests for information to DAN Medical Services since DAN started in 1981. Emergency calls and e-mail inquiries continue to rise gradually, slowly overtaking calls to the information line as the primary form of contact.
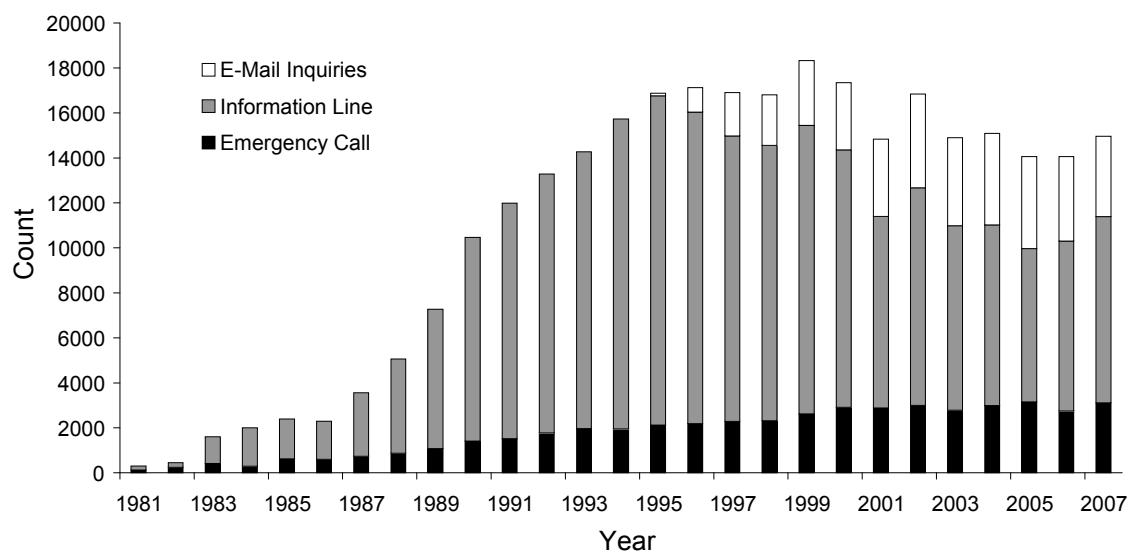

Figure 1.2-1 Emergency calls, information calls and e-mail requests for information

Project Dive Exploration (PDE) is a prospective observational study of recreational diving dating from 1995. The cumulative history of PDE data collection is depicted in Figure 1.2-2. The data capture for 2006 was 14,931 dives, representing 2,722 dive series by 1,081 divers. Participants ranged from 13 to 76 years of age, with 63% being male. Forty percent reported at least one chronic medical condition. The vast majority of the dives (almost 99%) were described as uneventful exposures. Procedural problems were reported in 1.3% of dives, with the most common involving buoyancy (0.9%) and rapid ascent (0.3%). The most commonly reported equipment problems involved dive computers (1.3% of dives). There were three cases of decompression sickness, thus making an annual incidence of 2.0 cases per 10,000 PDE dives. The most common non-decompression illness injury resulted from ineffective equalization (2.3% of dives). Details are found in Section 2.
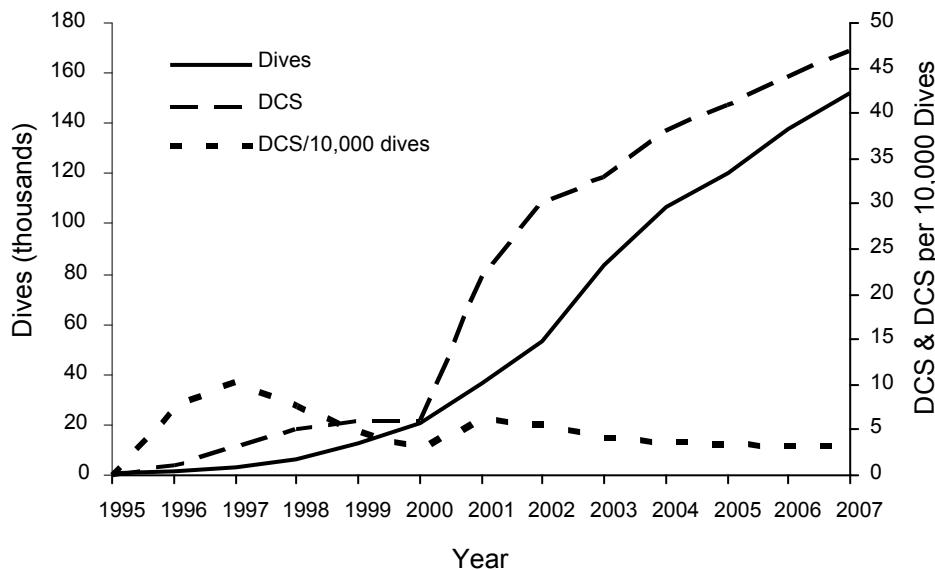
Figure 1.2-2 Cumulative Project Dive Exploration progress

Information on dive injuries is captured through the MSCC. A total of 7,872 calls or e-mails were logged into the MSCC system by DAN medics during the 2007 calendar year. There were 5,365 information calls and 2,507 calls regarding actual cases. The most common working diagnoses of the reported injuries were decompression sickness (DCS) and barotrauma (both at 26%), non-diving related (14%), envenomation (six percent), and trauma (two percent). DCS included a wide array of symptoms. Barotrauma most commonly involved the middle ear (50%), the lungs (15%), and the sinuses (14%). Details are found in Section 3.

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 through 2007 appears in Figure 1.2-3. The 2006 collection includes 75 scuba fatalities investigated by DAN. The most common medical history issue known for the cases was heart disease (38%). The majority of the victims were classed as overweight or obese by body mass index (73%). The primary disabling injuries identified were drowning (48%), arterial gas embolism (33%), and cardiac-related conditions (28%).
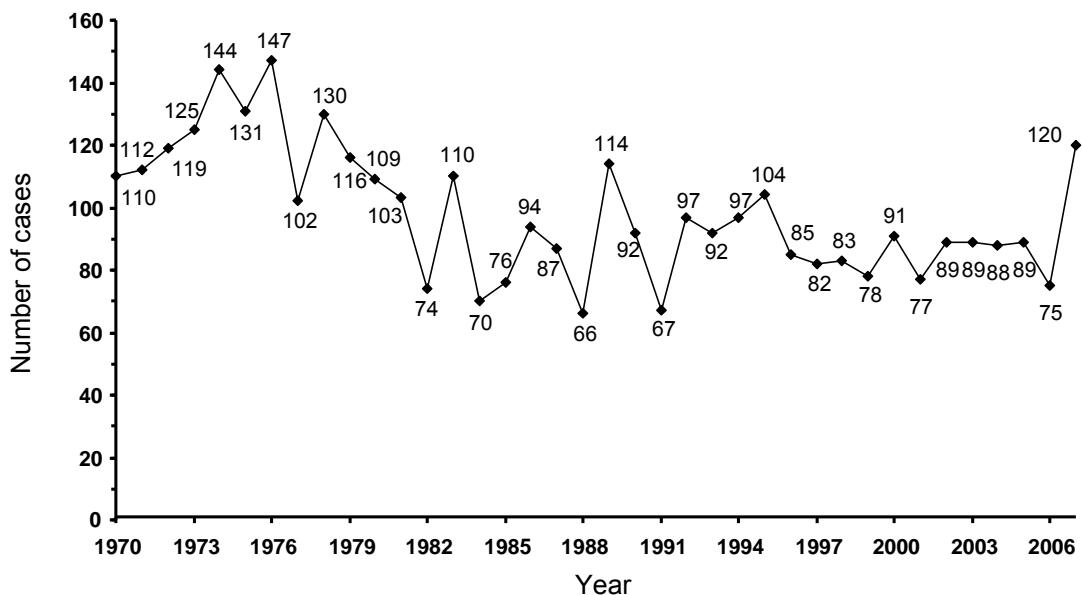
Figure 1.2-3 Annual record of U.S. and Canadian diving fatalities

Discussion of breath-hold diving incidents was added to the annual report in 2005. Breath-hold cases are not included in the compressed diving events depicted in Figure 1.2-3. Figure 1.2-4 represents the breath-hold cases recorded at DAN since 1993. The low numbers in the early years reflect the fact that these data were not actively sought. The visible increase seen in 1997 likely reflects improved accessibility to reports available through the Internet. The increase in the case count from 2006 may represent an increase in the absolute number of incidents and/or an increase in reporting resulting from greater community awareness.

The 2006 collection includes 40 breath-hold incidents reported throughout the world, but with more than half occurring in the U.S. The majority of cases identified (85%) involved fatal outcomes; understandable since serious cases receive more public attention. Activities being conducted ranged from casual snorkeling to competitive training. The most common problems believed to be responsible for the cases were personal health issues (33%) and blackout (30%). Many blackouts likely resulted from voluntary practices to increase breath-hold time. The next most common problems were interactions with boats (13%) and with animals (13%).
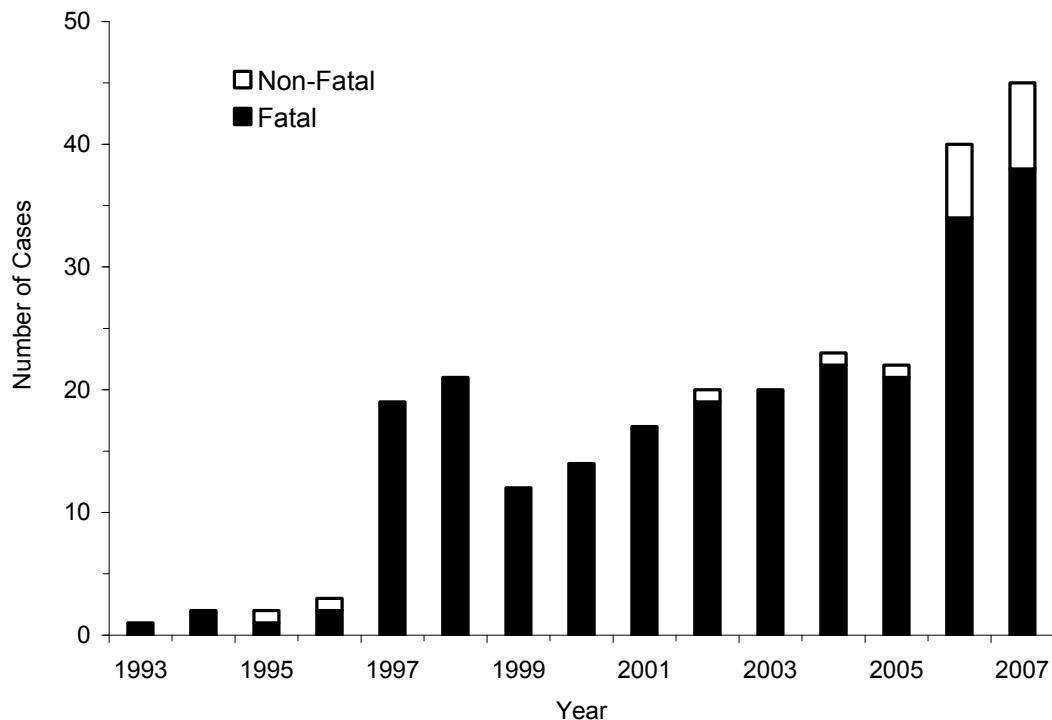
Figure 1.2-4 Annual record of breath-hold diving incidents

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 ensure that he or she is ready for whatever diving is to be undertaken. This requires the maintenance of 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 assist in the physical preparedness; appropriate initial and continuing training and education can address knowledge and physical competence issues.

The initial evaluation for psychological fitness is part of the medical review for clearance to dive. Maturity and sound judgment are critical. A common hazard in diving can be created when an individual is encouraged to dive by someone else who may be more enthusiastic, comfortable or capable. It is critical for each person to understand his or her strengths and limitations and choose accordingly when and where to participate. Activity must remain within personal comfort limits and employ appropriate equipment and team support. The actual conditions at the time of the dive - of divers, equipment and environment - need to be critically appraised to help ensure problem-free activity.

The last two paragraphs cover a lot of ground. The diving enthusiast will commit a great deal of time mastering the physics, physiology, equipment and environment to be fully prepared. Reading material like this annual diving report is part of the ongoing process of readiness. We learn a great deal through our mistakes, but we can save ourselves from a lot of 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 be easily broken at several points during its development. Learning to identify unsafe practices and patterns that can escalate risk can help ensure that unmanageable conditions do not arise. The tally of incidents described in this report should remind you that accidents can occur, and that preparation is essential.

The most important form of readiness will often be flexibility, both mental and physical. We can memorize rules and practice skills until our responses are automatic, but there is always the chance that some surprise, small or large, will put us off balance. Case summaries can be a powerful tool, providing an opportunity to safely place the reader into a wide array of situations. The scenario can stimulate the important 'What if?' thoughts that can help you to critically evaluate your equipment, practices and decision making ability.

1.4 Personal Fitness Maintenance

Surprisingly little is known of the physical fitness of the typical recreational diver (Pollock, 2007). The major challenge is finding simple measures to generate a comprehensive picture with limited face-to-face contact. Many readers will be familiar with body mass index (BMI), a measure frequently used as a predictor of body composition. BMI is based on the relationship between height and weight, and as such, may not be a good predictor of body composition. Individuals with a disproportionate amount of muscle mass, for example, are penalized. Practically, however, BMI is a reasonable tool to assess trends on a population scale, since increases are more likely associated with increasing body fat than with increasing muscle mass.

Data gathered by DAN in recent years indicate that high BMI values are common in persons involved in incidents. The measures are included where available to allow further evaluation of this trend. As a point of personal awareness, BMI is a reasonable benchmark to monitor. Tracking your own score can help you keep your personal fitness efforts focused. The 'normal' (optimal) range is 18.5-24.9 $kg \cdot m^{-2}$. The trap to avoid is the slow upward creep that often accompanies aging. Calculating your waist-to-hip ratio (WHR) will help to determine whether or not BMI is a good predictor for you. WHR is computed by dividing the circumferences of your waist at the narrowest point by that of your hips at the widest point. Optimal WHR values are ≤0.8 for men and ≤0.7 for women. Persons with relatively high BMI values and low WHR values may have disproportionate amounts of muscle tissue, which also increases BMI, but in a good way.

While it is understood that physical fitness is important for divers, the evaluation of physical fitness is generally minimal for recreational divers. A recent review of physical fitness standards and recommendations for scientific and professional divers may be of interest (Ma and Pollock, 2007). Those wanting to evaluate their own fitness should start with key areas of aerobic capacity and strength. Swimming performance is not a good predictor of aerobic capacity since it is so skill dependent. The ability to run three miles non-stop is a better predictor of reasonable capacity for those who can and do run. Strength could be measured through functional tests of lifting tanks or climbing ladders and/or steps while wearing tanks and weight belts but performance standards are not available. Alternatively, strength can be evaluated with standard normative tests such as those for push-up performance (Table 1.4-1). The 'excellent' category in your current or the next younger age-group is a great target.

Table 1.4-1 Push-Up Endurance[1] (Pollock et al., 1978)

Classification	Age (years)				
	20-29	30-39	40-49	50-59	60-69
Men (count)					
Excellent	>54	>44	>39	>34	>29
Good	45-54	35-44	30-39	25-34	20-29
Average	35-44	25-34	20-29	15-24	10-19
Fair	20-34	15-24	12-19	8-14	5-9
Poor	<20	<15	<12	<8	<5
Women (count)					
Excellent	>48	>39	>34	>29	>19
Good	34-48	25-39	20-34	15-29	5-19
Average	17-33	12-24	8-19	6-14	3-4
Fair	6-16	4-11	3-7	2-5	1-2
Poor	<6	<4	<3	<2	<1

[1] The military push-up is required for this test; straight body with a range of motion from fully extended to elbows bent beyond 90 degrees. Starting from the upright position with the elbows fully extended, the push-ups are done at a steady pace until they can no longer be continued.

Maintaining a solid knowledge base and sound medical and physical fitness will help ensure your diving safety.

1.5 REFERENCES

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

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

Pollock NW. Aerobic fitness and underwater diving. Diving Hyperb Med. 2007; 37(3): 118-124.

Pollock ML, Wilmore JH, Fox SM. Health and Fitness through Physical Activity. New York, NY: John Wiley & Sons, 1978.

2. PROJECT DIVE EXPLORATION

2.1 PDE in 2006

Project Dive Exploration (PDE) collected data from 14,931 dives, 2,722 dive series and 1,081 divers during 2006. The total number of dives logged by PDE through 2006 was 135,546. Figure 2.1-1 shows cumulative data collection from 1995-2006. A summary of PDE data collected by DAN interns and independent field research coordinators (FRCs) is found in Appendix 5. 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).
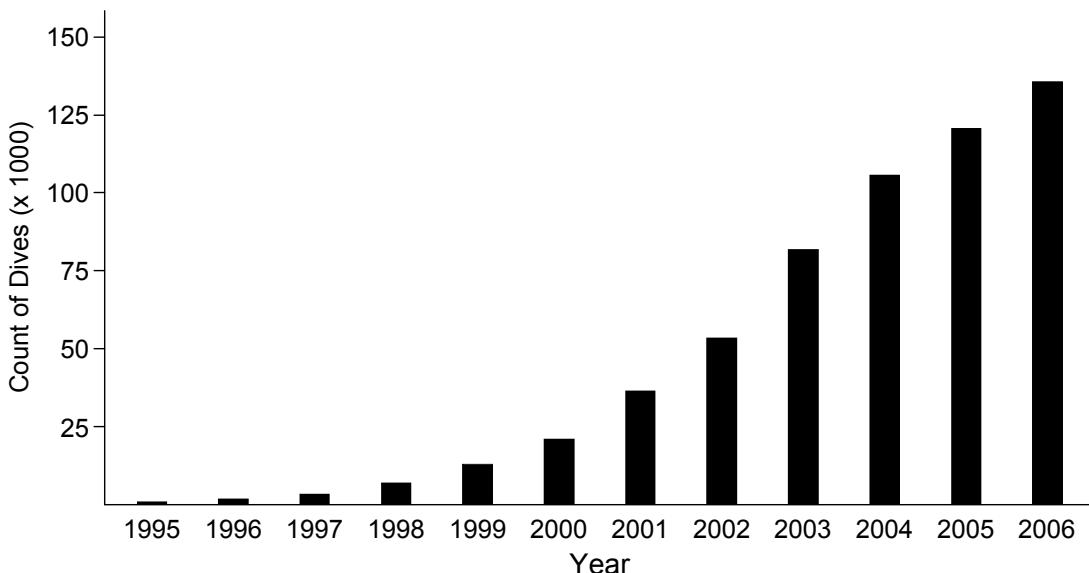
Figure 2.1-1 Cumulative number of PDE dives collected from 1995-2006

Table 2.1-1 shows dives in the groups that contributed PDE data from 2002-2006. DAN interns collected the largest amount of data for the last two years. The participation of independent divers and recreational dive professionals (RDP) has increased and they have become the second leading group in contributing dive data. The decrease in dives submitted in 2005 and 2006 compared to 2003 and 2004 is due to a reduction of nearly 10,000 dives from Nekton Cruise boats starting with 2005.

Table 2.1-1 Sources of PDE data

Source	2002	2003	2004	2005	2006
DAN Interns	4,878	6,449	3,939	5,545	6,292
Independent and RDP[1]	2,794	4,796	5,521	4,638	3,340
Liveaboard Collection Centers	6,593	13,046	12,040	2,874	2,688
Scapa Flow, Scotland	2,795	2,476	2,412	2,001	2,886[2]
Total	17,060	26,767	23,912	15,043	14,967

[1] Recreational dive professionals
[2] Includes 765 dives collected by DAN interns placed at Scapa Flow

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, gender, certification level, number of years since certification, chronic and acute medical conditions and an assessment of body fat.

The 1,081 diver volunteers participating in the 2006 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. Males (63%) outnumbered females 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 females was relatively flat across a 30-59 year span. Divers 50 years of age and older represent 26% of PDE volunteers, similar to the previous year.
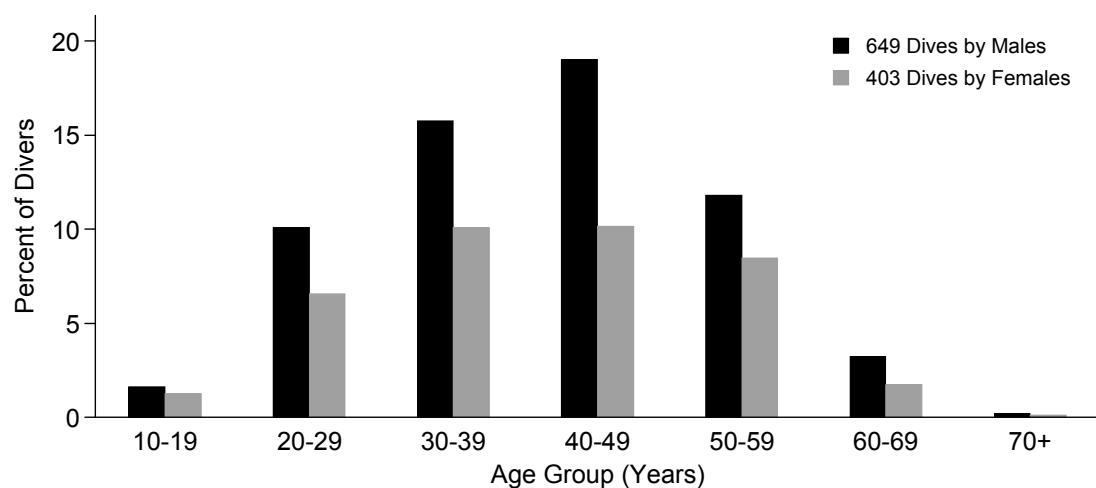

Figure 2.2-1 Age and gender of PDE divers (n=1,052)

Forty-four percent of PDE divers held 'recreational' certifications at basic, advanced, specialty or rescue levels and 28% held leadership qualifications of divemaster or instructor (Figure 2.2-2). Five percent held cave or technical certification. Students comprised 21% of volunteers, a four percent increase over the previous year. Students and divers at the recreational level represented 65% of volunteers while contributing 56% of dives to the PDE database, indicating that divers with leadership certifications contributed a higher proportion of dives per diver.


Certification Level
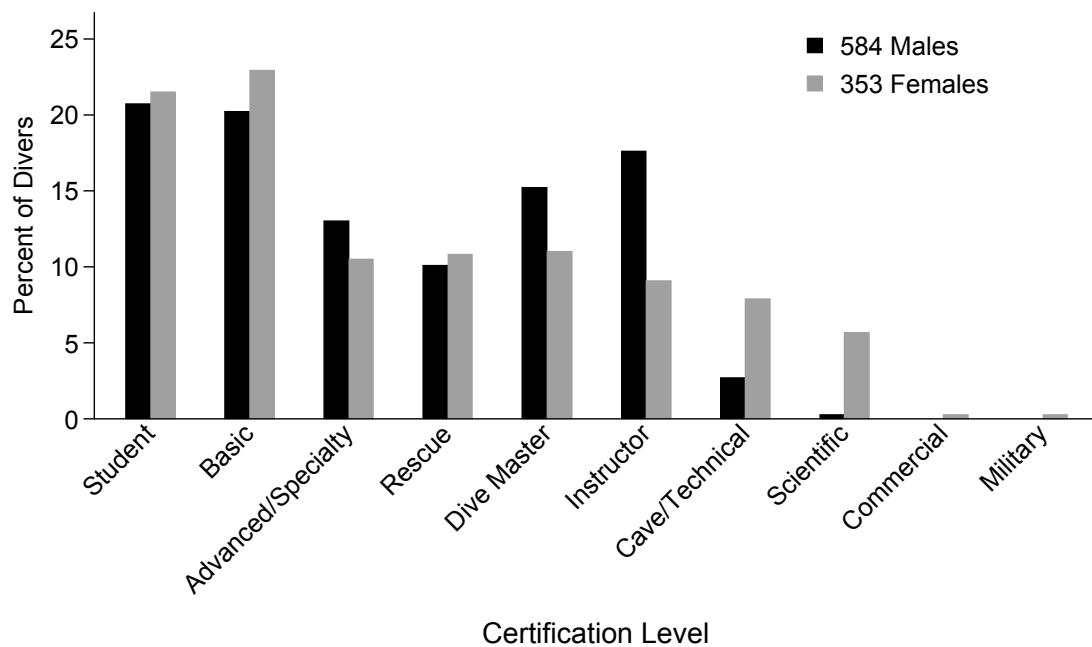
Figure 2.2-2 Certification level for males and females (n=937)

Thirty-one percent of volunteers were within five years of certification. This group has declined in size from about 42% recorded in 1998 (Table 2.2-1). Divers with more than 10 years since certification increased from 26% in 1998-1999 to >40% in 2005-2006, showing a 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
1-5	42.3	42.8	46.3	42.6	40.8	36.3	39.0	34.5	30.9
6-10	25.3	23.7	21.0	19.4	18.4	20.5	23.4	25.4	27.6
>10	26.7	26.2	29.3	26.3	30.1	35.6	37.6	40.2	41.5

Forty percent of all volunteers reported at least one chronic medical condition. As in previous years, allergies, high blood pressure, and ear or sinus problems (27% in all) were the most common chronic conditions (Figure 2.2-3). Interestingly, divers reporting psychiatric problems have increased over time from one percent and the tenth most frequent in the 2003 data to three percent and the fourth most frequent in 2006, while conditions typically associated with aging were unchanged (heart disease) or declining (diabetes) over the same period.
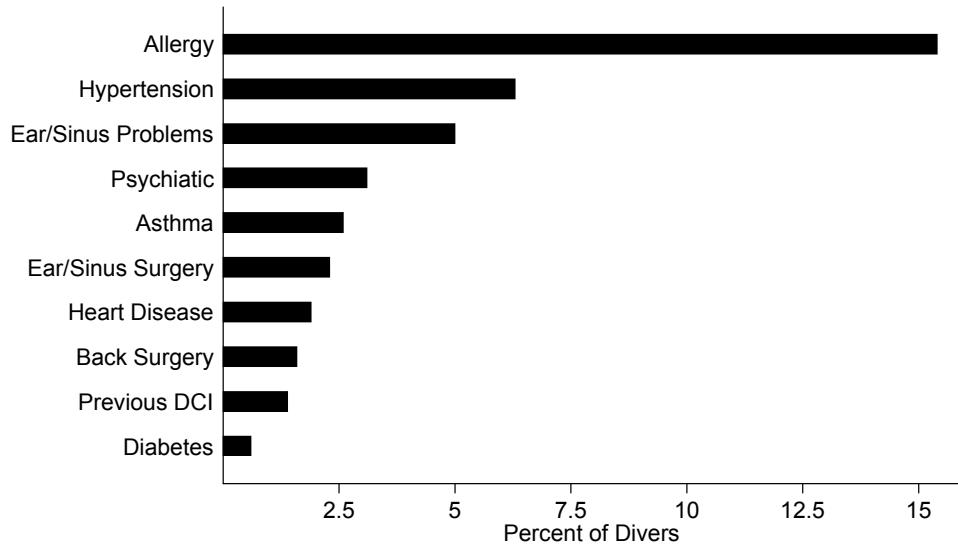
Figure 2.2-3 Chronic health conditions reported by PDE volunteers (n=1,081)

Acute health conditions were reported in 30% of volunteers during at least one dive. Figure 2.2-4 shows that 13% of divers reported seasickness and 10% of divers reported an episode of orthopedic problems (joint, muscle or back pain). Common cold-like conditions were reported by just over one percent of divers while the use of decongestants was reported by five percent of divers reflecting, possibly, a prophylactic use of decongestants.
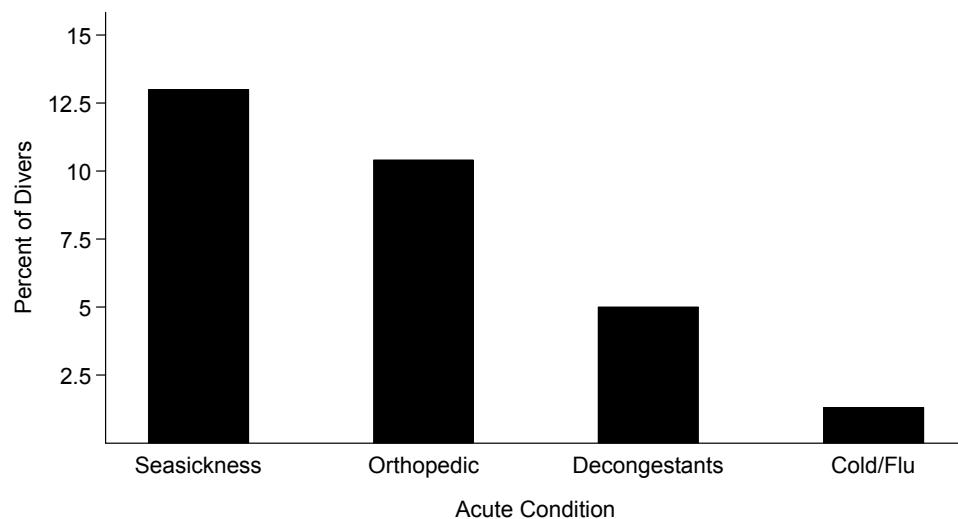
Figure 2.2-4 Acute health problems before diving reported by PDE divers (n=1,081)

Body mass index (BMI) is a simple population estimator of fatness. As seen in Figure 2.2-5, both male and female PDE volunteers showed an increase in BMI with increasing age (p<0.01). However, the correlations were relatively weak (0.250 and 0.152 for males and females, respectively). The majority of the females in this group fell into the normal range (18.5-24.9 kg*m^{-2}) while most males were in the overweight range (25.0-29.9 kg*m^{-2}). Sixteen percent of male PDE volunteers and 12% of females fell into the obese range (≥30.0 kg*m^{-2}) (Figure 2.2-6). National surveys have shown 31% of males and 33% of females in the obese range (Ogden et al., 2006). PDE volunteers show more favorable BMI levels than the national population trends, possibly resulting from more active lifestyles.
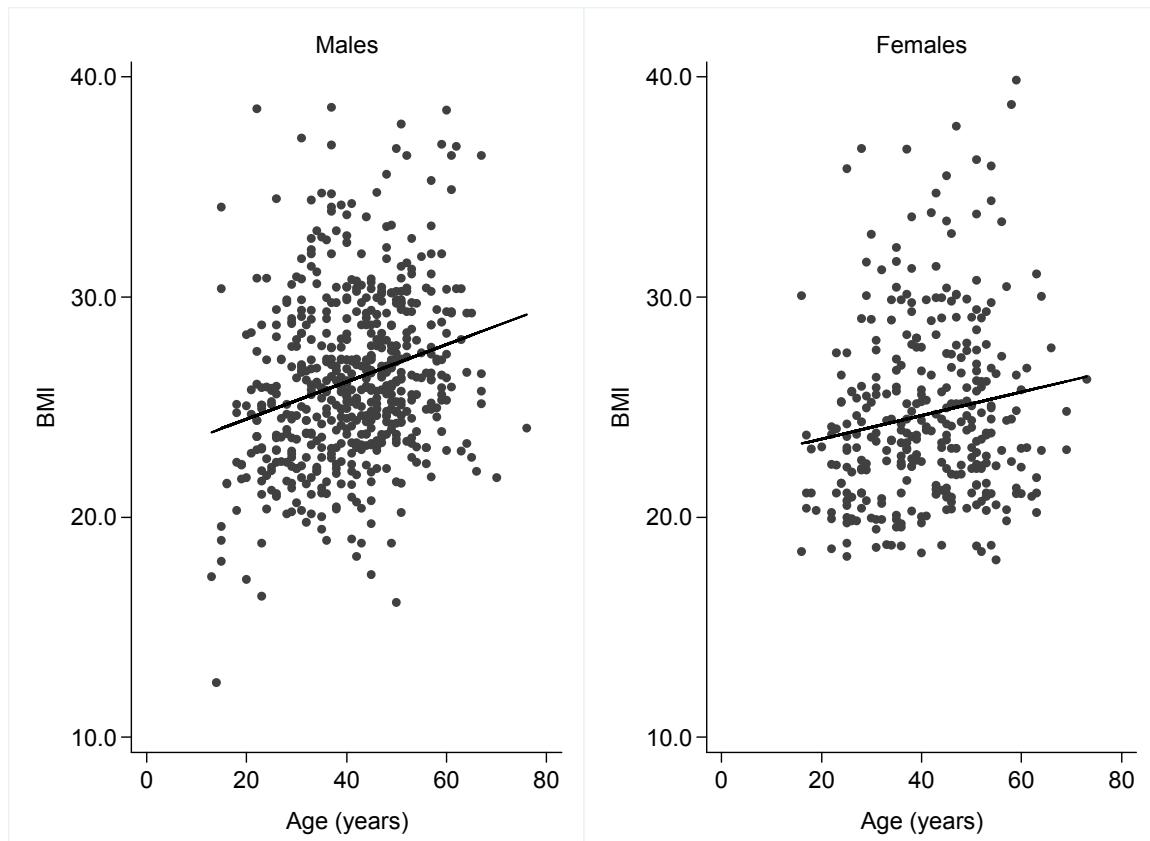
Figure 2.2-5 Distribution of body mass index (BMI [kg*m^{-2}]) in PDE divers by age and gender (n=898)
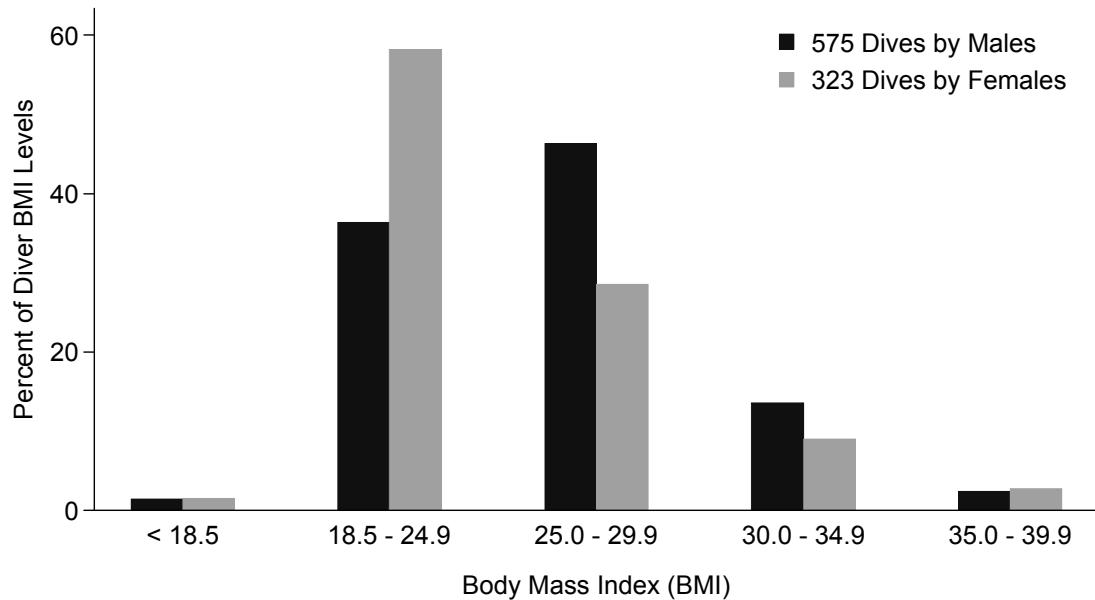
Figure 2.2-6 Distribution of body mass index BMI [kg*m^{-2}]) in PDE divers by gender (n=898)

2.3 Dive Conditions

This section reviews the diving environment, dive platform, breathing apparatus, reasons for diving, thermal protection, subjective thermal comfort, and subjective work rate.

Ninety-six percent of PDE dives were collected in saltwater while a little over two 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.) Less than one percent of dives (n=99) were in caves or caverns. Forty-one percent of dives were from dayboats (small) and 37% from liveaboard boats (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 two percent used rebreathers. Eighty-seven percent reported sightseeing as the purpose of the dive and seven percent were conducting research, a small but growing segment of the volunteer dives.
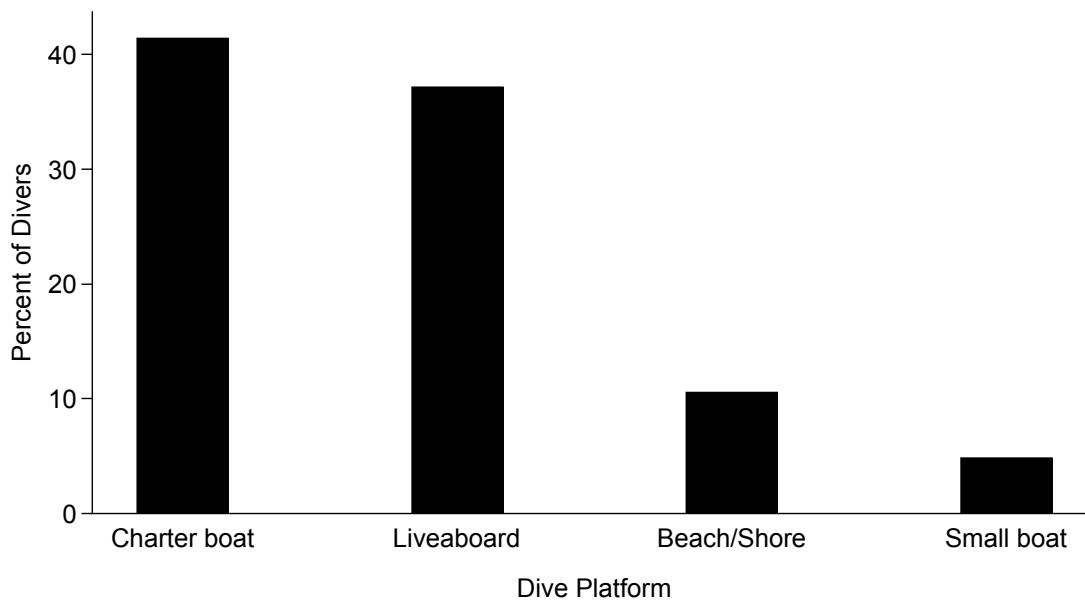
Figure 2.3-1 Percentage of the PDE dives by dive platform (n=14,044)

Thermal protection depended on the geographic area. Forty-seven percent used wetsuits, 31% drysuits, and 22% lycra, diveskin or swimsuit. Most divers indicated they were comfortably warm (Figure 2.3-2). Scapa Flow divers reported feeling hot on 19% and cold on 13% of dives. Beach divers reported 38% of dives as cold and 26% as very cold.
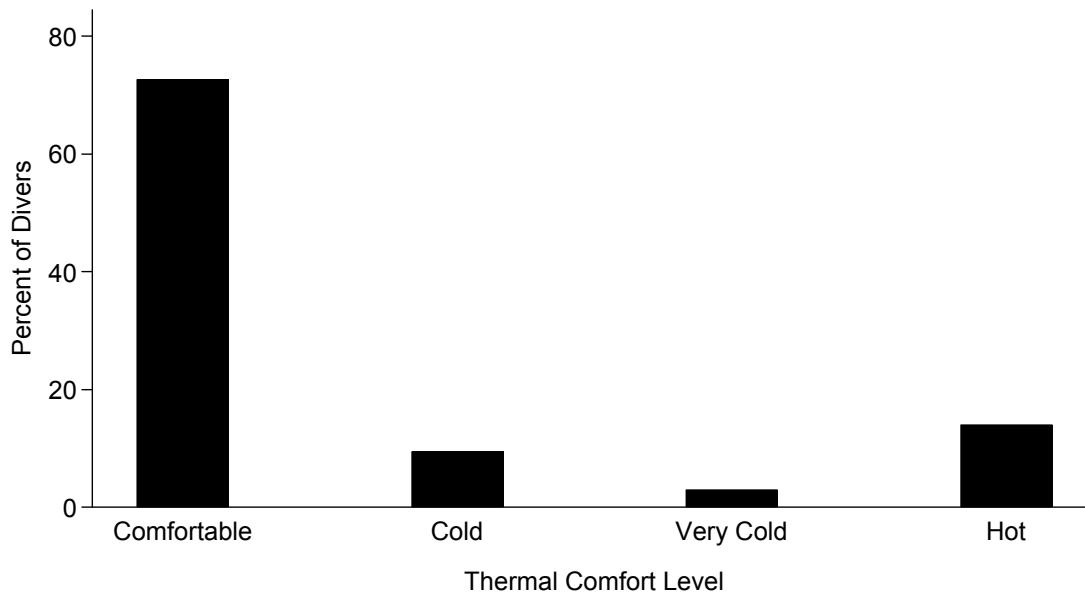
Figure 2.3-2 Subjective thermal comfort of PDE divers by subgroup (n=12,223)

More than 81% of PDE divers reported doing light work and 16% reported moderate or heavy work (Figure 2.3-3). Beach divers reported a higher proportion moderate or heavy work than Scapa Flow divers (Chi square p<0.01).
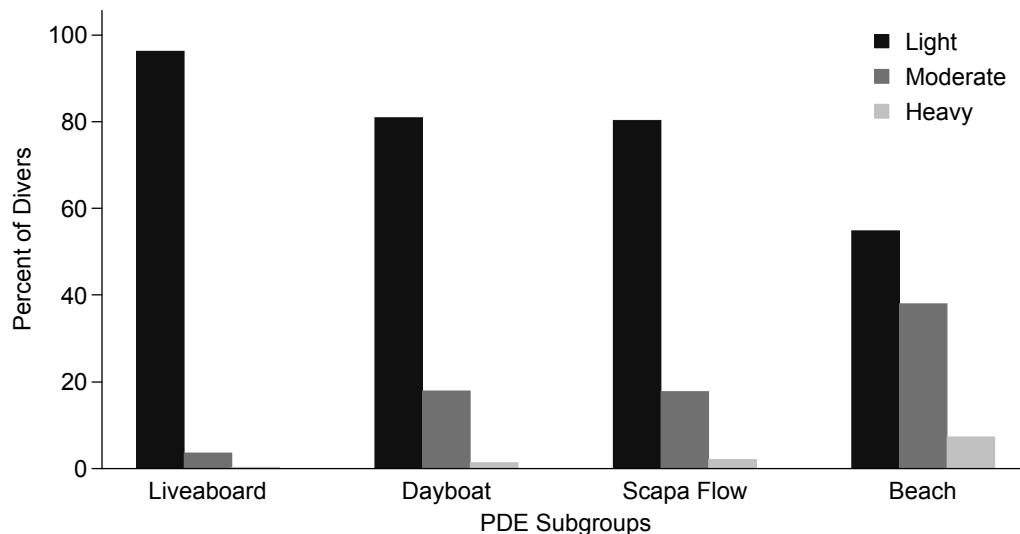
Figure 2.3-3 Reported work load in PDE divers by subgroup (n=12,218)

2.4 Dive Profiles

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

Air as the breathing gas was reported for 68% of PDE dives and nitrox (a nitrogen-oxygen mix with greater than 21% oxygen) for 28%. Heliox (a mix containing helium and oxygen) or trimix (helium, nitrogen and oxygen) was reported for 2% and 'other' for 2%.

This report defines a dive series as one or more dives separated by a surface interval no greater than 24 hours. This does not necessarily equate to standard definitions for repetitive dives. It is possible that a multi-day series could include a dive-free span of greater than 24 hours and be included here as a separate series. Forty-nine percent of the dive series were multi-day (Figure 2.4-1). Two dives per day was the most common pattern for either single-day series (65%) or a multi-day series (49% for multi-day dives of six days or less).
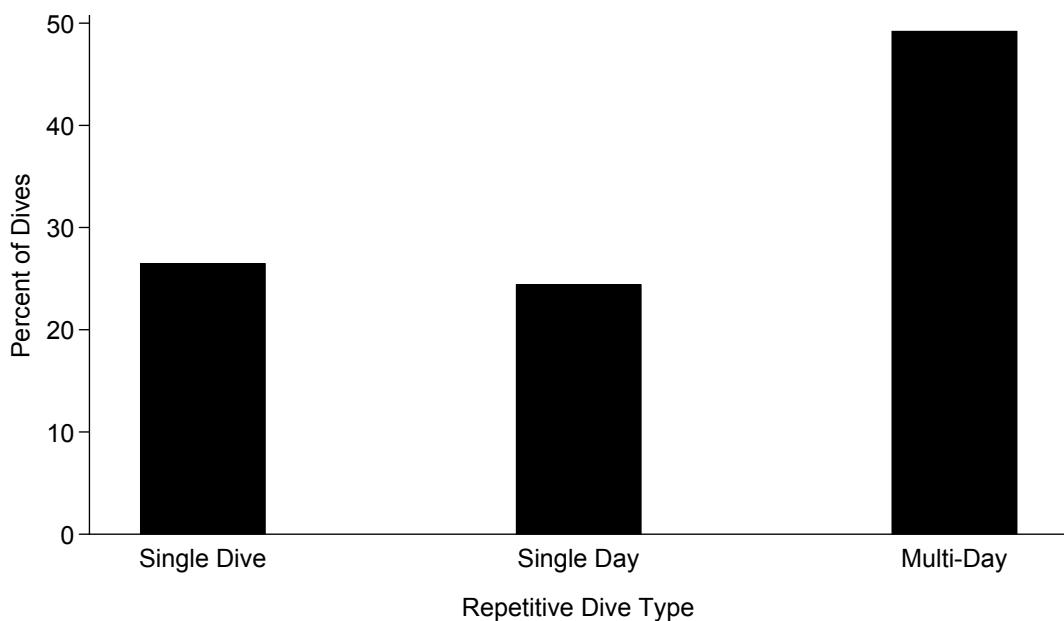
Figure 2.4-1 Repetitive dive type for PDE dive series (n=2,722)

Fifty-one percent of all dive series were single-day events (Figure 2.4-2). Thirty-four percent of all series totaled two to four exposures (Figure 2.4-3). The previous trend toward fewer multi-day dive series in favor of more single dives and single-day diving seen over several years was not evident in the 2006 data. The number of six day series and number of dives in a series with 10-19 dives both increased by about five percent.
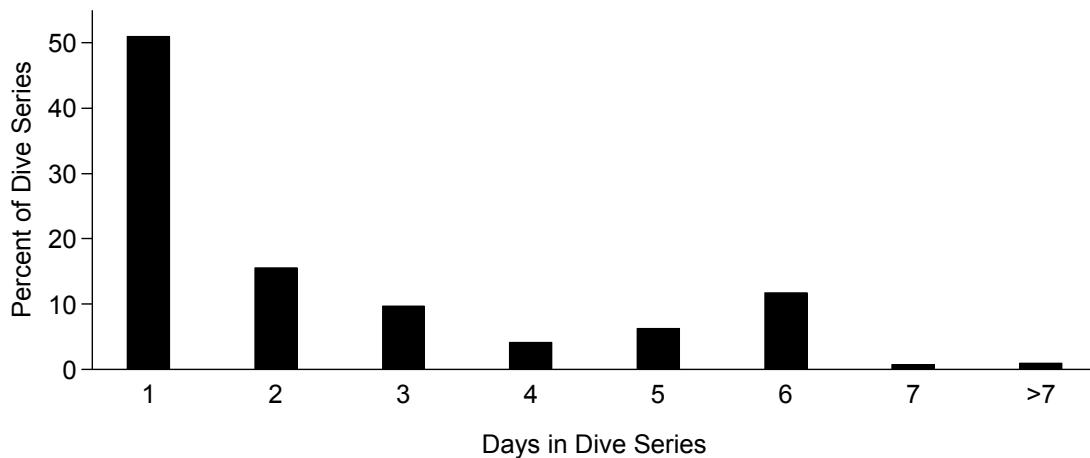
Figure 2.4-2 Number of days in dive series by PDE divers (n=2,721)
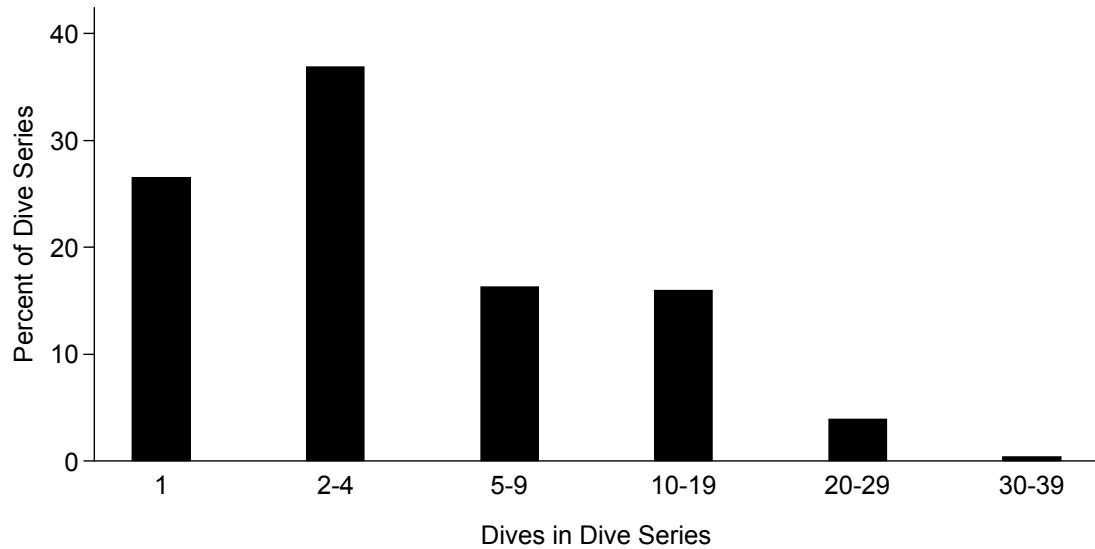
Figure 2.4-3 Number of dives in a series by PDE divers (n=2,721)

Thirty percent of the dives were to maximum depths >90 ft (27 m) compared to 20% in 2004 and 27% in 2005. The total number of dives by females increased from 31% in 2005 to 37% in 2006 (Figure 2.4-4). As shown in Figure 2.2-2, female divers contribute a large portion of the dives in the scientific and cave/technical categories, a trend not seen in earlier years.
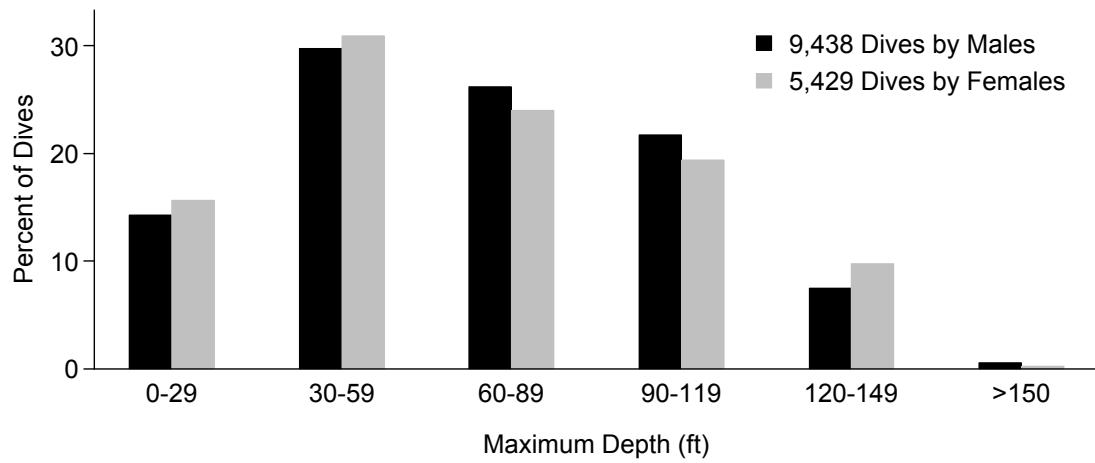
Figure 2.4-4 Maximum depth by males/females in PDE dives (n=14,486)

Seventy-three percent of dive series were made up of multiple dives. When multi-dive series are grouped by the maximum depth in the series, the mean of the maximum depth always

exceeded the mean of the last dive depth (t test p<0.05) (Table 2.4-1), indicating that the last dive was typically not the most aggressive in the series.

Table 2.4-1 Deepest and last dive depth by PDE divers (n=1,976)

Maximum depth of series	Number of series	Mean maximum depth		Mean last depth	
(ft)		(ft)	(m)	(ft)	(m)
0-29	179	19	6	18	6
30-59	190	48	15	39	12
60-89	470	78	24	58	18
90-119	766	104	32	61	19
120-148	364	136	42	92	29
>150	7	303	95	138	43

There was an apparent progressive decrease in the mean maximum depth with successive repetitive dives (Figure 2.4-5). In a two-dive repetitive series, the reduction in mean maximum depth was statistically significant (Spearman rank coefficient p<0.01). However, the relationship between the mean maximum depths of the first dive and successive repetitive dives was not significantly different in all series tested. For example, in a four-dive repetitive series, the mean maximum depth of the last dive was less than that of the first dive but not statistically significant due, perhaps in part, to a few of the last dives taken to deep exposures.
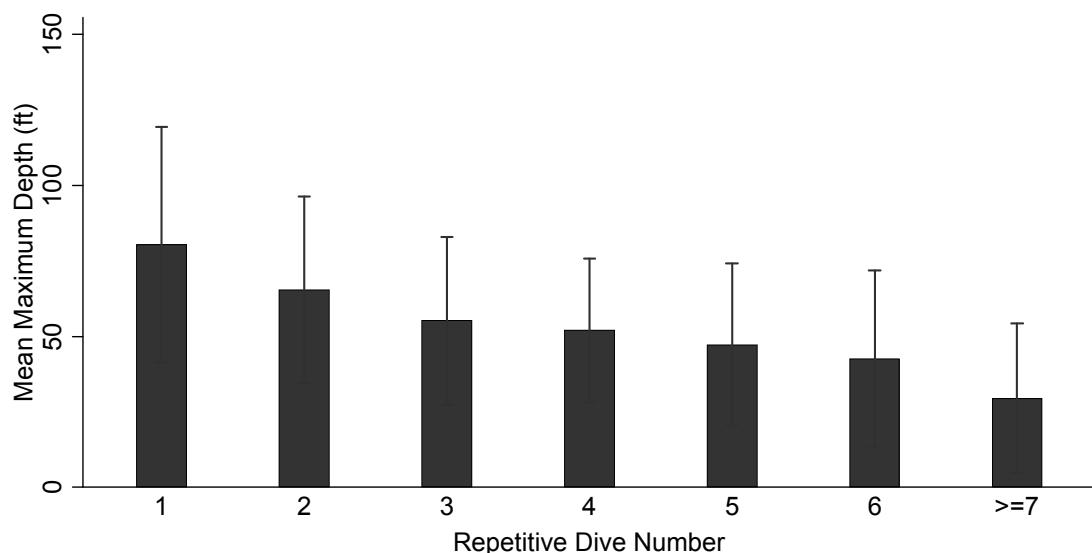
Figure 2.4-5 Mean (with standard deviation) maximum dive depth by repetitive dive number (n=14,492)

Scapa Flow dives were dayboat dives on wrecks with deeper depth distributions than other dayboat dives (Figure 2.4-6).
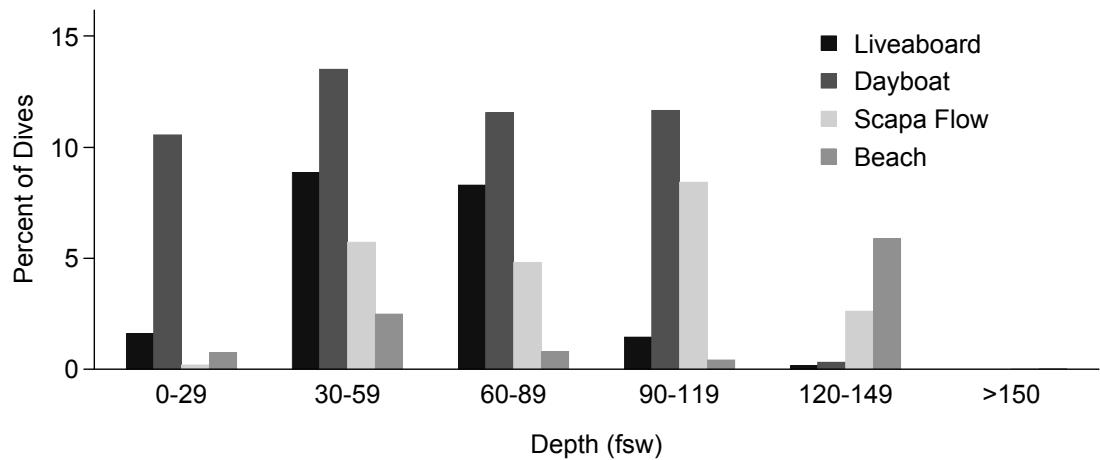
Figure 2.4-6 Distribution of dive depths among PDE subgroups

Dive computers were used to control the dive plan in 79% of the PDE dives. Ten percent reported using tables and nine percent followed no plan (Figure 2.4-7).The pattern in 2006 showed little change from the previous year.
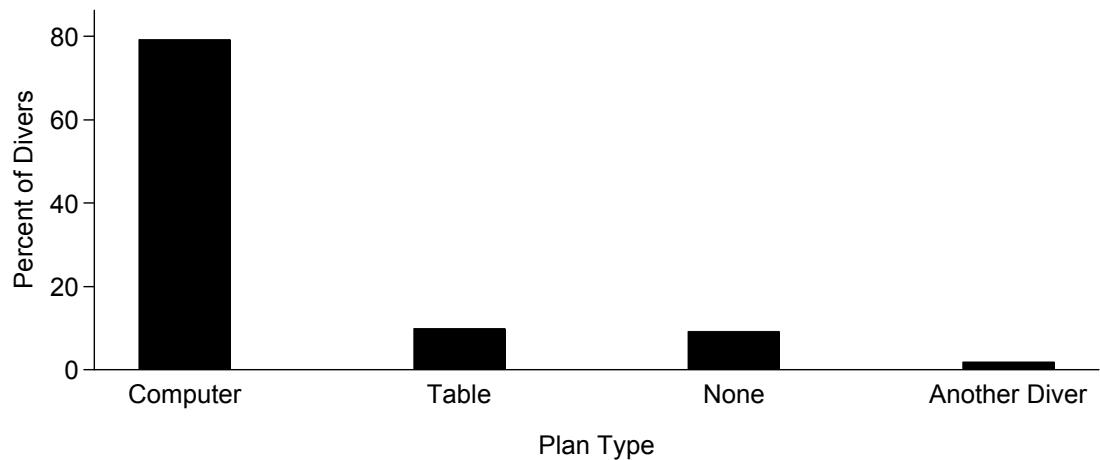
Figure 2.4-7 Dive plan method used by PDE divers (n=14,432)

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 reports by PDE volunteers of events, symptoms, and signs in 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 of 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 events were reported 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). The perceived severity index 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 11,869 responses concerning the dives procedural characteristics, 11,709 (98.6%) divers reported an uneventful exposure. Procedural problems were reported in 160 dives (1.3%) and are shown in Figure 2.5.1-1. The most common procedural incidents were buoyancy problems (0.9%) followed by rapid ascent (0.3%). The remaining procedural incidents, out-of-air, shared air and missed or omitted decompression, each represented a reported frequency of less than one-tenth of one percent.
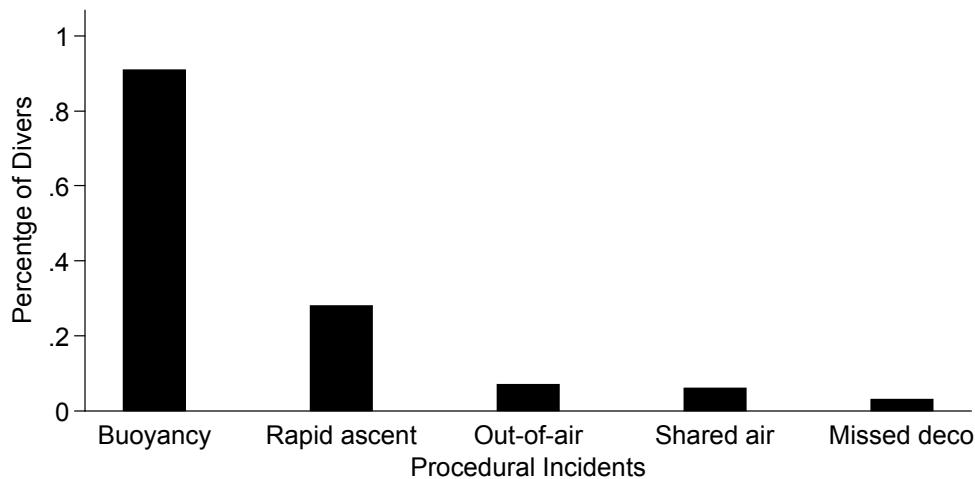
Figure 2.5.1-1 Procedural Problems in PDE dives (n=11,869)

Table 2.5.1-1 summarizes a total of 480 equipment problems of the 11,764 PDE reports received (4.1%). Dive computer issues were the most common described, replacing face mask problems as the most common issue in the previous three years. The following incidents were of note under the 'other' category although none were associated with injury (tank fell out of harness, suit leaked badly, and low pressure hose for suit burst on surface)

Table 2.5.1-1 Percent of PDE dives with reported equipment problems (n=11,764)

Equipment problem	Frequency	Percent
Computer	157	1.33
Face mask	73	0.62
Fins	65	0.55
Thermal protection	57	0.48
Buoyancy compensator	42	0.36
Regulator	19	0.16
Decompression reel	10	0.09
Weight belt	9	0.08
Breathing apparatus	8	0.07
Mouthpiece	4	0.03
Depth gauge	2	0.02
Tank valve	1	0.01
Pressure gauge	1	0.01
Other	32	0.27

Rapid ascent with missed decompression

This 37-year-old, male diver, first certified in 1992 reported over 300 dives in the preceding five years. During the first dive of the third day of this series, he had a rapid ascent and missed a five minute decompression stop at 10 fsw (3 msw) at the end of a dive to 141 fsw (43 msw) for a 25 minute underwater time (Figure 2.5.1-2). He did not experience any symptoms but, nevertheless, received oxygen for 30 minutes on the boat. He did not dive again until the fifth day of the series. The conditional probability for DCS (P_{DCS}) for this dive was 1.03%. P_{DCS} estimates the likelihood that DCS will occur given the time-depth profile of the previous profile including the residual effects of all prior exposures to depth since the last 12 hour surface interval.
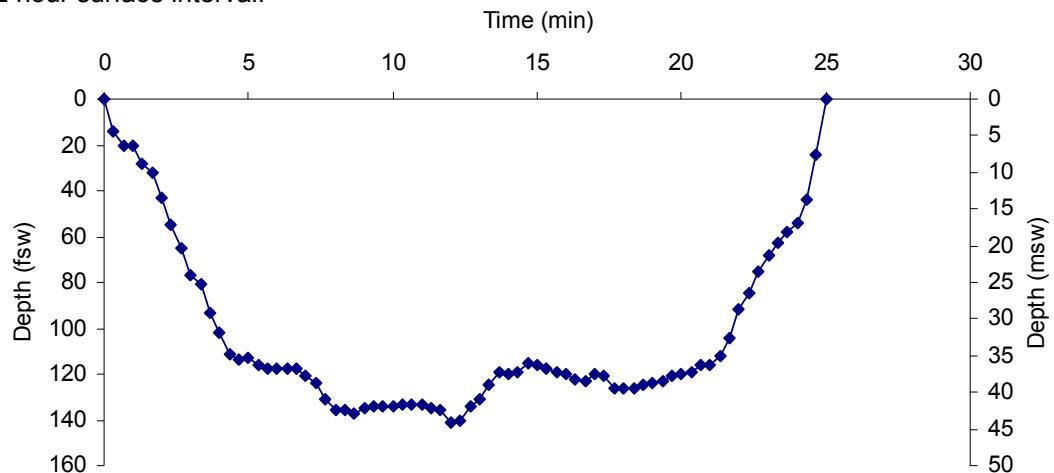
Figure 2.5.1-2 Dive profile containing rapid ascent and omitted decompression

2.5.2 Non-DCI Injury or Symptoms

The most frequent non-DCI injury reported was related to ear equalization (n=290). Seasickness, transient vertigo and headache occurred in less than one percent of dives (Figure 2.5.2-1).
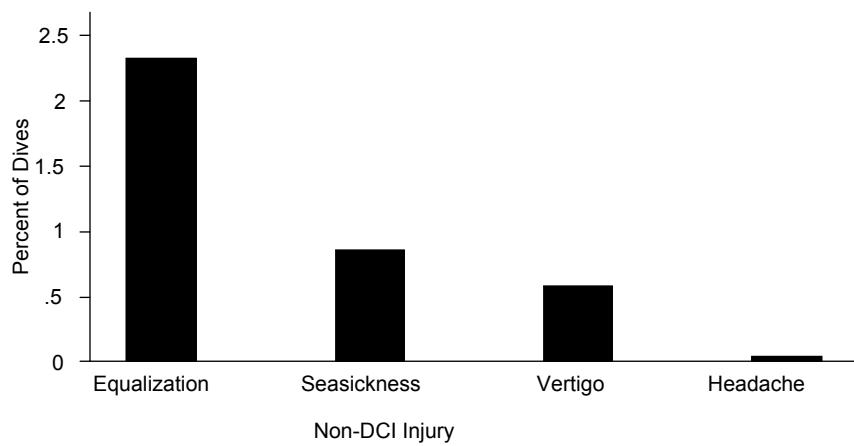
Figure 2.5.2-1 Non-DCI injury in PDE dives (n=12,486)

2.5.3 Ambiguous cases

Case 1. Pain in right shoulder

This 31-year-old diver, with no previous history of DCS, had eight years of experience, completing an estimated 75 dives per year. In this series, he carried out nine wreck dives in five days (Table 2.5.3-1).

Table 2.5.3-1 Summary of a four day, nine dive series

Day sequence	Dive sequence	Surface interval (min)	Maximum depth (ft [m])	Dive time (min)	Breathing gas	Deco gas	P_{DCS} (%)
1	1		54 (16)	57	air	same	0.31
1	2	116	49 (15)	41	air	same	0.18
2	1		106 (32)	50	EAN 27	same	0.93
2	2	137	83 (25)	48	EAN 22	same	2.09
3	1		110 (34)	55	EAN 27	same	1.12
3	2	164	50 (15)	46	EAN 22	same	0.51
4	1		113 (34)	44	EAN 27	same	0.97
4	2	179	66 (20)	50	EAN 22	same	1.62
5	1		140	43	EAN 27	EAN 50	1.07

The P_{DCS} in this series varied between 0.18% and 2.09%. The dive preceding the symptoms had P_{DCS} about half (1.07%) of the maximum recorded in the series. The range of calculated probabilities for these dives is common in recreational diving.
Here is how the diver described his dives:

We'd been rotating buddy on the boat and I was diving with XX that day. He'd broken his computer earlier in the week so we planned the dive using Buhlmann tables. I was using a Sunnto Gecko computer and in terms of the decompression stops the computer required it was a very conservative dive. We'd been diving on nitrox during the week (27%). The mix was picked for the first dive of the day and then our twinsets were topped up with air before the second dive. For the last dive (Figure 2.5.3-1) we'll have been using same nitrox on the bottom and I switched to 50% from 18 m [60 ft] up. This wasn't included in our deco planning so again added conservatism.
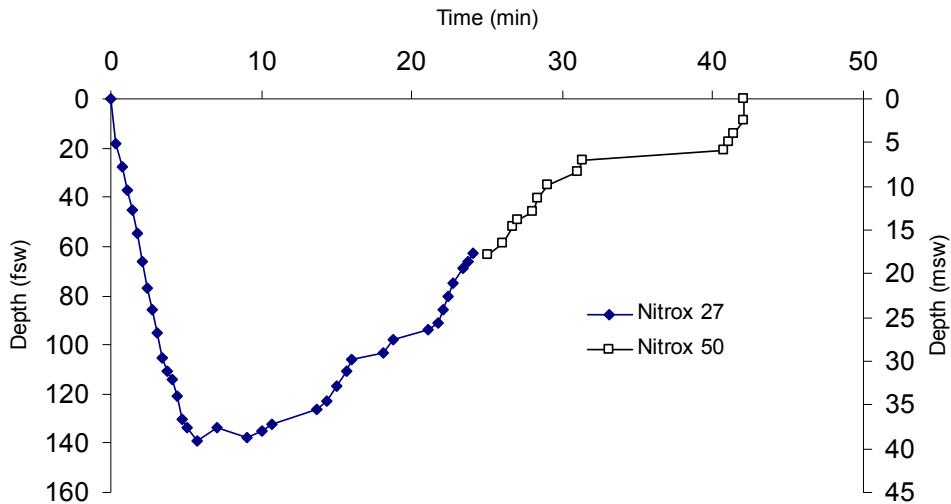
Figure 2.5.3-1 Last dive of series preceding shoulder pain

After the dive I had a pain in my left shoulder which initially I put down to a pulled muscle with all the heavy kit.

In the morning I spoke with our skipper and she ran a quick neurological exam. She didn't think it was a bend but offered to drive me to the doctors just to be on the safe side. I saw the doctor and he thought it more likely to be a pulled muscle. However, due to the depth of the dive he wanted to consult the local hospital. Their assessment was to put me in the chamber just in case.

While in the chamber the pain did vanish during the slow accent from 18 m [60 ft] to 9 m [30 ft], though I felt it again an hour or so after coming out of the chamber. It faded away over the next couple of days. I'm still not sure if it was actually a bend or not.

The doctor signed me off diving for seven days. I was then back diving almost immediately. I still dive regularly and average around 75 dives a year.

I had similar symptoms earlier this month. The diving was much shallower and less aggressive. We dived the previous three days and that morning I'd gone back to the boat to retrieve my diving gear. When I picked up my twinset by one shoulder strap to carry it off the boat I felt a similar pain in my shoulder. Because of the circumstances this time I again put it down to a pulled muscle and the pain again faded over the next couple of days. I did wonder whether I should have taken it more seriously.

The shoulder pain was possibly caused by lifting heavy gear. Pain caused by sprain may subside under hyperbaric oxygen but it usually comes back after the treatment. However, joint pain caused by DCS, if relieved by recompression, can also reoccur, especially if there is delay in entering the chamber after onset. In this particular case, the diver noted a previous episode involving lifting heavy gear one day after diving coinciding with similar symptoms and

evolution but this time without recompression treatment. We have, therefore, classified this case as ambiguous.

2.5.4 DCS

There were three DCS cases for an annual incidence of 2.0 cases per 10,000 dives. All three cases were classified as DCS I. One diver was recompressed with complete relief, one received first aid oxygen with complete relief and one received no treatment but resolved overnight.

Case 1. Itch and rash on shoulder (DCS I)

This diver was in his late fifties with a history of chronic muscle/joint pain and hypothyroidism. He undertook a series of three dives over two days using a rebreather. On the first day, he completed dives to 89 and 50 fsw (27 and 15 msw), respectively, with the oxygen set to a constant partial pressure of 1.3 ATA and nitrogen as the diluent. His third dive took place on the second day, using the equipment and gas settings noted above for a maximum depth of 106 fsw (32 msw) and a total dive time of 61 minutes. Soon after surfacing he felt itching and noticed a rash on his shoulder. He was transferred to the local chamber and recompressed in just over three hours following surfacing. His symptoms resolved during recompression on a USN TT6 protocol.

Case 2. Pins and needles in hand (DCS I)

This 38-year-old male reported completing over 100 dives since certification in 2001. In this series, he completed nine dives over six days ranging in depth from 33-114 fsw (10-35 msw). The third dive overall (first dive on the third day) was to a maximum depth of 114 fsw for 31 minutes (Figure 2.5.4-1). Following that dive, he felt pins and needles in a hand and felt lightheaded so he opted not to undertake a second dive that day. He slept overnight and woke without symptoms and continued diving. The P_{DCS} was 0.96%.
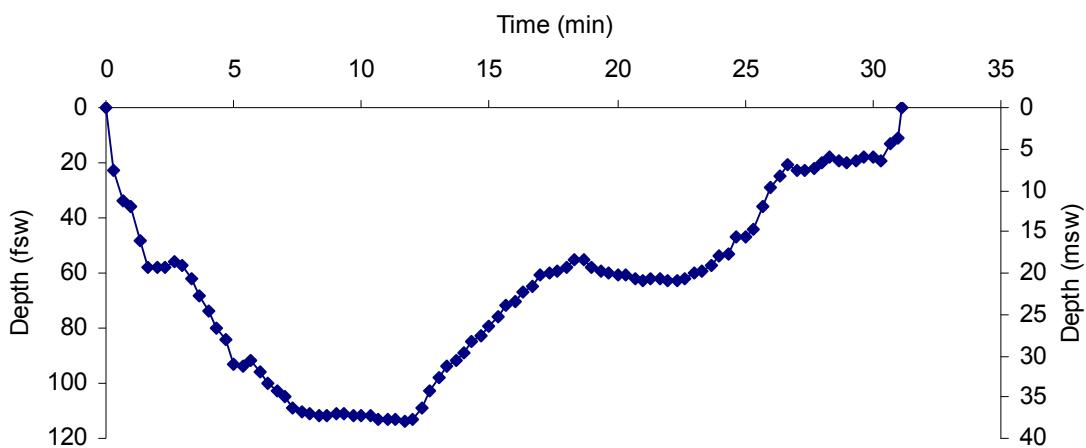
Figure 2.5.4-1 Dive profile preceding a case of mild neurological DCS

Case 3. Shoulder pain (DCS I)

This 51-year-old male diver with 16 years of diving experience reported at lifetime total of over 250 dives. In a series of 10 dives over six days, ranging in maximum depth from 57-117 fsw (17-36 msw), he developed pain in a shoulder after the first dive on the fifth day (ninth dive overall). This dive was to a maximum depth of 108 fsw (33 msw) for 34 minutes on air. He took no action but did not dive again that day. The next day he undertook his last dive to a maximum depth of 109 fsw (33 msw) for 37 minutes. Following that dive, the pain was more severe. He subsequently received first aid oxygen whereupon the pain resolved. The P_{DCS} for these two dives was 1.09% and 1.29%, respectively. The profiles of the final two dives appear in Figure 2.5.4-2.
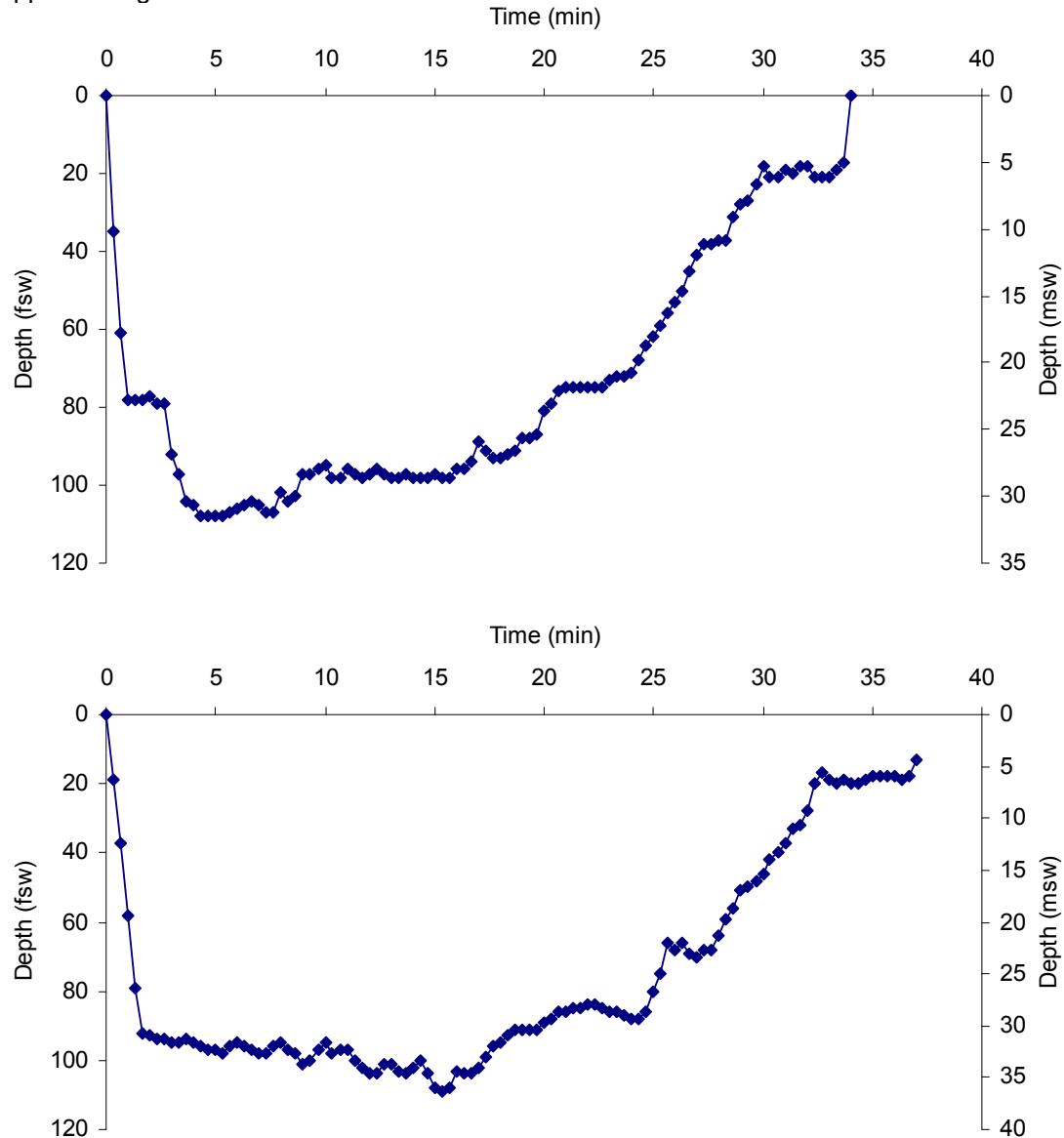
Figure 2.5.4-2 Last two dives of a 10 dive series producing shoulder pain
(lower panel last dive)

2.6 Summary

DAN's Project Dive Exploration (PDE) has acquired information on 135,546 volunteer dives from 1995-2006. In the 2006 dataset, most volunteers were between 30-59 years of age with recreational diving certifications. Males outnumbered females and contributed most dives but females contributed a slightly higher number of dives per volunteer. There were relatively few chronic medical conditions reported with allergy and hypertension the most common. Volunteers reported less obesity than has been reported for the general population. The reported dives were primarily from charter boats and liveaboard vessels. Beach divers reported more cold stress and higher workloads than other groups. Dive series of two to four dives were most common. For all dives, 70% were to less than 90 ft (27 m) and 95% were uneventful. Buoyancy and rapid ascent were the most frequent procedural problems and dive computer issues the most frequent equipment-related problem. Three mild cases of DCS were reported out of the 14,967 dives collected.

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.

Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999-2004. JAMA. 2006; 295(13): 1549-55.

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: 48-49.

3. DIVE INJURIES

3.1 Introduction

The Medical Services Call Center (MSCC), introduced in 2006, captures all calls to DAN Medical Department. These include information requests and requests for 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 telemedicine 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 what the final diagnosis was with emphasis on most common reasons for call. This approach is closer to the perspective of the first responder to an emergency and sees a different mix of cases than hyperbaric chambers that may be limited to cases most likely 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% through e-mail. Requests for assistance in actual cases did not come always 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	%	Frequency	%	Frequency	%
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% of all assigned working diagnoses; n = 424). Barotrauma, including all injuries of lung, ear, sinuses and mask squeeze caused by pressure change, was suspected in 25.6% (n=411). Non-diving related problems were the working diagnosis of 14.3% (n=229), envenomation for 6.0% (n=97), trauma 2.3% (n=37) and various other causes 25.4% (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% 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 common injuries rather than call DAN. For non-diving-related problems DAN members called Travel Assist about 130 times per month. If Travel Assist was called in error for dive-related problems, the call was 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 a 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 make it difficult to distinguish the 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 the 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 min post-dive and insufficient exposure for DCS
Possible	Present or transient neurological symptoms indicating brain involvement and onset <15 min post-dive Possibly sufficient exposure for DCS or operational cause and only transient loss of consciousness
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 nine out of 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 breathing 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% 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 hyperbaric oxygen (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 sinus problems 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 obviously had a lot of chores beyond tying and untying the buoy), AGE could not be excluded. While diver did not seem to be suffering from any health issue 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% of cases (Pearson, 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 was fine but felt 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 a 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 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 424 cases suspected for DCI. It was similar to the percentage of AGE described in recent DAN Annual Diving Reports (Vann et al., 2003) when data was provided by hyperbaric chambers. For example, in Diving Report 2003 described 29 cases of AGE (7%) and three cases of pulmonary barotrauma (PBT; <1%) 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 saw. In our current dataset there were more barotrauma cases with pulmonary manifestation only than cases 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 complains, no physical exam OR resolution upon 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 questions. The number of calls concerning DCS issues is listed in Table 3.6-2.

Table 3.6-2 Number of calls concerning DCS

	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%) 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%). 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.

Approximate 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%) 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 database by selecting all cases with bladder/bowel problems checked 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.
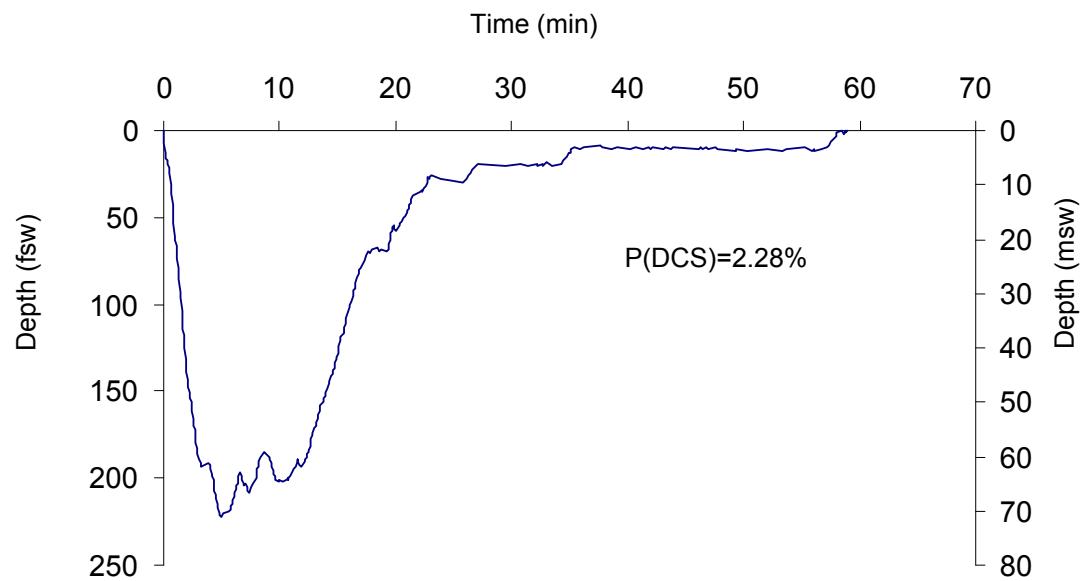

Figure 3.6.1-1 Dive profile which resulted in bladder dysfunction and severe quadriplegia

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 therapeutic recompressions (12 USN TT6 treatments over a nine day period) but the progress was slow. He was discharged after two weeks. He regained 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% 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% of normal and the right one probably around 80%. 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% of normal."*

This severe case of DCS occurred 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 the commercial divers in the North Sea are not allowed to dive breathing air deeper than 50 msw (164 fsw). This was a very deep dive and the estimated risk was 2.28% what is quite high in comparison to most recreational diving which are at 1% or less risk established by the same predictive model.

Relapse may occur even if a diver is treated in the best circumstances as was the case with the 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 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. History of dive

in this case is 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.

Besides the paralysis and loss of bladder control, there are two other manifestations of DCS that is 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 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.
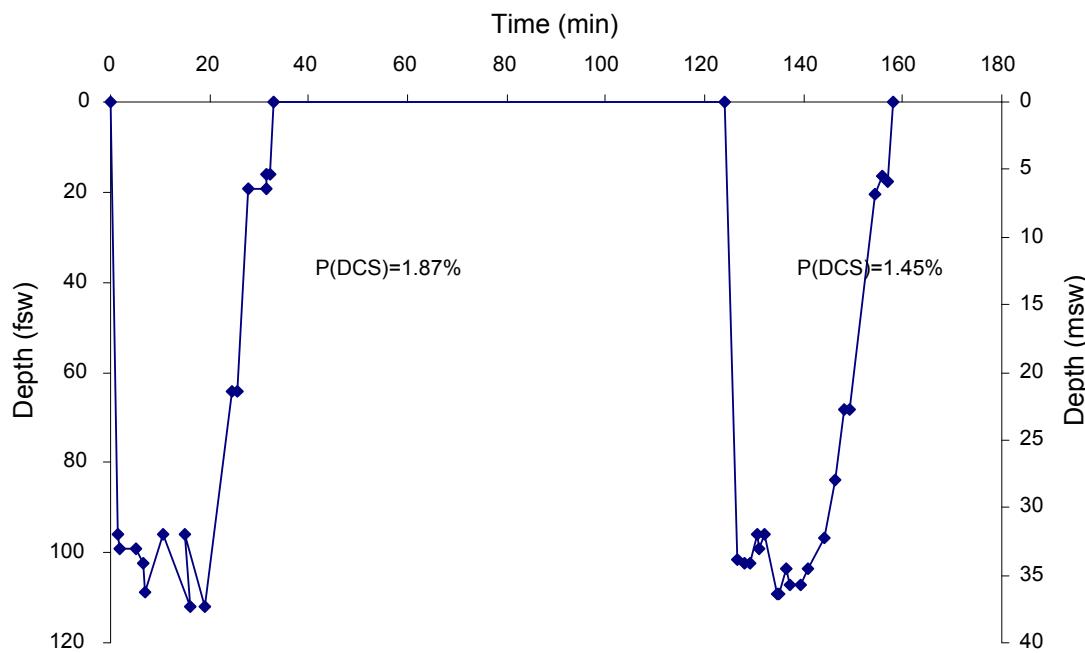
Figure 3.6.2-1 Dive profile in a case that started with skin manifestations and later developed neurological symptoms

Both dives were square dives with estimated risks of 1.87% and 1.45%, 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 DCS with motor involvement, rash and mild chokes. An elevated hematocrit indicated some concentration of her blood. 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 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 two-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% 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 manifestation often preceded or were concurrent with neurological symptoms. Out of 23 confirmed cases, 11 were associated with cerebral symptoms, three with motor weakness of the 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%) 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

Shoulder pain is a frequently reported symptom of DCS. 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 and with follow up missing in most cases, we did not feel comfortable in classifying any case 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 symptom severe enough 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 the case of shoulder pain may be less useful than 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 dive deserve more attention than we could dedicate to it for the purpose of 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 DCS and 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 determined to be a possibility in 22 cases.

In this case, a medic from the local hospital called DAN concerning a 55-year-old male patient with a 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% oxygen. His dive profile is shown in Figure 3.6.4-1.
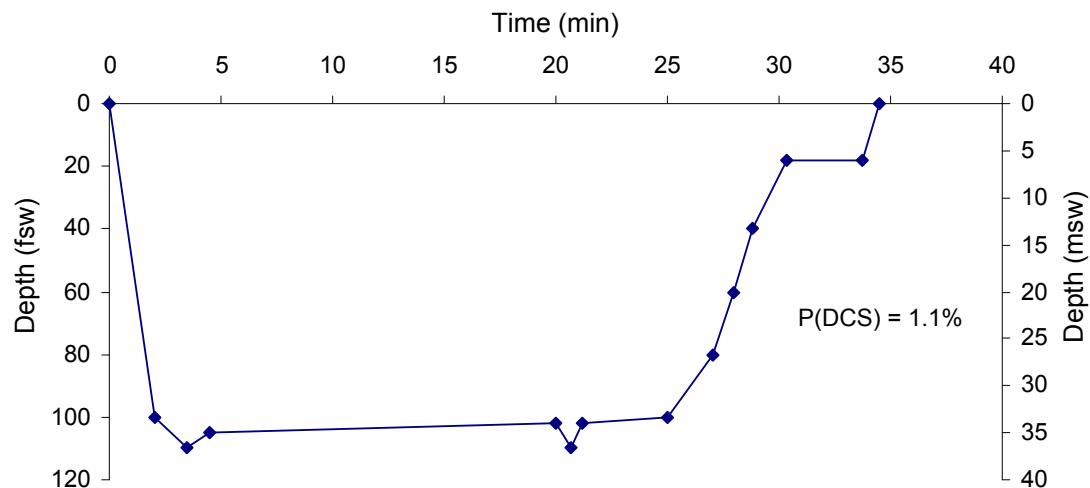
Figure 3.6.4-1 Dive profile on 30% nitrox preceding development of vertigo, left-side paresthesia

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's no-decompression limits and a safety stop was performed (the decompression model employed was not reported). The estimated risk was 1.1%. This means that DCS is expected in approximately one out of hundred repeats of this dive. As a caveat, it is noted that the model used for risk estimation was calibrated with experimental dives that may have been of greater stress 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 bent 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, or find 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 (by 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 cases retrospectively more likely cerebral DCS than inner ear DCS.

In another case diver made two dives both to 120 ft (37 m) on 30% 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.
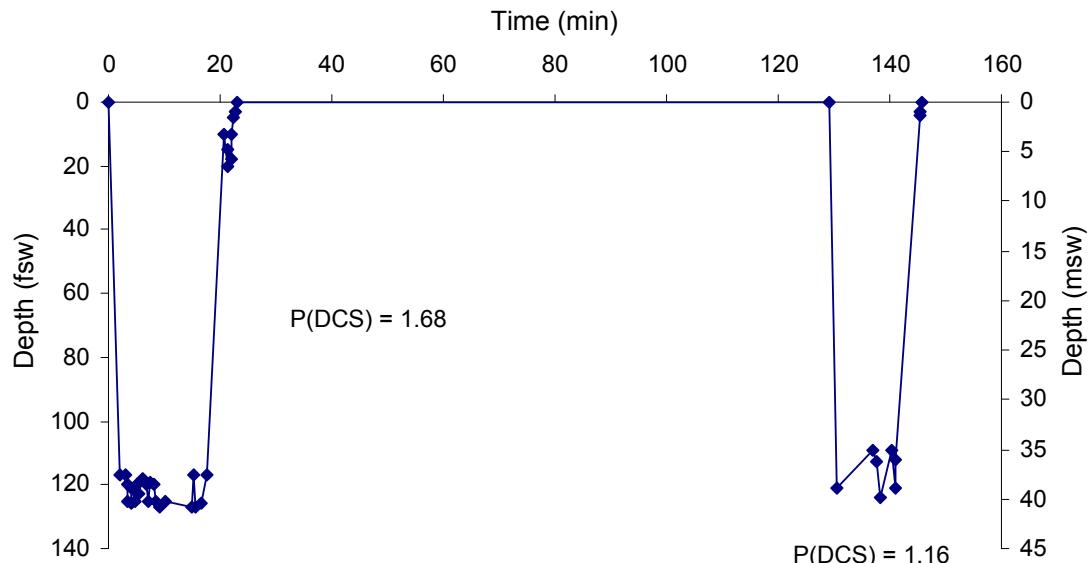
Figure 3.6.4-2 Dive profile that preceded vertigo, nausea and difficulty walking. Breathing gas used for these dives was nitrox 30

Both dives were square dives. The estimated risk reached 1.68% after first dive, despite 30% 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.
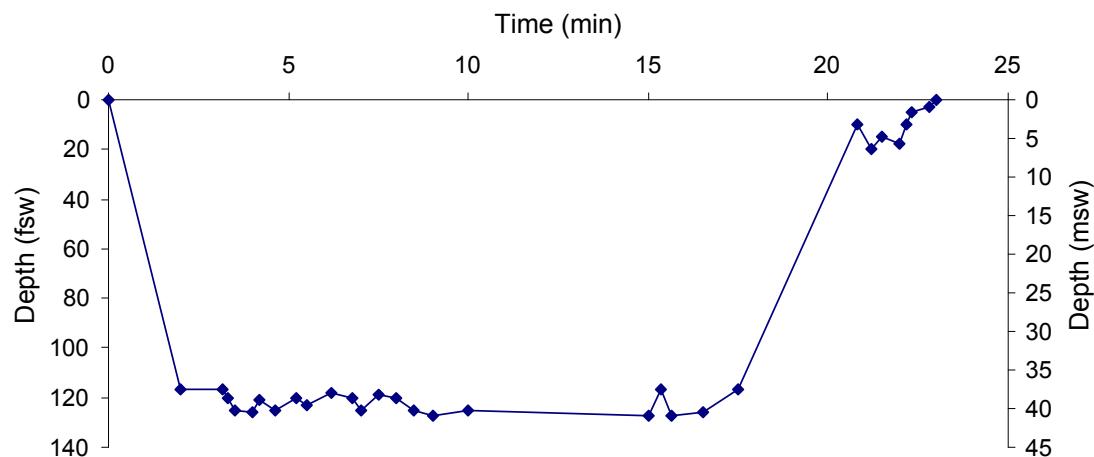
Figure 3.6.4-3 Expanded view of dive 1 in Figure 3.6.4-2

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} (12 m·min^{-1}) and the safety stop was brief. Possibly the first dive created conditions for DCS which occurred 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 third treatment but after the fourth recompression treatment there were no additional improvements. He was released from the hospital with difficulty walking.

On 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 a 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. 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 resulted from compensation for the lost function rather then resolution of the insult. The compensation may not be effective in dark and in weightless environments and divers 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 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%) or IWR (n=3, 7.5%) 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% 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. 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 at all.

The third case of IWR involved a young male technical diver calling from his home. He did two cave dives breathing 24% 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% oxygen and 100% 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% oxygen as an attempt at recompression therapy. At the surface he continued breathing 100% 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. Risks involved with protracted immersion breathing oxygen at high partial pressure are known to technical divers and thus they tend to keep it short.

We must recognize that these calls were mostly because the attempted IWR failed. In case the IWR were successful, diver would 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%) 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% of barotrauma cases with data and 7% 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% of barotrauma cases with data and 0.6% of all MSCC cases). Sinus barotrauma was reported in 57 cases (14.4% of barotrauma cases with data and 2% of all MSCC cases).

Table 3.7-1 Cases suspected of barotrauma

Area Affected	Count	Injury	Frequency	%
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	barodontalgia	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 more difficult to establish without an otoscopic examination of ears by a trained physician. MEBT may feel as a mild soreness in ear, fullness due to clear or bloody liquid filling the middle ear, or bleeding from the ear canal due to eardrum rupture. Association with tinnitus and vertigo must be always explored 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 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 his 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 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 rather 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 external ear canal (otitis externa). This was surprisingly low since many divers dive for hours in warm waters and run the risk of ear infection. Some divers use solutions available on the market to prevent ear infection, possibly indicating that they had experienced problems with ear canal in the past. The low number of cases reported through DAN medical lines probably reflects referral bias rather then true low incidence. Divers may be self-treating or going to their primary physicians who treat them without need for a consultation.

In two cases MEBT was associated with face drooping or weakness of facial muscles on the same side. This may have been so-called facial baroparesis which is 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 a 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 the diver to stop diving and seek evaluation from his primary physician.

There was one case of suspected alternobaric vertigo. Alternobaric vertigo is caused by unequal pressures in left and right middle ear cavities during ascent and descent or by unequal sensitivity of vestibular organs to the 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 return to diving may be considered.

3.7.2 Pulmonary Barotrauma (PBT)

PBT is an injury due to excessive stretching of lungs by expanding alveolar gas during ascent from depth. The consequence is that gas leaks from injured alveoli into 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 that form the surface of the lungs rupture and let gas into the pleural space. The relative vacuum of the pleural space that keeps the lungs in close contact with the chest wall is lost and the lungs 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 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 higher pitched response than normal to percussion of the chest wall. In milder cases, symptoms are less dramatic and diagnosis may not be established without 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 by stethoscope, percussive signs and/or 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 is rare in diving. In 2007 there were 52 cases of suspected pulmonary barotrauma in MSCC database, but no confirmed cases of 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% of cases. Many cases are associated with pre-existing blebs at the surface of the lung that burst during everyday life activities. Smoking is known risk for pneumothorax. Because of a 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 are disqualified from scuba diving.

Another manifestation of PBT is a pneumomediastinum. Pneumomediastinum occurs when gas leaks out of stretched or ruptured alveoli into 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 move also in other directions, but this is rarely seen in diving-related cases.

Symptoms and findings in pneumomediastinum may include chest discomfort to chest pain, shortness of breath, difficulty swallowing, pain in the neck, 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-ray may show gas in 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 patient becomes aware of symptoms. Characteristically, patients with pneumomediastinum generally feel well.

The chance that pneumomediastinum will be suspected when DAN emergency line is called depends both on reported symptoms and the availability of additional test results. If a caller complains of subcutaneous edema 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 classified emergency calls concerning the 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
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				Frequency	Percent
	Certain	Possible	Unlikely	Excluded		
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

The majority of calls (57%; n=29) were made by divers from home. This may reflect the mildness of most cases and the delay in development or recognition of symptoms. Twenty-seven percent (n=14) of calls were made 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%) 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

| | 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, the 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 dive or within hours post-dive. In one case, symptoms occurred more than 24 hours post-dive and symptoms 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 evaluated and treated as appropriate.

In 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 time of the consult 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 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 possible and two cases were classified unlikely.

Divers calling post-evaluation were typically interested when they could go diving again. It was not uncommon for divers to be concerned more about return to diving than about their 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 with DAN medical specialists.

3.8 Immersion Pulmonary Edema (IPE)

IPE is a rare condition recently described in the scientific literature but seems to be increasing in occurrence (Hampson, 1997, (Cochard, 2005). DAN published an article on its website and since that time the number of calls regarding this condition seems to have increased.

"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" (McAfferty, 2006).

In 2007, there were 20 calls regarding patients under consideration for the IPE. Among them there were nine cases with either confirmed diagnosis by clinical tests or considered very likely based on the presentation of symptoms. In another nine cases there were other underlying causes of symptoms or the presentation was not typical of IPE. In two cases IPE could not be proved nor disproved.

Out of nine 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 by-stander reporting a case he witnessed that appeared to be IPE as described in the material on the DAN website. Only one call came from diver who thought he may have suffered from transitory symptoms of IPE.

IPE is an emergency that may present less or more dramatic symptoms at onset. Mild cases recover spontaneously soon after diver exits the water while severe cases require medical assistance. Most IPE cases are taken care of before DAN can be called.

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 thinking 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 and DAN member 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 DAN website (diver over 50, wetsuit diving in cold water) 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 suffered from insufficient oxygen which further exaggerated the condition. Breathing 100% 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 diver reported that symptoms occurred on 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 breathing and noticed the presence of "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 rales bilaterally. 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 finding of low arterial oxygen saturation and positive chest x-ray (diffuse bilateral edema, patchy edema, perihilar infiltrates). The patients were male and female divers between 45 and 58 years of age. In all four cases difficulty breathing started at depth. One case was associated with a rapid ascent. Consults were requested regarding a possibility that barotrauma or DCS may have been involved, which were not in any of the 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 [note: 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 IPE since the symptoms were unrelated to immersion.

In one case aspiration was so obvious that there were no doubts. A male recreational dive student in his late sixties did 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 water 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. The diver was placed on oxygen and transported to the nearest emergency department where he was diagnosed with pulmonary edema. He was treated with Lasix® (furosemide), a diuretic medication which reduces the amount of water in the body by increasing urination. By the next day all his symptoms were gone 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 immersion edema 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 medical attention and received proper 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 on a dive training dives 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 alone can produce pulmonary edema.

Another call came from an emergency department regarding a diver that was admitted with difficulty breathing after a dive during 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 right lung, with no other significant findings. The diver recovered within one day and was released. This was also not considered IPE; the findings were more typical of aspiration. Due to the size and position of right bronchus, aspirated content more often ends up in the right than in 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 case mix seen through MSCC data provides a broader spectrum of recreational diving injuries than can reports by 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 diagnosis. Follow-up is required as a standard procedure but is often unsuccessful although DAN is working to increase the rate of successful follow-up. DAN is also training hyperbaric centers in use of the MSCC as a case management tool. The MSCC has been in use 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.

3.11 References

American Lung Association. Spontaneous pneumothorax fact sheet. http://www.lungusa.org/site/apps/nlnet/content3.aspx?c=dvLUK9O0E&b=2060727&content_id=%7B1D74D C3D-E1AF-4FFB-A314-CC584935C391%7D&notoc=1. Edited 2005. Last accessed Oct 13, 2008.

Cochard G, Arvieux J, Lacour JM, Madouas G, Mongredien H, Arvieux CC. Pulmonary edema in scuba divers: recurrence and fatal outcome. Undersea Hyperb Med. 2005; 32(1): 39-44.

Hampson NB, Dunford RG . Pulmonary edema of scuba divers. Undersea Hyperb Med. 1997; 24(1): 29-33.

McAfferty M. Immersion Pulmonary Edema. http://www.diversalertnetwork.org/medical/articles/article.asp?articleid=82. Last accessed Sept. 23, 2008.

Moon R. Scanning for blebs. http://www.diversalertnetwork.org/medical/articles/article.asp?articleid=40. Edited 2005. Last accessed Oct. 13, 2008.

Pearson RR, Goad RF. Delayed cerebral edema complicating cerebral arterial gas embolism: case histories. Undersea Biomed Res. 1982; 9(4): 283-296.

Vann R, Denoble P, Uguccioni D, Freiberger J, Reed W, Dovenbarger J, Caruso J, Duncan R, Hyatt W. Report on decompression illness, diving fatalities and project dive exploration - 2003 Edition. Durham, NC: Divers Alert Network; 2003; 130 pp.

4. DIVE FATALITIES

4.1 Introduction

Recreational scuba diving deaths are rare events, but the risk is never insignificant and vigilance is required to keep it as low as possible. 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). Similar surveillance is maintained by the British Sub-Aquatic Club (BSAC) in Great Britain (Cumming, 2006) and in Australia with Project Stickybeak (Acott, 2003). The numbers reported by all three groups 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, the BSAC data includes data for BSAC membership only and not for British divers affiliated with other organizations.
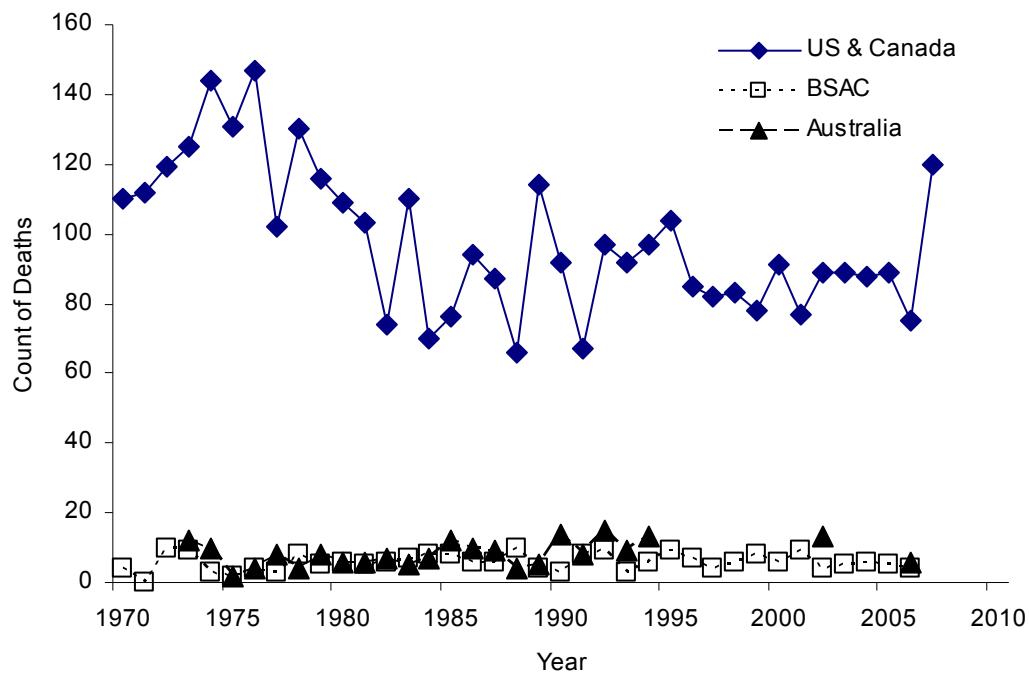
Figure 4.1-1. Annual counts of deaths related to recreational scuba diving

The patterns appear to be fairly stable over time but firm conclusions cannot be drawn since the amount of diving activity, the denominator in the risk assessment, is not known.

BSAC data are presented in Figure 4.1-2. While the number of memberships has increased to a maximum of 50,000 in 1995, the annual number of diving-related deaths varied between two and 10 since the 1970s. Information about the number of dives completed was not available.
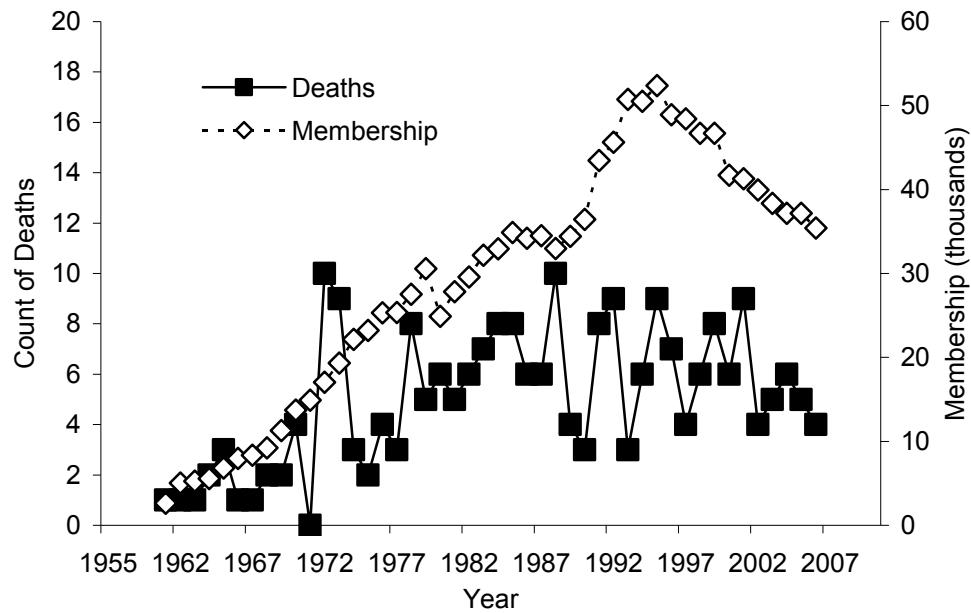
Figure 4.1-2. BSAC annual membership numbers and counts of deaths

Figure 4.1-3 shows the dive fatality rates among BSAC members from 1959 through 2006 and among DAN members from 2000 through 2006. The BSAC rates decrease from the peak value of 60/100,000 in 1972 to 15/100,000 in 2006. Due to the rare occurrence of death in diving, the annual rates vary substantially but the overall trend is a decrease in rate on a per diver basis. In the period of 2000 to 2006 for which DAN membership fatality rates were available, there was no statistical difference between DAN and BSAC rates (Denoble et al., 2008b).
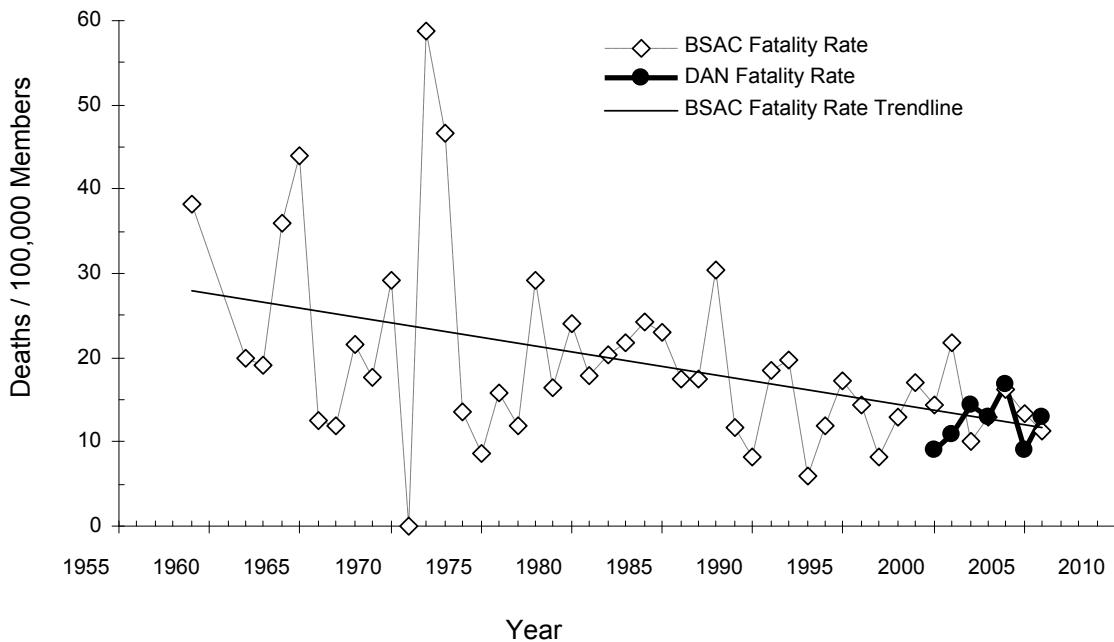
Figure 4.1-3. 50-year fatality trends among BSAC and DAN members

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 is increasing (Denoble et al., 2008b). Figure 4.1-4 shows the mean age of male and female insured DAN members. In the period from 2000 to 2006, the mean age increased, advancing approximately six months per year for females and slightly less for males.
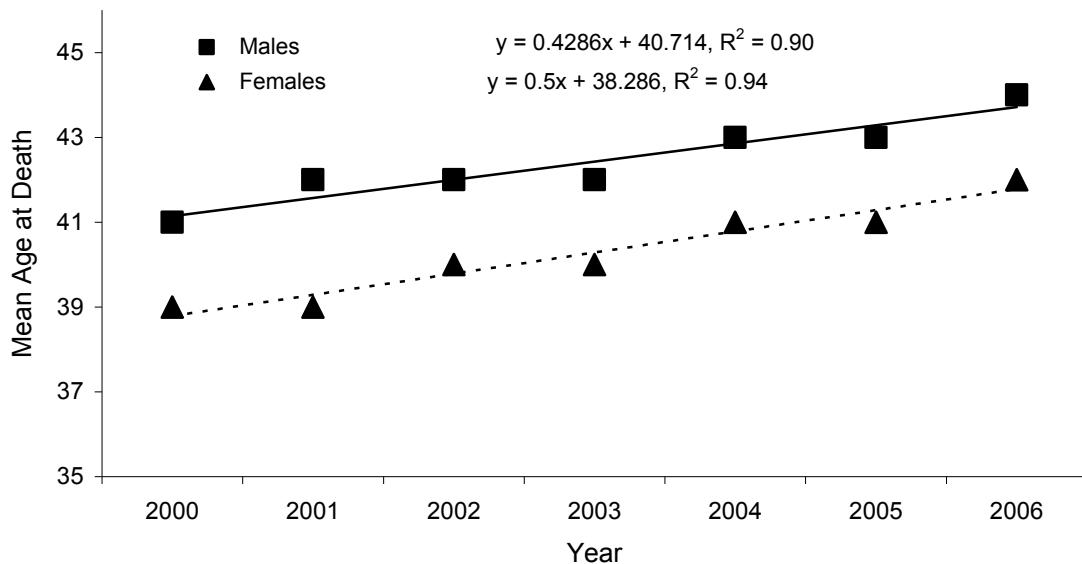
Figure 4.1-4. The mean age of male and female DAN insured members

The mean age of all decedents in US and Canadian diving accidents increased from 42 in 1998 to 48 in 2005 (Figure 4.1-5). The decedents among insured DAN members generally followed a similar pattern.
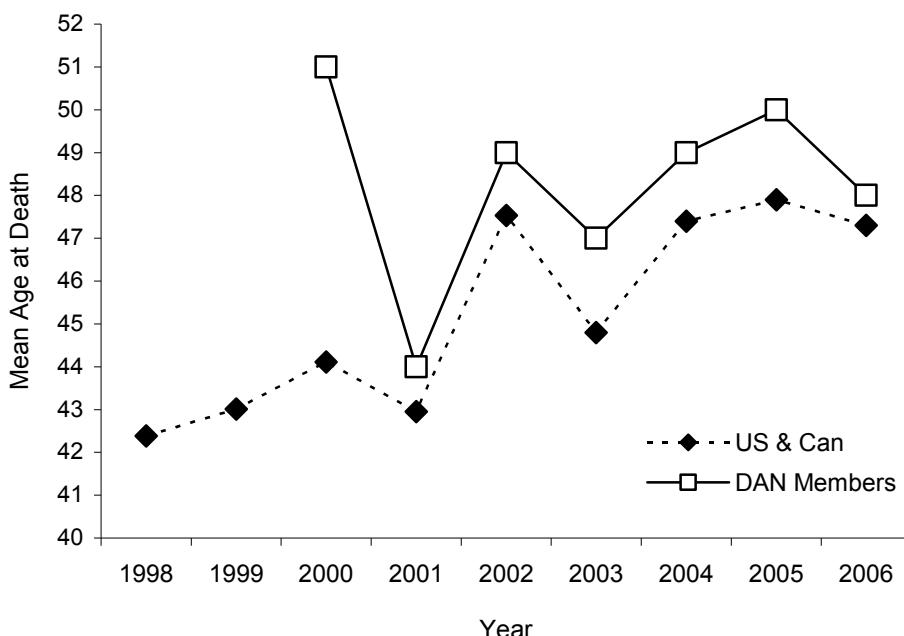
Figure 4.1-5. The mean age of decedents at the time of scuba-related death in the US and Canada

As the fraction of older divers in diving population increases, the health-related causes of death while diving become more frequent. In this chapter we present fatality surveillance data for 2006. One year of surveillance data may not follow the long term trends and caution must be used in drawing conclusions about prevailing causes and risk factors. Regardless, each case reviewed can serve as a lesson to help prevent similar accidents.

4.2 Fatality Statistics

Worldwide, DAN received notification of 138 deaths involving scuba diving in 2006. Table 4.2-1 shows the frequency of deaths by country and DAN International region for all recreational incidents known to DAN. Only the deaths of 75 US and Canadian recreational divers have been actively investigated by DAN America. Reports of dive-related deaths from other regions were provided by International DAN (I-DAN) organizations or by individuals communicating with DAN America. This is a first attempt to include worldwide data and the tally is most likely incomplete. DAN Europe reports the second highest total with 35 cases. Only 12 of the 35 decedents were members of DAN Europe. DAN Asia-Pacific reported 25 fatalities but did not specify how many were DAN Asia-Pacific members. DAN Latin America reported five fatalities, DAN Japan one fatality and DAN Southern Africa no fatalities in 2006.

The 75 cases discussed in this report were US or Canadian recreational divers (64 male and 11 female). Fifty-nine (79%) of these cases occurred in the US or Canada and 16 (21%) occurred abroad. Table 4.2-2 shows the geographic distribution of US and Canadian fatalities by state or province. The greatest concentration of cases was seen in Florida (29%) and California (19%).

Table 4.2-1 Frequency of accidents by country (all known recreational incidents)

DAN Region/Country	US & Canada Residents	Non-US & Canada Residents	All Cases
DAN America			
Antilles	1	2	3
Bahamas	3		3
Canada	8		8
Cayman Islands	3		3
Jamaica	1		1
Turks and Caicos Islands	1		1
United States	51	2	53
DAN America Totals	**68**	**4**	**72**
DAN Europe			
Czech Republic		1	1
Egypt	1	2	3
France		1	1
Germany		1	1
Ireland		1	1
Israel		1	1
Italy		4	4
Malta		4	4
Norway		1	1
Poland		1	1
Scotland		2	2
Spain		1	1
Ukraine		1	1
United Kingdom		13	13
DAN Europe Totals	**1**	**34**	**35**
DAN Asia-Pacific			
Australia	1	6	7
China		1	1
Fiji		1	1
French Polynesia		3	3
Indonesia	1		1
Malaysia		3	
New Zealand (Aotearoa)		5	5
Northern Mariana Islands		1	1
Thailand		3	3
DAN Asia-Pacific Totals	**2**	**23**	**25**
DAN Latin America			
Brazil		1	1
Honduras	2		2
Mexico	2		2
DAN Latin America Totals	**4**	**1**	**5**
DAN Japan			
Japan		1	1
DAN Japan Totals	**0**	**1**	**1**
DAN Southern Africa	**0**	**0**	**0**
South Africa	0	0	0
DAN Southern Africa Totals	**0**	**0**	**0**
Total	**75**	**63**	**138**

Table 4.2-2 Distribution of US and Canadian fatalities by state or province (n=59)

State or Province	Number
Florida	17
California	11
Washington	7
Michigan	4
Ontario	4
British Columbia	2
Maine	2
New Jersey	2
New York	2
Hawaii	1
Illinois	1
Louisiana	1
Massachusetts	1
Minnesota	1
North Carolina	1
Newfoundland	1
Quebec	1
Total	**59**

Autopsies were conducted in 48 cases and reports available for 34 cases. Death certificates were available for seven cases and there was a coroner summary for one case. The body of the decedent was not recovered in four cases. An autopsy was not performed in two cases. It was unknown if an autopsy was performed in 13 cases.

There were known witnesses to the event in 49 cases (65%).

4.3 Characteristics of Divers Who Died

Figure 4.3-1 shows the age distribution for dive fatalities. Eighty-two percent of females and 72% of males were 40 years or older. The range of male victims was 23-74 years, with a median of 50 years. The age range of females was 28-66 years, with a median of 43 years.
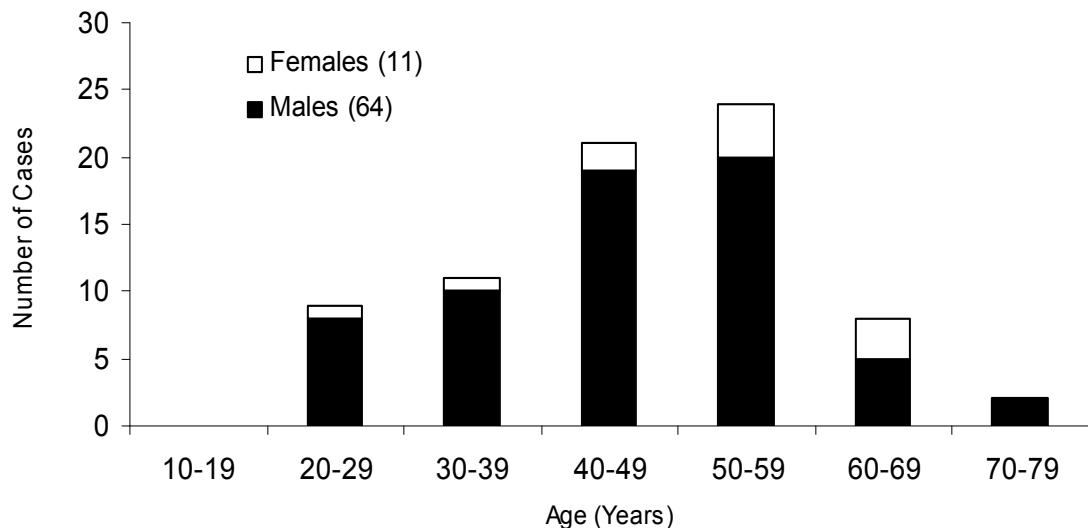
Figure 4.3-1 Distribution of fatalities by age and gender

Medical history was available in 37 cases (49% of the total), mostly incomplete. The most frequently reported medical conditions were heart disease (n=14; 38% of the known cases) and high blood pressure (n=4; 11% of the known cases). One diver in his late forties went for lobsters and was found unconscious and non-responsive at the surface with his BCD inflated. He had two previous myocardial infarcts, a stent in place (device maintaining a diseased coronary artery open), elevated serum cholesterol, hypertension and was overweight based on body mass index (BMI = 29.6 kg·m^{-2}). The autopsy disclosed cardiomegaly (enlarged heart), severe coronary atherosclerosis with a large scar on the lateral ventricle of the heart from previous infarctions, atherosclerosis of the aorta and its branches, fatty change of the liver, and arterionephrosclerosis (chronic degenerative disease of the kidney). No signs of injury or pulmonary barotrauma were found. An adverse cardiac event was the probable disabling injury and cause of death in this case. It is not known whether the diver was cleared for diving by his cardiologist. Fitness to dive after myocardial infarction may be considered if the person has appropriate exercise capacity. Two myocardial infarctions in a short period should raise a serious concern.

Another diver in his late fifties had a sick sinus syndrome and had a pacemaker to control his heart rhythm. He was also taking morphine for chronic shoulder pain. He had previously experienced seizures and blackouts while diving. However, he went diving again, solo, to gather lobsters. He was found unconscious at 50 fsw (15 msw), 60 minutes after the start of his second dive of the day. For more details about pacemakers and scuba diving see in DAN Diving Medicine FAQs an article by Dr. James Caruso, Pacemakers and Diving, http://www.diversalertnetwork.org/medical/faq/faq.aspx?faqid=143.

In a third case, the autopsy findings included a myxoid degeneration of the mitral valve of the heart. In this condition, a healthy and strong connective tissue on the base of the mitral valve is replaced with an abnormal, weak tissue called myxoid. It is a known potential generator of the life-threatening arrhythmias but there was no indication that it occurred in this case.

Two decedents were cancer survivors and one had asthma. One decedent had a known history of seizures but there was no evidence that he seized before he died.

Figure 4.3-2 depicts height-weight proportionality in the fatality population as indicated by BMI. Disproportionately large muscle mass will raise BMI but high values are more frequently associated with obesity on a population basis. BMI data available for 37 (49%) fatality victims indicated that 10 (27% of known) were classified as normal weight (18.5-24.9 kg·m^{-2}), 14 (38%) were overweight (25.0-29.9 kg·m^{-2}) and 38% were obese (30.0-39.9 kg·m^{-2}). There were no underweight or morbidly obese among the decedents.
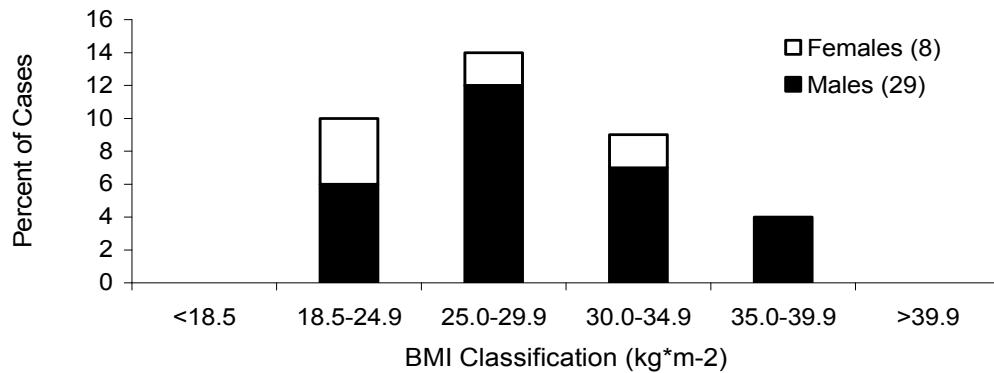
Figure 4.3-2. Classification of fatalities by BMI (n=37)

Similar to recent years, the percentage of decedents with a BMI of $\geq$25.0 kg·m^{-2} (n= 55; 73%) appears to be greater than reported by the National Center for Health Statistics for US adults aged 20 years and older (66%) (Ogden et al., 2006). The percentage of obese (BMI $\geq$30.0 kg·m^{-2}) was similar in both groups (35% among fatalities vs. 32% for US adults).

Fifty-six of the victims (75% of all cases) were known to be certified but information on the certification level was missing in half of these cases. The cases with known information included three student divers, six with open water certification, six with an advanced or specialty certification, six with technical certifications, and four instructors.

Figure 4.3-3 shows the number of years since initial certification. It is based on 38 cases (51% of total) with known information. Thirty-nine percent of those with known history had been certified 10 years or more, and 19% one year or less. This pattern can change dramatically from year to year given the small sample size. Evaluation of the specific risk factor is not possible based on one year of data.
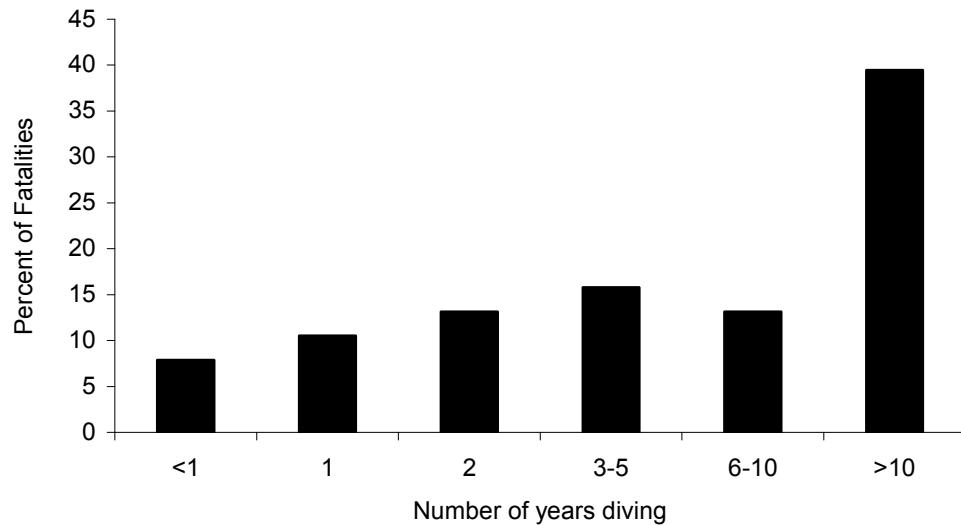
Figure 4.3-3. Number of years since initial certification of divers who died (n=38)

The time between the most recent previous dive day and the day of the fatal accident was known for few cases. There were at least three divers with a hiatus of more than one year.

4.4 Characteristics of dives

Figure 4.4-1 shows the month of death. Our previous reports have found that the number of fatalities can double in summer months (June through August) versus non-summer months (Vann et al., 2006; Pollock et al., 2007). In 2006, July presented a singular peak with 17 cases (23%). Five of these cases occurred while the divers were harvesting lobsters during the lobster mini-season.
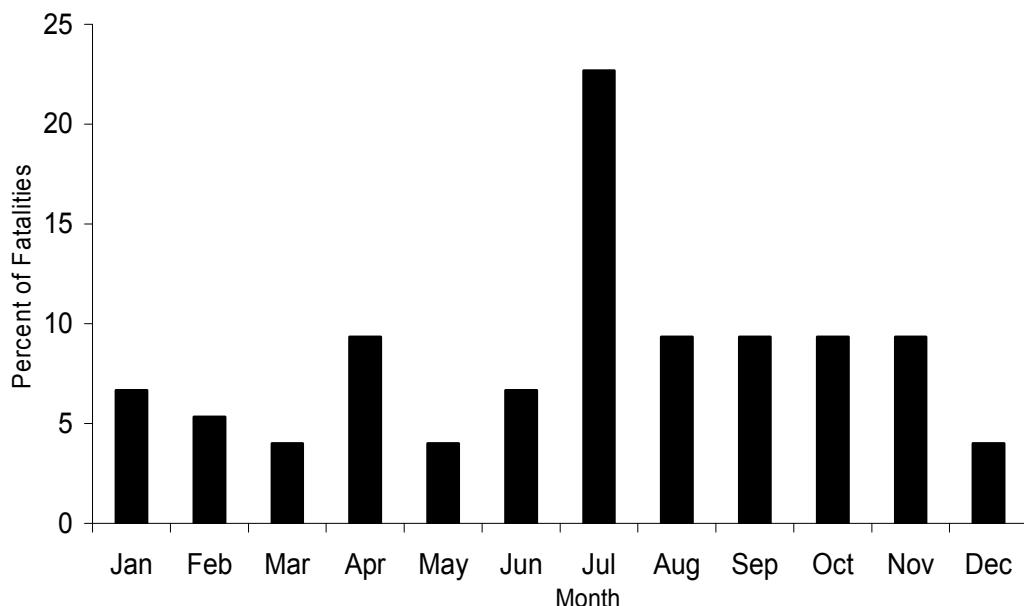
Figure 4.4-1. Month when diver deaths occurred (n=75)

Figure 4.4-2 shows the type of diving activity during the accident. Information was missing in eight cases (11%). Forty-four (66% of known cases) of the fatal dives involved pleasure or sightseeing, 14 cases (21% of known cases) involved spearfishing, hunting or collecting game, six (9% of known cases) involved training, two were described as personal tasks and one as photography.
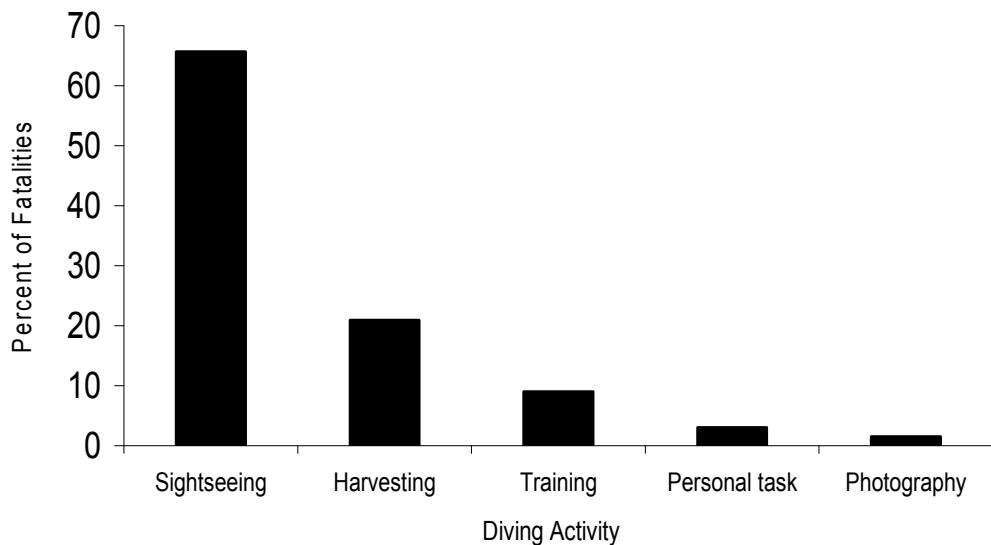
Figure 4.4-2. Diving activity (n=67)

Figure 4.4-3 shows the platform from which the fatal dives began. Data were available in 70 cases (96%). In most cases the dive began from a charter boat or private vessel (n=46; 66% of known cases), consistent with previous reports. Dives began from shore in 23 cases (n=33% of known cases) and from a pier in one case.
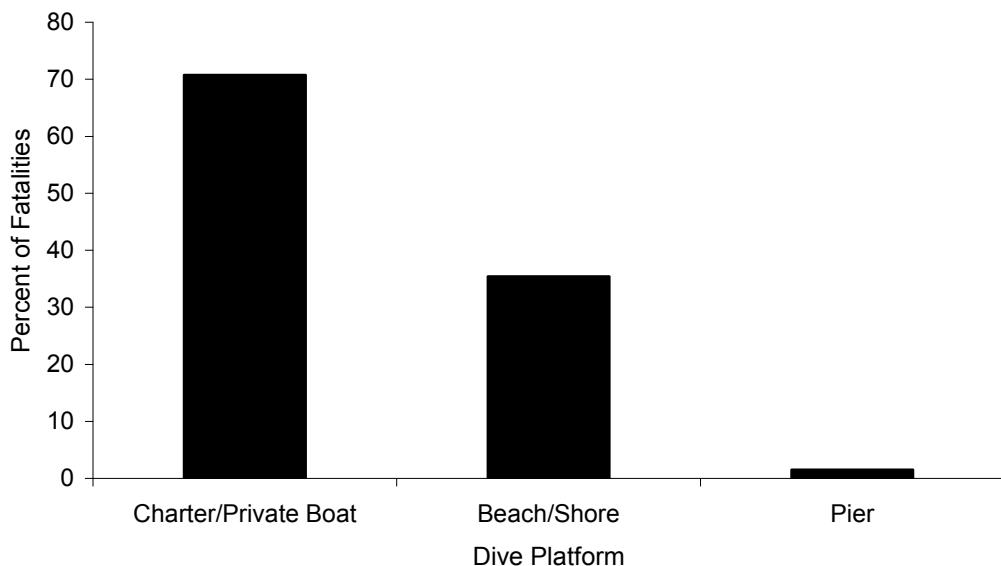
Figure 4.4-3. Dive platform (n=70)

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

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

Figure 4.4-4 shows the maximum dive depth reported for known cases (n=48; 64% of total). The median reported depth of underwater accidents was 65 ft (20 m). Thirty-five cases (73% of known) occurred in 30-120 ft (10-36 m) of water, nine cases (19%) in 120-150 ft (36-45 m), and two cases in <30 ft (10 m). One death occurred at 250 fsw (76 msw) with a rebreather. One victim was lost while on open-circuit scuba. His body was recovered five days after he went missing from the bottom at 250 fsw (76 msw). Information on his dive profile was not available.
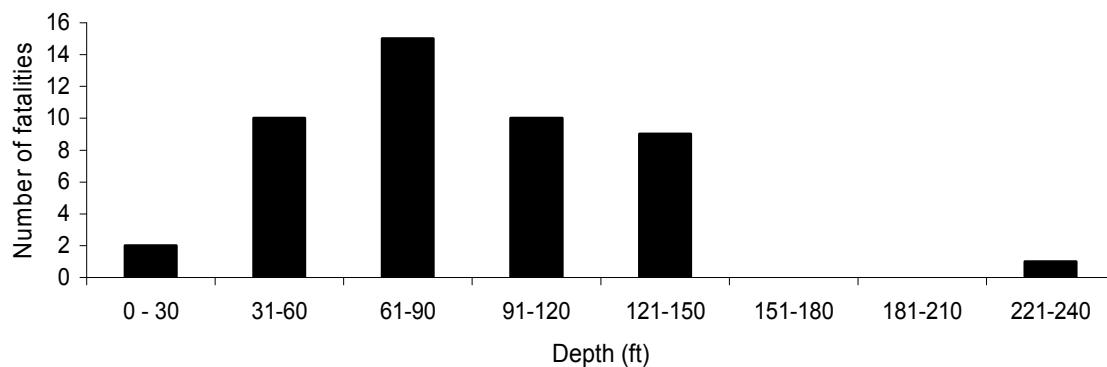
Figure 4.4-4. Maximum depth of accident dive (n=48)

The dive day sequence was known in 39 cases (52% of total). In 28 cases (72% of known) death occurred on the first day of diving. The fatal dive was the first dive of the day in 34 cases (87% of known) and a repetitive dive in five cases (13% of known).

Only six of the fatal dives were intended as solo dives. Most dives started with a buddy or with more divers in a team, but the buddy system was not maintained in many instances.

Figure 4.4-5 shows the type of breathing equipment used. Scuba was used in 64 cases (88% of total), rebreathers in seven (10% of total), and surface-supply in two cases. Breathing equipment was not specified in two cases. Nitrox was used with scuba in one case and with rebreathers in five cases. Trimix was used with open-circuit in one case and with rebreathers in two cases.
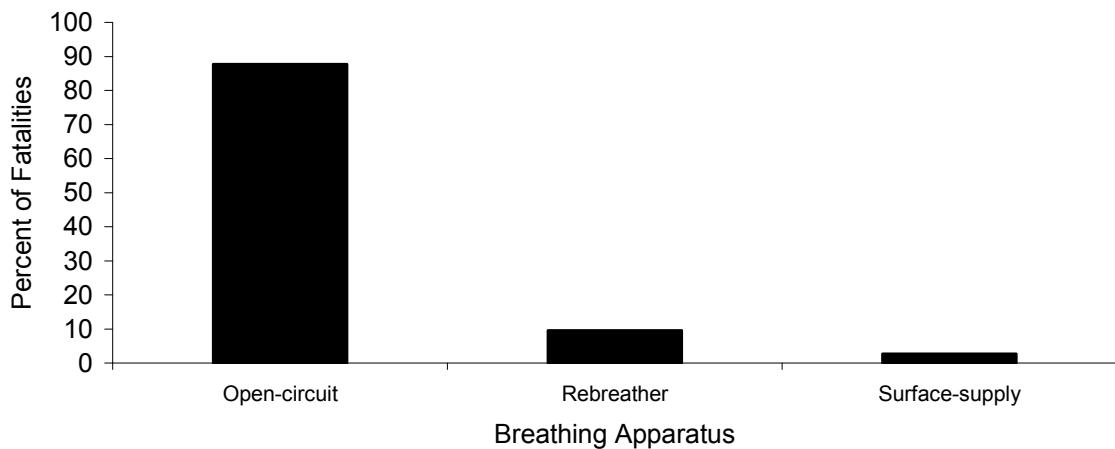
Figure 4.4-5. Breathing equipment used (n=75)

4.5 Analysis of situations and hazards

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

4.5.1 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 include all fatalities in this analysis that occurred from the moment when a scuba equipped diver entered the water. Figure 4.5.1-1 shows the distribution of fatalities by dive phase when the problem became obvious.
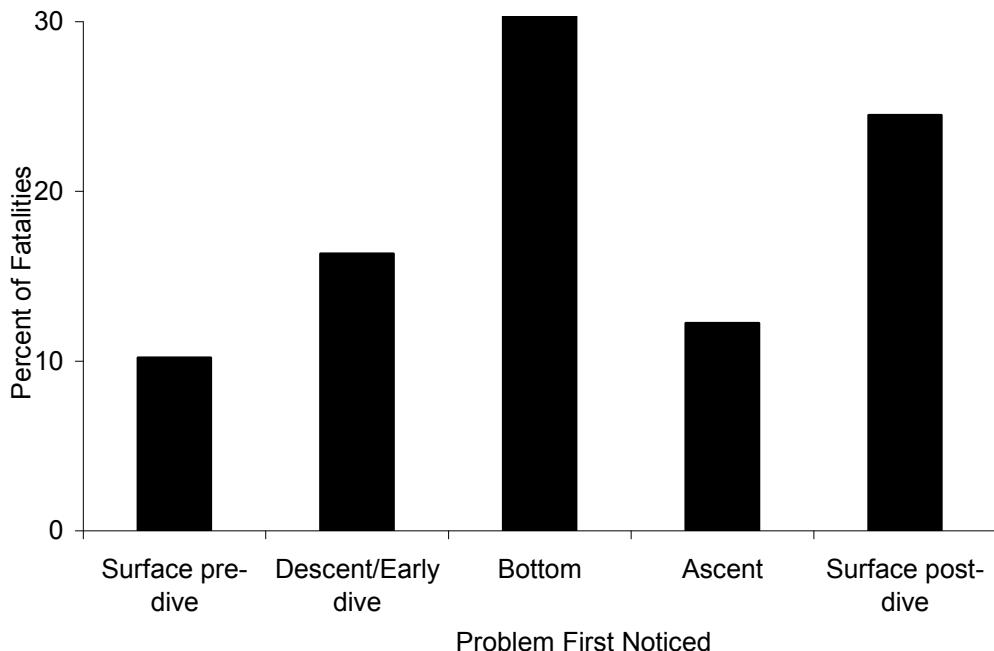
Figure 4.5.1-1. Dive phase when it became obvious that dive has a problem (n=49)

The accident description was available in 49 cases (65% of total). Problems developed before descent in five cases (10% of known) and during descent or soon thereafter in eight cases (16% of known). Problems were noticed at the bottom in 18 cases (37% of known) and at the surface post-dive in 12 cases (24% of known).

Figure 4.5.1-2 shows the distribution of fatalities by the phase in which diver lost consciousness.
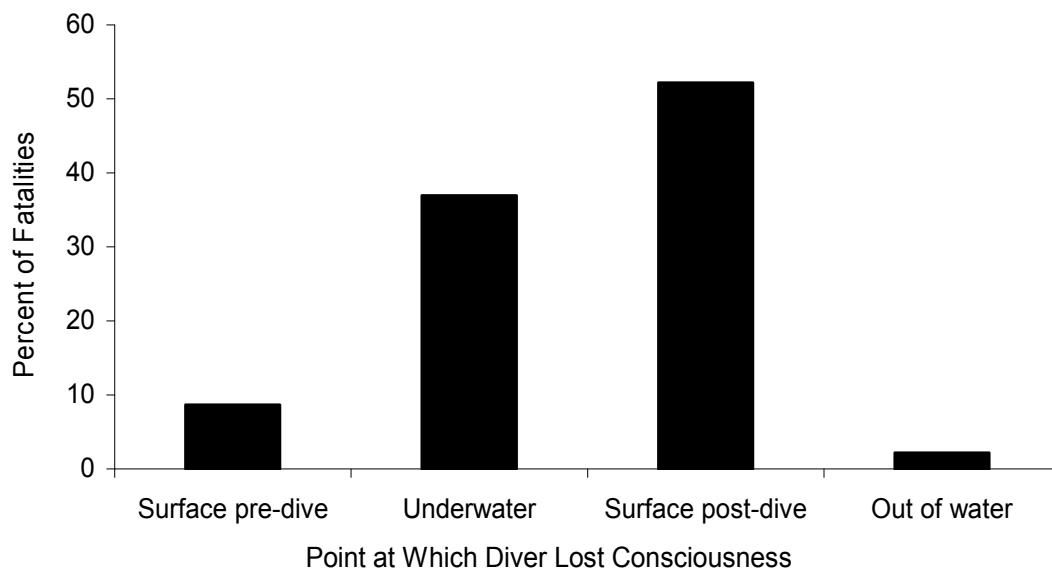
Figure 4.5.1-2. Dive phase when diver lost consciousness (n=46)

The point at which the victim lost consciousness was reported in 46 cases (61% of total). Most victims (n=24; 52% of known) were reported to have lost consciousness at the surface post-dive. The victims were reported to have lost consciousness while underwater in 17 cases (37% of known), at the surface before they submerged in four cases (9% of known), and after leaving the water post-dive in one case. Three of the four divers who lost consciousness before they submerged experienced acute heart problems. One rebreather diver disappeared suddenly from the surface without it being noticed if he had started breathing from his apparatus.

Fatalities often began and evolved over several dive phases. Table 4.5.1-1 shows the phase when problems started and when the diver lost consciousness.

Table 4.5.1-1 Accidents by stage of dive

Problem Started	Diver Lost Consciousness					
	Surface pre-dive	Underwater	Surface post-dive	Out of water	Missing Data	Total
Surface pre-dive	3		1		1	5
Descent/Early dive	1	1	3		3	8
Bottom		7	4		7	18
Ascent		4	2			6
Surface post-dive		1	8	1	2	12
Missing data		4	6		16	26
Total	4	17	24	1	29	75

4.5.2 Cause of Death (COD)

Cause of death (COD) was usually the best defined characteristic of a diving fatality, but preceding events were frequently more relevant to understanding what happened. In reverse chronological order, we defined the key events as COD, disabling injury, disabling agent, and trigger; where possible, we identified these components for individual cases. The disabling injury was not necessarily the COD but was ultimately responsible for the death. The disabling agent was the cause of the disabling injury, and the trigger was the event that began the sequence that ultimately culminated in death.

Figure 4.5.2-1 shows the distribution of COD as reported by coroners and medical examiners. COD was assigned in 58 cases (77% of total), not reported in 13 cases (17% of total) and the body not found in four cases (5% of total). Fifty cases (86% of known) were designated as drowning, five (9% of known) as acute heart condition, two (3%) as arterial gas embolism, and one as DCS.
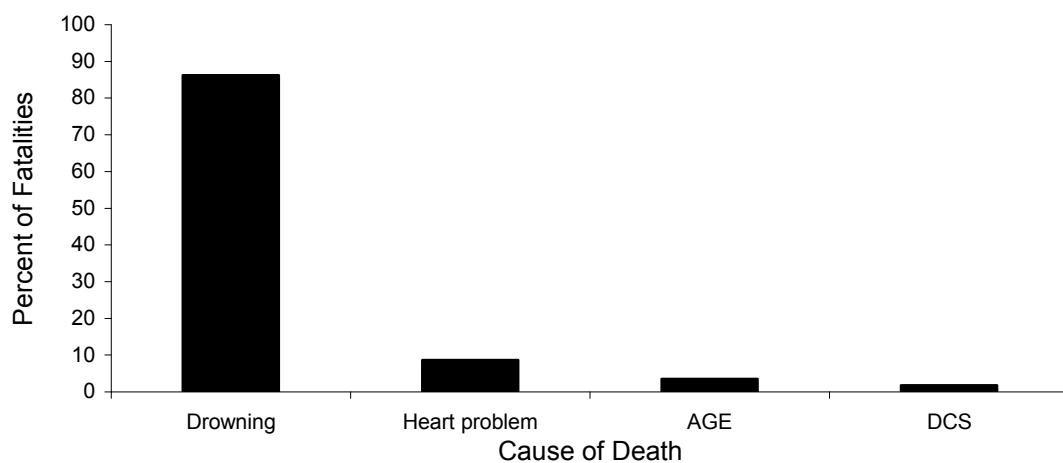
Figure 4.5.2-1. Cause of death (n=58)

4.5.3. Disabling Injury

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

Figure 4.5.3-1 shows the distribution of the disabling injuries. Decompression sickness, oxygen toxicity and hypoxia were suspected each in one case. The majority of cases with established disabling injury (n=46; 61% of total) were assigned drowning (n=22; 48% of known data), AGE (n=15; 33% of known data) or cardiac-related disabling conditions (n=13; 28% of known data).
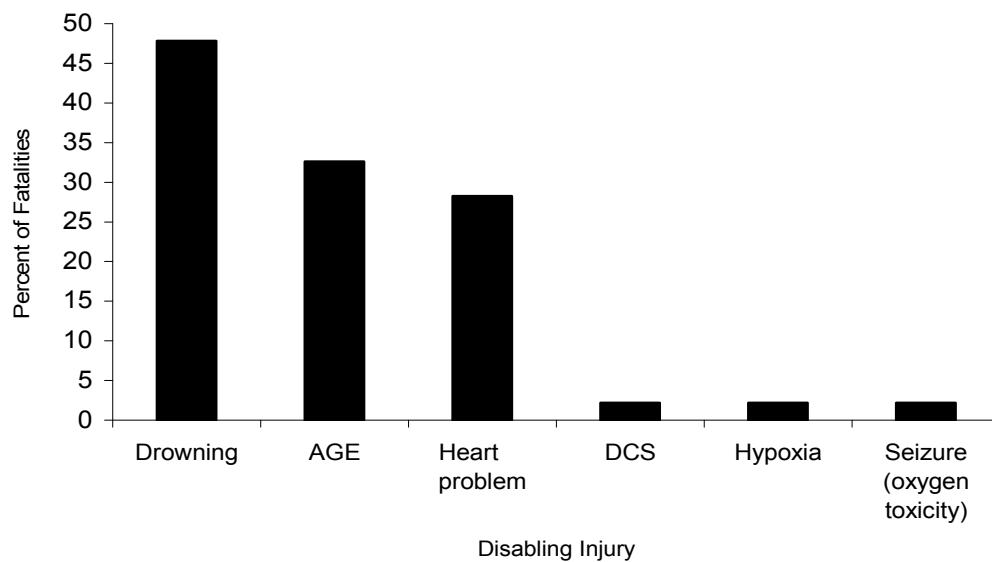
Figure 4.5.3-1. The distribution of the disabling injuries (n=46)

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 22 cases (48% of known). A typical drowning case is described below.

An inexperienced female diver in her late fifties was going to join a large group of divers, making a shore entry into poor visibility water. She was in a hurry and had someone else assemble her equipment. She descended quickly and had an early problem with her air source. Her buddy rendered assistance, providing an alternate air source and trying to assist her to the surface but he lost her and she sank back down. Two other divers brought the victim to the surface where resuscitation efforts were started. She never regained consciousness and died five days later in a hospital. An examination of the equipment showed that the tank valve was in the closed position and the power inflator hose to the buoyancy compensator was disconnected. The person who assembled the gear stated that all was in order with the gas turned on when the diver entered the water. It is unclear when the air was turned off in this scenario.

Criteria for the diagnosis of AGE include direct (finding of gas in cerebral arteries, signs of lung barotrauma) and circumstantial evidence (report of an emergency ascent; diver losing consciousness soon after surfacing, with or without signs of distress), evidence of a rapid ascent (electronic dive profile), and expert opinion of DAN reviewers. There were 15 cases (33% of known) that met the criteria as illustrated by the following case.

A male diver in his late forties was an experienced diver with basic open-water certification. He was diving with a group on a wreck to 130 fsw (40 msw). His deepest dive previously was to 85 fsw (26 msw). Shortly after descending the diver panicked while at 90 fsw (27 msw). The victim's buddy and a dive instructor held the diver back as he tried to make a rapid ascent and they all ascended together. On the surface the victim was breathing rapidly and lost consciousness while being pulled to the boat. Resuscitation efforts were unsuccessful. The autopsy demonstrated intravascular gas, pleural adhesions, and changes associated with drowning. The cause of death was drowning and the disabling injury was an air embolism that resulted from a rapid, panicked ascent.

In another case, both COD and disabling injury were AGE. An experienced diver in his sixties did a dive from a boat along with a group of divers. The dive was to 62 fsw (19 msw) for 36 minutes and included a safety stop. As the diver began to climb into the boat he lost consciousness and fell back into the water, sinking slightly below the surface. He was recovered immediately but never regained consciousness. The autopsy disclosed large amounts of intravascular and intracardiac gas, along with some evidence of saltwater aspiration. The cause of death was determined to be air embolism. Saltwater aspiration may have made him cough, contributing to lung barotrauma.

Cardiac-related death in diving is hard to prove. Acute cardiac event-like rhythm disturbances may cause sudden unconsciousness and lead to drowning leaving no traces pointing to heart function. Myocardial infarction may occur spontaneously or be provoked by exertion, possibly disabling a diver and resulting in drowning before changes in heart tissue are evident. Autopsy findings of the cardiovascular system primarily describe chronic changes that may be associated with increased risk of cardiac-related death, not direct proof of acute involvement. To implicate acute heart problems in diving death experts rely mainly on the circumstances of the accidents and medical history of decedents. The following case was assigned as cardiac-related death in diving.

A male diver in his early sixties was making his second dive of the day with a buddy. According to witness reports the victim complained of shortness of breath, lost consciousness and sank. The buddy was just below the surface and pulled him back up. Resuscitation efforts were unsuccessful. If an autopsy was performed the findings were not made available. Given the witness accounts and other circumstances, the fatal outcome was most likely due to a cardiac event. The incident was classified as a dive-related death because the victim entered the water equipped with scuba equipment and the intent to dive. While life-threatening cardiac events may occur unprovoked, we recognize that the physiological strain of immersion may trigger cardiac problem in people at risk, and that any problem involving loss of consciousness in the water can increase the risk of a poor outcome.

In many cases evidence is incomplete and may appear controversial. Recorded dive profiles downloaded from dive computers may help clarify circumstances of the dive. Figure 4.5.3-2 shows the dive profile of a six minute dive to 130 fsw (40 msw) with an ascent to the surface in 45 seconds. The dive profile record helped to resolve some conflicts in witness reports regarding when and how the victim reached the surface.
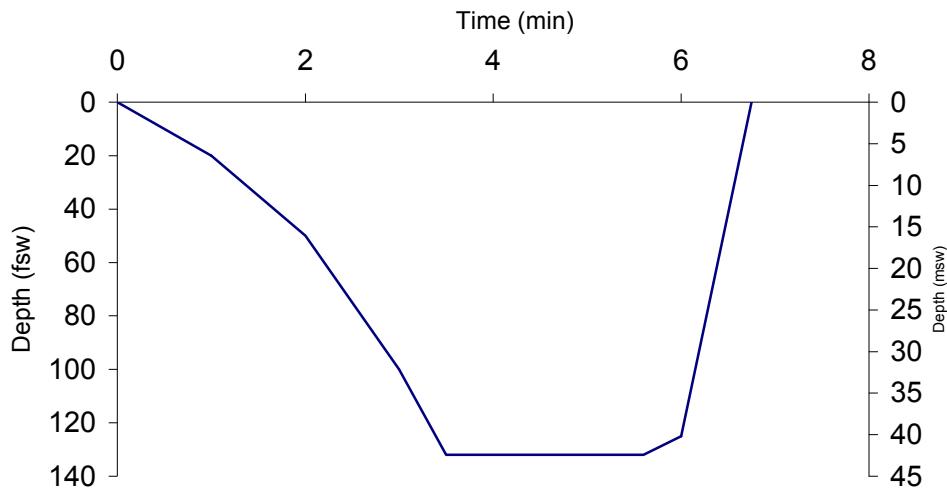
Figure 4.5.3-2. The dive computer recorded dive profile in a fatal accident involving an emergency ascent

This 35-year-old male was reportedly an experienced diver with divemaster and rescue diver certifications. He was assisting with an advanced open-water certification class on a dive planned to 130 fsw (40 msw) for five to seven minutes. When the group was ready to ascend, the victim could not get off the bottom. It took the instructor and another diver to get him to 80 fsw (24 msw). From there the assistant who inflated his buoyancy compensator did a buoyant ascent to the surface and instructor got the victim to the surface by himself. The instructor thought the victim lost consciousness before they reached 50 fsw (15 msw). The victim was unconscious at the surface. Resuscitation efforts were unsuccessful. The inspection of the equipment showed that the diver carried 17 lb (7.7 kg) of weight in each of two pouches on his weight belt and 6 lb (2.7 kg) in his BCD. One pouch was released in the process of the rescue but the other 17 lb was not released despite the fact that the mechanism worked perfectly. The autopsy demonstrated changes associated with drowning and extensive intravascular gas, including involvement of the cerebral arteries. The decedent also had focally severe coronary artery disease, a patent foramen ovale, and a family history of early death due to heart disease. While the drowning was the cause of death in this case, the existing coronary artery disease probably impaired diver's performance and even rendered him unconscious. The arterial gas embolism most likely occurred while the unconscious diver was brought to the surface.

4.6 Conclusion

Death while diving may occur regardless of age, skill and experience level, in any environment and during simple as well as complex dives.

Proper preparation, adherence to sound safety practices and good decision-making will decrease the chance of individual divers becoming victims.

Deaths in diving related to the acute health conditions may seem unpredictable but they are often associated with multiple risk factors in the health history of decedents and thus may be preventable.

4.7 References

Acott CJ. Recreational scuba diving equipment problems, morbidity and mortality: an overview of the Diving Incident Monitoring Study and Project Stickybeak. *SPUMS J.* 2003; 33(1): 26-33.

Cumming B. BS-AC NDC diving incidents report. *http://www.bsac.org/page/805/incident-report-2006.htm*.

Denoble PJ, Caruso JL, Dear DL, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med.* 2008a; 35(6): 393-406.

Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA, Vann RD. Scuba injury death rate among insured DAN members. *Diving Hyperb Med.* Diving Hyperb Med. 2008b; 38(4): 182-8.

Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA.* 2006; 295(13): 1549-55.

Pollock NW, Vann RD, Denoble PJ, Freiberger JJ, Dovenbarger JA, Nord DA, McCafferty MC, Caruso JL. *Annual Diving Report - 2007 Edition.* Durham, NC: Divers Alert Network; 2007; 118 pp.
Vann RD. The history of Divers Alert Network (DAN) and DAN Research. In: Moon RE, Piantadosi CA, Camporesi EM, eds. *Proceedings of Dr. Peter B. Bennett Symposium.* Durham, NC: Divers Alert Network; 2007: 81-120.

Vann RD, Freiberger JJ, Caruso JL, Denoble PJ, Pollock NW, Uguccioni DM, Dovenbarger JA, Nord DA, McCafferty MC. *Annual Diving Report - 2006 Edition.* Durham, NC: Divers Alert Network; 2006; 99 pp.

5. BREATH-HOLD DIVE INCIDENTS

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. 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 dive depth and/or breath-hold time are common goals. The nature of the dives will vary dramatically with the individual skill and training level of participants.

Freediving, perhaps the purest form of breath-hold diving, has generated substantial public interest. Developing rapidly as an extreme sport, there are numerous competitive disciplines recognized by the International Association for the Development of Apnea (AIDA; http://www.aida-international.org). The disciplines and current record performances are summarized in Table 5.1-1.

Freediving competitors have far exceeded what were previously believed to be human capabilities. The advancement of record performance in the 'No Limits' category, in which freedivers reach the greatest depths, is shown in Figure 5.1-1 (Pollock, 2008).

Table 5.1-1 AIDA-Recognized Competitive Freediving Disciplines and Record Performance
(current September, 2008)

Discipline	Description	Record Performance Male	Female
Static Apnea (min:s)	resting, immersed breath-hold in controlled water (usually a swimming pool)	10:12	8:00
Dynamic Apnea - with fins (m [ft])	horizontal swim in controlled water	801 (244)[1]	673 (205)[1]
Dynamic Apnea - no fins (ft [m])	horizontal swim in controlled water	610 (186)[1]	495 (151)[1]
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	459 (140)	400 (122)
Constant Weight - with fins (ft [m])	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	370 (113)	312 (95)
Constant Weight - no fins (ft [m])	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	282 (86)	197 (60)
Free Immersion (ft [m])	Vertical excursion propelled by pulling on the rope during descent and ascent; no fins.	354 (108)	280 (85)

[1] horizontal swim
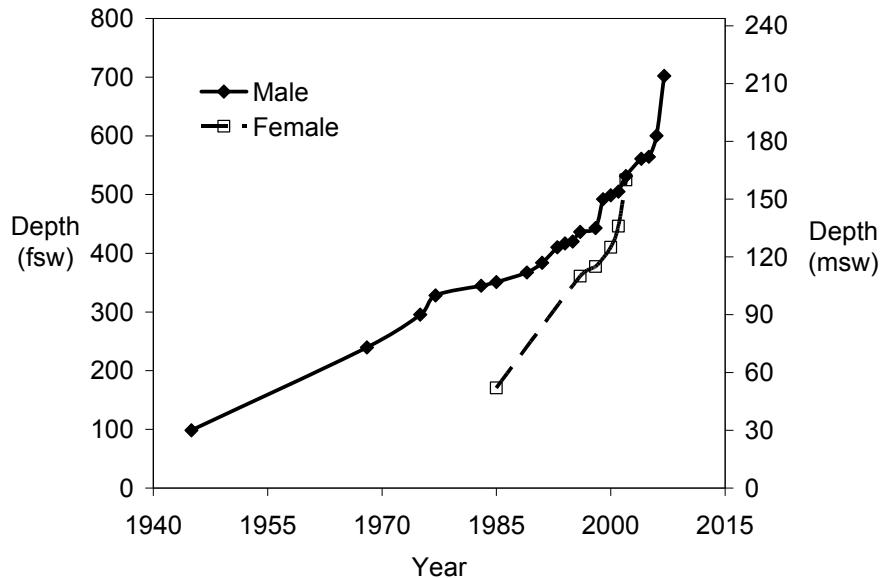
Figure 5.1-1 World record depths in freediving 'No Limits' competition (Pollock, 2008)

Extensive safety protocols and procedures 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.

DAN began active collection of breath-hold incident case data in 2005. The initial effort was a retrospective review of 2004 events (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 case intake from 2004 through 2006 was 85 incidents (23, 22 and 40, respectively). Unlike the data analyzed by DAN for compressed-gas diving accidents, the breath-hold incidents include cases from around the world. 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 DAN at no cost (www.dan.org).

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.

The greatest challenge in the study of accidents is incomplete information. The investigative effort can require a substantial amount of deductive reasoning and occasionally 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 example cases.

5.2 Cases in 2006

Most cases were initially identified through automated internet searches, typically as online newspaper articles. A small but growing number of cases were reported to DAN directly by individuals involved in the incidents. Complete details were rarely available, particularly for international cases.

Forty cases are included in this summary, 34 fatal (85%) and six non-fatal.

Incidents were reported from 14 different countries. More than half (n=23; 57%) occurred in the United States. The U.S. incidents occurred in four states: Florida (61%; 14/23), Hawaii (26%; 6/23), California (9%; 2/23), and Texas (4%; 1/23). The concentration on U.S. incidents likely reflects a bias in the available reports rather than a true worldwide pattern. Similarly, the distribution of U.S. incidents may reflect the popularity of breath-hold activities in certain states but may also include a reporting bias. It is anticipated that case identification will continue to improve in all areas as our data collection program is recognized by breath-hold divers and support groups.

The majority of known incidents occurred in the ocean (85%; 34/40). Three cases occurred in rivers or springs (10% of known), two in pools, and one in a lake.

Categorical descriptions of the primary activity of the incident victim are shown in Figure 5.2-1. Snorkeling remains the most commonly applied descriptor of the activity. The annual pattern of activity assignment shows fluctuations expected with a small total number of cases. The increase in activity identified as freediving may reflect a shift to this activity or a growing public awareness and use of the term.
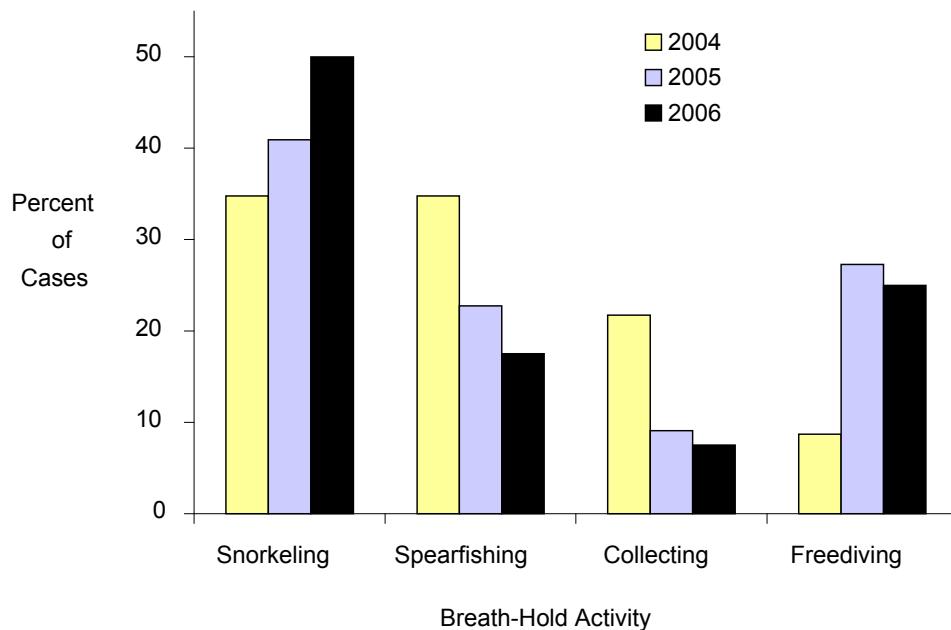
Figure 5.2-1: Distribution (percentages) of described primary activity for breath-hold incident casualties in 2004 (n=23), 2005 (n=22), 2006 (n=40)

Figure 5.2-2 describes the gender and age of all known victims. Males constituted 80% (32/40) of the victims. The representation of females increased from 1/23 in 2004 and 0/18 in 2005 to 8/40 in 2006. The average age (± standard deviation) was 41±16 years, ranging from 6 to 77 years. The age of victims in 2005 was 38±15 years (range 18 to 68 years).
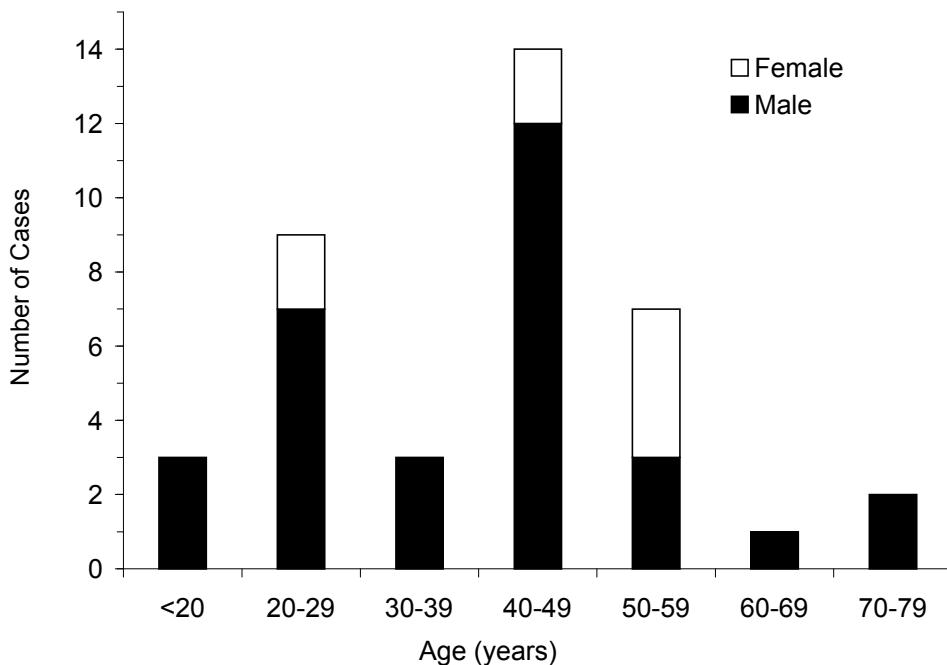
Figure 5.2-2: Age and gender distribution of breath-hold incident victims in 2006 (n=39)

Information regarding the support available to the diver was captured in 90% (n=36) of the known cases. Of these, the activity was conducted in a group in 36% (n=13), solo or with no support in 33% (n=12), with a dive partner in 28% (n=10), and with watchers remaining in a boat in one case.

Information regarding the availability of eyewitness accounts was determined in 88% (n=35) of the known cases. Witnesses were present in less than half (46%; n=16) of the cases. The availability of assistance to the victim was established in almost two-thirds of the known cases. Timely assistance was provided in 52% (n=13) of the cases with documentation.

The type of dive platform used was determined in 80% (n=32) of the known cases. Dayboat-based activities represented 59% (n=19) of the documented cases. Beach- or shore-based activities represented 31% (n=10) of cases. Two cases occurred in swimming pools and one involved the use of a jetski as a base.

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 is the effort to identify the problem or problems that created the situation in which the drowning ultimately occurred. The search for contributing factors is challenging, particularly in the case of unwitnessed events.

Very few records for the 2006 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 2006 breath-hold incidents

Hazard Cluster	Count	Percent
General Health	13	32.5
Blackout	12	30.0
Boat Strike	5	12.5
Animal	5	12.5
Poor Practice	2	5.0
Physical Skill	2	5.0
Unknown	1	2.5
Total	40	40

General Health

Thirteen cases were associated with personal health issues, all fatal. This represented the largest share of cases (35%). Cardiorespiratory problems were most commonly suspected.

Victims classified under the health cluster were 54±10 (41-77 years (mean±standard deviation). This is not surprising. Older persons may suffer from a range of health issues, a relative lack of physical fitness, and possibly limited experience with breath-hold activity. There were a substantial number of cases of physiological collapse associated with what might best be described as holiday snorkeling activity, six on commercial tours and three during self-guided activity. The mean age of this group of nine was 51±7 (42-65) years. It is unclear if the number of cases reflects an increase in participation or an increase in case identification. It is common for news reporting to increase once multiple cases of a type are recognized.

Current and wave conditions that may not pose a challenge to physically fit and/or experienced individuals 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.

Blackout

Twelve cases were associated with blackout; all but two fatal. The victims were 33±10 (16-45) years of age (mean±standard deviation), on average, 21 years younger than those classified under the health cluster.

Contrasting the casual holiday snorkeler, serious freedivers are more likely to employ various strategies to extend breath-hold time. This can increase the risk of blackout independent of health status and age. It is not unreasonable to expect, however, that there might be a positive relationship between age and caution.

Blackout can occur during breath-hold for a number of reasons. The most common are related to hypoxia, often aggravated by hyperventilation.

Each of our respiratory cycles is followed by a brief period of breath-hold (apnea) prior to the next inspiration-expiration pair. 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 exchanging gas - breathing - in excess of metabolic need (i.e., hyperventilation) will flush carbon dioxide from the body and delay the point at which carbon dioxide accumulates to the breakpoint during a subsequent breath-hold. The accumulation of oxygen stores associated with hyperventilation is far less than 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. Effectively, the loss of consciousness that can follow hyperventilation-augmented breath-hold may occur with absolutely no warning. Blackout occurring at or near the maximal depth of the dive is often associated with hypoxic loss of consciousness (HLOC).

A major effect of the increasing pressure of depth is an increase in the partial pressure of gases in the lungs and bloodstream. This makes more oxygen available to the cells and shifts the carbon dioxide concentration closer to breakpoint. The carbon dioxide partial pressure may still be far below breakpoint if a substantial amount of hyperventilation was employed to lower it pre-dive. The more critical evolution occurs during surfacing, when the ambient pressure reduction makes the partial pressure of oxygen fall at a faster rate than by metabolic consumption alone. A state of problematic 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 and therefore unlikely to stimulate a strong urge to breathe. Effectively, the risk of hypoxia-induced loss of consciousness 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 (before the oxygen in the first inspired breath has time to reach the brain). Again, the loss of consciousness will be without warning. Many will be familiar with this as 'shallow water blackout' but since that name was first used to describe a condition subsequently determined to be hypercapnia associated with scrubber failure in closed-circuit divers, 'hypoxia of ascent' is used here.

The categorization of cases of blackout as HLOC or hypoxia of ascent is generally dependent on witness observations. Confirming where the loss of consciousness developed is often not possible unless the actual event was witnessed.

Hypoxia-induced blackout continues to be a major life threat to healthy and often extremely capable breath-hold divers. The 10 cases identified in 2006 (excluding those with insufficient information to draw confident conclusions) could probably all have been avoided with additional caution in personal practice and/or the availability of adequate backup. Four of the 10 blackout cases were known to have involved spearfishing or seafood collection. At least four more fatalities involved solo divers for which the details leading to death cannot be determined. There is a tendency for spearfishermen to resist being limited by close support, but independent operation clearly represents a substantial compromise in safety. Intemperate

use of hyperventilation compounds the risk. The combination can easily result in poor outcomes.

One of the non-fatal blackout cases captured in full detail in the DAN breath-hold database occurred in early 2006. The availability of a fast response depth-time data logger and multiple witness statements made this a good example of the detail we would like to be able to get from all cases (Pollock, 2006). Briefly, a 41-year-old male was one of a group of four experienced freedivers spearfishing during a vacation in Hawaii. His current maximum dynamic breath-hold time was 2:30 min:s. The conditions were light seas, slight current, and visibility greater than 50 ft (15 m) on this first day of the trip. He completed 12 modest dives (maximum depth 44 fsw [4-13 msw] and maximum duration 59 s) followed by one more aggressive dive (90 fsw [27 msw] and 1:43 min:s duration) - the incident dive.

The diver later reported doing no hyperventilation before the dive, but described "several slow full exhalations and inhalations before taking a full breath." He planned to descend to approximately 60 fsw (18 msw) but the bottom was deeper than anticipated and he was approaching 90 fsw (27 msw) before he realized it. He paused briefly at his maximum depth to consider three fish targets but then decided they were not worth his attention and began his ascent. He chose to drop his speargun early in the ascent since it was negatively buoyant and attached to his float line. He then pulled hand-over-hand on the float line for the last half of the ascent.

The diver's narrative describes his perception of the end of the dive:
> *"I knew it was going to be a long haul, but I wasn't feeling much air hunger. As I passed 20 ft [6 m] I felt a little tired but relaxed. As I passed 10 ft [3 m] I knew I'd make the surface and began to relax a little. When I hit the surface, I blew out to take a breath, and then it was 'lights out.' I didn't feel it coming on at all."*

The narrative of one of his rescuers provides a second perspective:
> *"I saw that he was fairly deep during the dive, so I kept my eye on him as he was coming up. I noticed he left his gun below and that he was ascending hand-over-hand on the tag line. He came up calmly, with no sign of anxiety. I swam towards him and watched him surface and then thought to myself that I had been overly concerned and started to swim away from him. I didn't want him to think I was crowding him. I was breathing up when I decided to take another look his way to make sure he was still okay. It was a shocking sight. He was unconscious below the surface of the water, in a T position, with arms straight out, his face slightly upward, one of his hands twitching, and he was sinking."*

The diver sank to a depth of eight feet (2.4 m) in approximately five seconds. He was then pulled to the surface, his weight belt removed, and supported closely until he regained consciousness. Transient headache, slight nausea and some difficulty concentrating persisted for the next hour. There were no other complications.

This case highlights several issues. The diver was unfamiliar with the diving area, overweighted (22 lbs [10 kg] with a 7 mm wetsuit), and overconfident in his capabilities. Members of the group were aware of the importance of direct supervision post-dive, but did not employ it uniformly. Self-consciousness regarding supervision left the victim exposed and could easily have resulted in a much worse outcome. Finally, the poorly defined separation between hyperventilation and 'deep breathing' or 'workup breaths' is subjective and potentially a poorly appreciated source of risk (Pollock, 2006).

The preceding case demonstrates how the chain of errors can quietly grow to the point that a significant life threat develops. The chain could have been broken at many points. The diver could have watched his depth more carefully to limit the dive to the planned depth; he could have begun the ascent as soon as the greater depth was noticed, and he could have worked less during ascent by wearing less weight. Positive buoyancy at the surface would have also reduced the risk of less-than-scrupulous close supervision by other members of the group. There was a good deal of fortune involved in the victim being spotted sinking through five feet. The outcome of having to recover him from a deeper depth might well have been different.

The most important lesson from this case are that experience alone does not provide adequate protection. Thoughtfulness and vigilance by both the diver and a support team are necessary to ensure safety. This was demonstrated in the second non-fatal case, one involving disorientation rather than complete blackout during a no-limits training dive. Quick response and adequate support resulted in immediate resolution.

Boat Strikes

Five cases were associated with boat strikes; three fatal and two non-fatal. This contrasted two cases (one fatal, one non-fatal) identified in 2005. It is unclear if the increase represents normal annual variability or an increase in the overlap of activity areas. One of the saddest cases in 2006 involved a six-year-old killed by a 13 year-old operating a speedboat. Education of both breath-hold divers and boaters is critical to improve awareness and reduce the risk of conflict.

Animal Interactions

Five cases of injurious animal interactions were captured in 2006, four fatal and one non-fatal. One breath-hold diver was killed by an alligator while snorkeling, one drowned while trying to manipulate a 300 lb (136 kg) turtle to the surface to be tagged (Pollock, 2007), one died from the trauma of being struck in the chest by a stingray barb as he swam over the animal in shallow water, and one drowned after being entangled by his line after a speared fish swam into a hole. The one non-fatal case identified involved an individual seriously stung by Irukandju jellyfish. It is guaranteed that many minor and major animal-involved injuries to breath-hold divers were not reported in a manner that allowed them to be identified in our effort.

Poor Practice

Two cases, one fatal and one non-fatal, were assigned to this cluster. In reality, marginal or poor practice can be implicated in many cases. The non-fatal case involved a freediver who became unconscious after taking a breath from a gas pocket within a cave. He was saved by the immediate action of his partner. The fatal case involved a breath-hold diver who died alone in a cave when four friends using a single set of equipment took turns diving from the surface to explore.

Physical Skill

There were two fatal cases for which the lack of skill with swimming and/or snorkel gear appeared to be important factors in the loss of life. Both involved physically fit individuals under less than optimal sea conditions. One had been swimming alone in rough seas. The second was in a group having to swim back to shore from a buoy in an area with substantial current activity.

Unknown

There was one fatal case in which snorkel gear was worn that could not be classified since sufficient details were not available.

5.4 Reducing Breath-Hold Risks

Breath-hold diving includes a range of activities. Some are appropriately described as extreme; others as 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 2006 data differs from the two previous years in implicating pre-existing medical health/fitness conditions as a dominant factor in breath-hold incidents. The majority of these cases occurred during organized snorkeling tours or independent casual snorkeling. It is unclear if the case count reflects an increase in participation or reporting. Regardless, the data highlight the need for attention. Water immersion applies a physiological strain to the body. The strain can be compounded when inexperience, lack of ability with the equipment, and anxiety are also factors. Adding current or rough seas, even those perceived as mild to the experienced diver, may produce a high degree of effective stress.

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 shallow pool or confined water is much more appropriate to 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 hazard of blackout 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 the divers without the 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 water shallow enough that all divers can get to the bottom easily can take the novice diver 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 twice the dive duration for modest 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. Effective direct supervision requires close monitoring throughout the breath-hold and 30 second post-breath-hold periods. 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. Part of the problem is the sense of invincibility often used to explain the behavior of young males. 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 safety vest is currently under development 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.

The opportunity to swim with other animals is a major draw for many divers. Caution is warranted with animals capable of threatening diver safety. The animal interaction cases in 2006 were varied. Physically manipulating large animals is always a risk, but particularly so when limited to a single breath. Protective suits should also be worn when stinging organisms may be present. The best protective suit for diving with aggressive shark species is probably a big, metal cage. Chumming to attract animals is a dangerous strategy to employ with divers in the water. The spearfishing equivalent is carrying catch directly - best to be avoided.

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 DAN effort to collect breath-hold incident data initiated in 2005 relies primarily on automated internet keyword searches and volunteer submission of reports. The vast majority of cases captured in this effort are fatal events. While it is clearly important to identify such cases, it is also problematic that complete details are rarely available. An online reporting system is being initiated to expand the collection of cases, particularly non-fatal events for which more complete details will likely be available. It is expected that the additional insights available from those involved will be extremely helpful in identifying the chain of events involved in incidents.

5.6 Conclusion

A total of 40 breath-hold diving incidents occurring in 2006 were collected by DAN; 32 (80%) involving males and 34 (85%) fatal. Diver medical and physical fitness and hypoxia-induced loss of consciousness were the greatest problems. Efforts to promote diver medical and physical fitness, evaluations of readiness, and to share incident information may significantly reduce incident rates. Our efforts will continue to expand case collection, both fatal and non-fatal, and to provide insights to the community.

5.7 References

Butler FK. A proposed 60 second limit for breath-hold diving. In: Lindholm P, Pollock NW, Lundgren CEG, eds. Breath-hold diving. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006: 64-74.

Fitz-Clarke JR. Adverse events in competitive breath-hold diving. Undersea Hyperb Med. 2006; 33(1): 55-62.

Pollock NW. Breath-hold diving: performance and safety. Diving Hyperb Med. 2008; 38(2): 79-86.

Pollock NW. Development of the DAN breath-hold incident database. In: Lindholm P, Pollock NW, Lundgren CEG, eds. Breath-hold diving. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006: 46-55.

Pollock NW. Scientific diving safety: integrating institutional, team and individual responsibility. 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: 45-50.

APPENDIX A. DIVE INJURY CASE REPORTS

Case 1

This diver was a 44-year-old female in good health, on no medications, with no history of trouble on her previous dives. She was on a week long dive vacation in the Caribbean. She was diving on air and using a computer to calculate her bottom time.

The diver did three days of diving and performed 10 dives. Four dives were completed on the second day: Dive #1-80 fsw (24 msw) for 60 min, 45 minute SIT, #2-65 fsw (20 msw) for 50 min, 90 minute SIT, #3-50 fsw (15 msw) for 40 min, 45 minute SIT and #4-50 fsw (15 msw) for 40 min. The dives were uneventful and she reported no problems. Two hours after her dives, she noticed a sensation that the skin on her abdomen and thighs felt tight and she had mild itching and redness developing on her thighs and buttocks. She thought it unusual but attributed it to her wetsuit.

The following morning all symptoms had resolved and she performed three similar dives, all greater than 50 fsw (15 msw), all multilevel and with the maximum bottom times allowed by her computer. The decompression model employed was not known. Within minutes of her final dive on the third day the skin redness returned along with a more marbled looking rash and painful discomfort in her thighs and abdomen. She decided to wait for medical evaluation. The symptoms had not fully resolved by the next morning and friends convinced her to be seen by a physician at the local medical clinic.

She was diagnosed with skin bends and pain-only DCI in one thigh. She was treated with a USN TT6 with full resolution of her symptoms. She continued to have skin sensitivity to touch one week after treatment. The treating physician suggested she not dive for at least four weeks, be evaluated by her personal physician before returning to diving and use more conservative profiles and surface interval times to minimize decompression risk.

Thirteen months after this incident she contacted DAN to report she had another episode of itching and rash on abdominal area, more mild compared to her first episode and it resolved within one hour. She also had some chest tightness, described as "not bad" but resulting in her being winded with exertion. She was referred to her personal physician for evaluation before returning to diving.

Case 2

This diver was a 57-year-old female instructor. She reported no health issues and maintained physical fitness with regular exercise and teaching scuba. She had never had DCI. She was on vacation with her dive students doing deep and repetitive diving. She completed four dives over a single day.

She began her dive day with a 30 ft (9 m) dive for 30 min followed by a 30 minute SIT and then the same dive again followed by a three hour SIT. She then started her personal dives. The first one was to 110 ft (33 m) for 20 min followed by a 45 min surface interval. Her final

dive was to 150 ft (46 m) for 20 min which took her out of the water in the late afternoon. She had no problems or complications during any of the dives.

Approximately two hours after the final dive she experienced mild nausea and some visual (fuzzy) disturbances. She had a history of seasickness and was wearing an anti-motion sickness patch. She felt her symptoms were due to the patch needing to be changed. Thirty minutes after these initial symptoms she noticed a discolored skin rash on her abdomen that she had never had before. This was followed by the feeling of generalized weakness in all extremities. She then realized it may be DCS and presented herself to the local hospital four hours after symptom onset.

She was started on oxygen and her symptoms begin to improve after 30 min. She was then placed in a chamber and received a USN TT6 with complete relief of symptoms by the end of treatment. She had no residual symptoms and none came back with subsequent diving. She now has a less aggressive attitude toward diving and uses conservative methods for her repetitive dive profiles. At a two-year follow-up she reported that she continued to dive and teach without incident.

Case 3

This diver was a 37-year-old male recreational diver. He had no significant medical history and no medication use. He was an experienced diver and frequent weekend diver. He decided to dive during the mini-season for lobster in Florida.

He performed six dives over a 14 hour period using 32% nitrox. He used his computer to keep track of times and depths but did not give surface intervals. He did report the following approximate profiles: #1-85 fsw (26 msw) for 50 min; #2-75 fsw (23 msw) for 50 min; #3-75 fsw (23 msw) for 35 min; #4-70 fsw (21 msw) for 50 min; #5-85 fsw (26 msw) for 50 min; #6-70 fsw (21 msw) for 50 min; exiting the water at 2200 in the evening. Roughly 30 min after his final dive he noticed left arm pain that he described as 3 out of 10 in severity. It was present throughout the biceps and triceps regions. At first he believed it may be related to overexertion but remarked that it was unlike any pain he has experienced in the past. The pain was not affected by arm use or positioning. The diver denied the presence of any other symptom.

DAN was contacted 30 min after the pain had begun. It was recommended that he start oxygen via a demand valve and a friend volunteered to drive him to the referral hospital for physician assessment. The local recompression chamber was at the same location. His neurological examination was normal. His only complaint remained the arm pain. He was given a USN TT6 approximately 2.5 hours after symptoms began with good, but not complete, relief of the pain. The following morning the pain had resolved but chest burning was reported that was attributed to the chamber oxygen exposure.

On follow up the diver waited the suggested six weeks before returning to diving and had no further incident. He also admitted he was not sure what his breathing mix had been on the day of his injury. Two years out from the incident he continued to dive but less aggressively.

Case 4

This diver was a 22-year-old female, recently certified, with less than a dozen open water dives. She was in good health and was taking no medications. She was weekend diving off the coast, completing a total of four dives over two days. The final day of diving began with an 86 fsw (26 msw) dive for 36 min, an indeterminate SIT, and then a 67 fsw (20 msw) dive

for 36 min. The breathing gas was air and the dives uneventful except that she felt cold during the last dive and for a while post-dive.

Approximately three hours after surfacing she experienced a strange feeling in her right knee. It was described as kind of tingly, weird, dull pain, uncomfortable feeling. It was constant without change and she has never experienced anything like it before. The patient called her parents the next day because the feeling would not go away. DAN was called for assistance and referred her to a local physician for evaluation.

She was seen at the hospital and was placed on oxygen via mask. She did not notice any change in her symptoms from the oxygen. She received a CAT scan with no unusual findings. Her neurological exam was normal except for her subjective feeling of knee discomfort. She was then transferred to the closest chamber; three hours away. Chamber treatment began approximately 19 hours after the final dive. Treatment was a USN TT6. Her knee symptoms were greatly reduced but not completely resolved.

The patient continued to have mild knee discomfort for about one month. She also complained of a new symptom of sporadic pins and needles sensation in both legs for two days following the treatment. This was not part of her initial symptoms and likely unrelated. On follow up at two years, she reported no return of symptoms after they resolved post-treatment. The diver had decided not to return to diving.

Case 5

This 63-year-old male was a diving instructor and frequent diver. He had a clear medical history and was taking no medications. He was on a dive vacation in Latin America with his wife.

On his first day of diving he completed one dive to 97 ft (30 m) for approximately 20 min breathing air. He was not using his own equipment and the BCD he was using was continuously adding air causing him to end his dive with a rapid ascent in the last 30 ft (9 m). He was able to get his ascent under control before reaching the surface. He did not omit any decompression.

Approximately two hours after surfacing he began to experience right shoulder pain that he described as 6 out of 10. He waited for the pain to resolve for 48 hours and went to the chamber when the pain persisted. The physician evaluated the diver and diagnosed him with pain-only DCI, treating him with a USN TT6. There was a mild reduction in his symptoms (pain receding to 4 out of 10). He received an additional two USN TT6 treatments with progressive resolution with each treatment. After the third treatment, he felt he had improved to 80% of normal. He and his wife were told to wait 72 hours before flying home, which they did.

The flight home caused a slight increase in the diver's pain and DAN was contacted again for advice and local referral. He received another USN TT6 which resolved most of the remaining symptoms he was experiencing. The residual symptoms resolved in about one month. At a two-year follow-up, the diver reported having returned to diving without further problems.

Case 6

This 64-year-old female was a frequent, recreational diver. She was traveling with family and friends on an extended dive and travel vacation. She was taking a daily aspirin and medication for her liver. Her history included a mild DCS incident 14 years earlier.

The diver completed 21 dives over a 13 day period. The day prior to her call she completed a series of three dives breathing air. Her profiles were #1-82 ft (25 m) for 40 min; SIT=2 h; #2-59 ft (18 m) for 40 min; SIT=3:30 h:min; and #3-59 ft (18 m) for 40 min. She exited the water at 1630.

Approximately 90 min after her final dive she complained of difficulty moving the fingers of her right hand and right elbow and shoulder pain. She was immediately placed on surface oxygen. Twenty minutes later she experienced difficulty walking and described weakness in her lower extremities. In another 30 min she developed left shoulder, arm and hand pain. She was transported via boat for four hours to a ground ambulance and then a four hour ride to a hospital. It was 12 hours after symptom onset when the patient began hyperbaric recompression. The oxygen given during the transfer helped, but symptoms came back when she was off of oxygen for any length of time.

The diver received a USN TT6 with extensions at 60 fsw (18 msw). She had significant improvement in her symptoms but symptoms did not completely resolve. She received a USN TT5 the following day with complete resolution of her pain and weakness, but with no change in the remaining numbness and tingling sensation of her left arm. The residual symptoms remained for several months with gradual clearing to involve just her left hand. Resolution continued slowly, but at the two year follow up, she still had some numbness and tingling.

She returned to diving but limited her dives to no more than 80 ft (24 m), no more than two dives per day and no more than two consecutive dive days.

Case 7

This diver was a 61-year-old male who's only reported medical history was medication for hypertension. He was on a liveaboard vessel in the Gulf of Mexico, 80 mi (128 km) from the mainland. He was diving on air and using a computer to calculate his dives. He had performed 14 dives over the previous four days.

On the final day of diving he completed two dives. The first was to 79 fsw (24 msw) for nine minutes of total bottom time, followed by a two hour surface interval. The next dive was to 175 fsw (53 msw) for 17 min with a total run time of 91 min. All decompression stops were on air. Dives were uneventful.

Thirty minutes after the second dive he experienced the sudden onset of acute vertigo with nausea and vomiting. He felt it was probably motion sickness. He waited 90 min before deciding to try oxygen. There was no improvement after 15 min and the boat crew encouraged him to stay on oxygen. A physician onboard also started fluid replacement with an intravenous line. He was airlifted to a mainland hospital for further care and hyperbaric therapy. His first treatment started eight hours after surfacing from the dive.

At the chamber he was found to have severe gait disturbance, was unable to stand unaided, and continued mild nausea. He was diagnosed with vestibular (inner ear) DCS. He was treated with a USN TT6 that provided improvement but not resolution. He was treated six more times but still had problems with heel-to-toe walking. He was referred to his personal

physician for follow up. It was suggested he not dive for at least three months. The slight unsteadiness of his gait cleared up in two months; he returned to diving three months and subsequently performed over 70 dives without incident. He had switched to nitrox blend gas for diving and set his computer for air dives. He also decreased his frequency of dives, dive times and depth to lessen nitrogen absorption.

Case 8

This diver was a 61-year-old male in good health, taking no medications. He was on a liveaboard dive vessel in the South Pacific, vacationing with his son. He had completed 700 lifetime dives over 35 years. On this trip he had performed 13 dives over a five day period breathing air (two or three dives per day). His deepest dive was to 148 fsw (45 msw) and he reported having no problems with any of the dives. This was his typical style of diving.

His final day of diving started with a 148 fsw (45 msw) dive for 37 min with a customary safety stop. Upon surfacing, he became disorientated and had numbness and weakness in both legs. He required help getting back into the boat. The only oxygen immediately available was a nitrox blend. He was able to get up and walk to his cabin without assistance after breathing the blend; but his symptoms had only slightly improved. He was then taken to a medical clinic and placed on 100% oxygen. From there he was transported to a remote chamber facility. His only improvement to this point was a slight reduction in disorientation. Six hours after initial symptom onset he received his first USN TT6. A physician's evaluation revealed numbness, weakness and hyperreflexia in his legs. His mental clarity issues resolved, but his other symptoms progressed to lower extremity paralysis, severe pain in the abdomen and legs and loss of bowel and bladder function.

His symptoms worsened by the next morning, whereupon he received a second USN TT6 and a USN TT5 each day for two more days. He was then transported to a second hyperbaric medical clinic and received two more wound healing treatments without improvement. He was then evacuated home.

Two years from the incident; his legs remain paralyzed with minimal movement, he had limited bowel and bladder function and was medicated for his chronic pain. Further diving was not possible for this individual.

Case 9

This diver was a 50-year-old male, reportedly recovered from pneumonia one month prior and with a history of back injuries which usually did not affect him. He was an experienced diver with hundreds of dives completed over 20 years.

He was on a week long dive vacation at a Caribbean resort. He performed six dives over three days. He breathed a nitrox blend on the first two days and air on the third day. On the third day he performed a dive to 133 fsw (41 msw) for 37 min. Following the limits given by his computer, he performed an obligatory decompression stop. Following a one hour SIT he completed an 88 fsw (27 msw) dive for 47 min. His computer indicated the need for two decompression stops. He completed the first without incident. During the final stop, current and rough surface conditions jerked him upward to 13 fsw (4 msw) from 20 fsw (6 msw) while waiting on the dive line.

Within 10 min of surfacing he experienced mild right shoulder pain and numbness in arm and hand. He was immediately placed on 100% oxygen via a demand valve with symptoms resolving. He was symptom-free for about 20 min. He then experienced dizziness and

bilateral numbness with tingling in both legs and difficulty standing and walking. He was again placed on oxygen and got what he felt was complete resolution of symptoms. Within 30 min the boat had come back into shore and he reached the local clinic with a chamber.

On physician's examination, the diver had an unsteady gait but an otherwise normal neurological examination. He had no urinary or bladder problems prior to entering the chamber, but he did complain of the return of leg tingling and weakness. A USN TT6 was started and he felt better, with resolution of symptoms at 60 ft (18 m). When the chamber went to 30 ft (9 m) he experienced a return of tingling in both legs and felt pressure in his abdomen. After the treatment he had some difficulty with urination. By the next morning his symptoms had worsened. He could not produce any urine, his legs were numb to touch, and walking was difficult due to weakness. The physician was not available for assistance or retreatment. The diver was evacuated to the US for a higher level of medical care.

The patient received two additional USN TT6 treatments and gradually improved. He continued to have altered skin sensations in his lower legs and feet and a feeling of leg weakness for two months. He returned to diving seven months after the event without any new or worsening symptoms. Two years out from the incident he still had periodic hot and cold sensations on the soles of his feet.

Case 10

This 54-year-old male was an experienced technical diver, nitrox and trimix certified. He performed over 80 dives per year in the last 10 years. He frequently participated in deep wreck and decompression diving. He had no previous DCS history but admitted to aches and pains after diving that sometimes took a day or more to resolve. The only relevant medical history was that he was taking antidepressant medication.

He completed a single weekend air dive to 195 ft (59 m) with a 15 min run time and 24 min of required in-water decompression, some of which was done on 100% oxygen. He planned the dive using air tables and a wrist worn dive slate. The dive was complicated by overstaying the bottom time by two minutes to assist another diver. He completed decompression for the planned 13 min of bottom time, ignoring the extension.

Fifteen minutes after the dive he found a consolidated red raised rash around his right shoulder. The area also became painful, about a '2' on a 0-10 intensity scale, and he then experienced a weak sensation in the right arm, 30 min post-dive. He believed this could be DCS and treated himself with oxygen via demand mask for 30 min without change in symptoms. The next day the pain continued to worsen, a level of '8' out of 10 and he again tried oxygen for 30 min without relief. The pain was constant, not affected by movement and he could not find a position of comfort. He tried a non-steroidal anti-inflammatory drug (NSAID) with very little relief.

On the second day post-dive he realized the pain was not changing and likely to be DCS at which point he called DAN. He denied having any other symptoms and was referred to a local physician. On examination the shoulder pain was identified as well as continuing weakness in the right arm. He was diagnosed with neurological DCS.

He received a USN TT6 which resolved the rash, lessened the pain, but did not affect the mild weakness. After a second USN TT6, the weakness resolved completely. He was advised not to dive for four weeks and followed that recommendation. At a two-year follow-up, he reported completing over 120 dives, most of them technical, since the incident. He

changed to a computer with more capabilities and limited the depth on his air dive profiles. He had not experienced any similar incident and planned to continue his diving career.

Case 11

This 45-year-old male was a technical diver, healthy, taking no medications, with a history of patent foramen ovale repair specifically for his technical diving. He exercised regularly. He completed a series of two weekend dives on a rebreather operating in open-circuit mode with nitrox.

The first dive was to 120 fsw (37 msw) for an actual bottom time of 32 min followed by a surface interval time of two hours. The second dive was also to a maximum depth of 120 fsw (37 msw) but for an actual bottom time of 25 min. Both dives required staged decompression stops which were completed on various mixes of EAN and 100% oxygen following a schedule set forth by his dive computer. There were no reportable problems or complications with either dive.

Three minutes after surfacing from his final dive, he experienced a sudden onset of persistent right shoulder, elbow and wrist pain, judged to be a magnitude of '8' on a 0-10 intensity scale. He noted perceptible motor weakness in his right hand and wrist one hour later while trying to hold eating utensils to eat lunch. His medical history was unremarkable and non-contributory, except for the patent foramen ovale (PFO) closure approximately five years earlier.

The diver was transported to the nearest hospital with a hyperbaric center where he was evaluated and treated with hyperbaric oxygen seven hours following his last dive. His initial exam revealed acute right upper extremity pain and weakness with active power against gravity but not resistance. He was diagnosed with a neurological decompression incident. Hyperbaric treatment began with two USN TT6 treatments without extensions, followed by a daily series of five wound healing treatments at an equivalent depth of 45 fsw (14 msw) for three hours each. He received a total of seven hyperbaric treatments, effectively resolved the motor weakness and pain. He returned to diving five months later and has completed 175, mostly technical, rebreather dives without further problems over the following 1.5 years.

APPENDIX B. DIVE FATALITY CASE REPORTS

Proximate Cause: Air Embolism

06-10 Certified, experienced diver, diving with group, lost consciousness on climb back into boat and fell back into water.

Cause of Death: Air Embolism due to Scuba Diving

This 62-year-old male was an experienced, certified diver making a dive from a boat with a group of divers. The dive was to 62 fsw (19 msw) for 36 minutes and included a safety stop. As the diver began to climb into the boat he lost consciousness and fell back into the water, sinking slightly below the surface. The other divers rendered aid but the stricken diver was pronounced dead on arrival back at the dock. The autopsy disclosed large amounts of intravascular and intracardiac gas, along with some evidence of saltwater aspiration. Toxicology studies were positive for buproprion (generic name for prescription medication with brand names including Wellbutrin and Zyban) and diphenhydramine (generic name for prescription medication with common brand name Benadryl). Additional medical problems included obesity and degenerative joint disease involving the spine. The cause of death was determined to be air embolism.
BMI = 31.3 kg·m^{-2}

06-29 Experienced technical diver, diving with buddy on rebreather, switched to open-circuit and made rapid ascent, lost consciousness on swim to boat.

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

This 59-year-old male was an experienced, certified diver with technical diving training and certification. He was making a dive from a boat with a buddy and was using rebreather apparatus. The buddy stated that the victim unexpectedly bailed to open-circuit, made a rapid ascent, and began to swim toward the boat. The crew on the boat said the victim then lost consciousness and they dragged him onboard. Resuscitation efforts were unsuccessful. The victim's dive profile was 80 fsw (24 msw) for four minutes with a rapid ascent. The victim apparently had trouble with the mouthpiece of his rebreather on the previous dive; he could not close it off completely and the bore seemed narrowed by a foreign object. He did drop his weight belt at depth. There was no mention of an autopsy being performed but the most likely cause of death would be an air embolism due to a rapid ascent, given the circumstances provided by the witnesses.
BMI = na

Proximate Cause: Drowning/Air Embolism

06-01 Inexperienced diver, diving with buddy in group, surfaced from dive in distress, sank below surface, brought to boat by buddy.

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

This 44-year-old male was a certified diver with 20 lifetime dives. He was participating in a multi-day dive trip, making dives with a buddy in a group of four divers. The divers surfaced from a dive to 77 fsw (23 msw) that included a safety stop at 18 fsw (5 msw). The diver was in obvious distress on the surface and while the buddy deployed a safety sausage, the victim sank below the surface. The buddy brought the victim to the boat where resuscitation efforts were unsuccessful. The autopsy findings and results of an investigation were consistent with air embolism as the cause of death.
BMI = 24.9 kg·m^{-2}

06-04 Certified diver with unknown experience, made shore entry dive with buddy, ran out of air and attempted to share air with buddy, panicked, lost consciousness.

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

This 50-year-old female was a certified diver with an unknown amount of diving experience. She made a shore entry dive with a buddy to a maximum depth of 100 fsw (30 msw) for a bottom time of 25 minutes. The victim ran out of air at depth and made an unsuccessful attempt to share air with her buddy. The victim panicked and during the ascent lost consciousness at approximately 10 fsw (3 msw). The autopsy report was not made available and the death certificate lists both drowning and air embolism as the cause of death. This most likely represents drowning secondary to an air embolism initiated by an out-of-air situation.
BMI = na

06-08 Experienced diver with basic certification, diving with group on wreck, panicked at depth, tried to make rapid ascent, buddy and instructor held back for normal ascent, lost consciousness while boarding boat.

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

This 48-year-old male was an experienced diver with basic open-water certification. He was diving with a group on a wreck to 130 fsw (40 msw). His deepest previous dive was to 85 fsw (26 msw). Shortly after descending, the diver panicked while at 90 fsw (27 msw). The victim's buddy and a dive instructor held him back as he tried to make a rapid ascent and they all ascended together. On the surface the victim was breathing rapidly and lost consciousness while being pulled to the boat. Resuscitation efforts were unsuccessful. The autopsy demonstrated intravascular gas, pleural adhesions, and changes associated with drowning. Other autopsy findings included hypertrophy of the left ventricle of the heart and fatty change of the liver. The cause of death was drowning secondary to an air embolism that resulted from a rapid, panicked ascent.
BMI = 29.6 kg·m^{-2}

06-31 Certified diver with unknown experience level, medical history of bipolar disorder and obesity, multiple days diving, with group and buddy, panicked and made rapid ascent, lost consciousness on surface.

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

This 52-year-old female was a certified diver with an unknown amount of experience who was participating in multiple dives over multiple days. Her medical problems included obesity and bipolar disorder for which she took medications. The diver and her buddy went to 100 fsw (30 msw) with a group of divers and the buddy was occupied taking photographs. For an unknown reason the victim panicked and made a rapid ascent from 65 fsw (20 msw). She lost consciousness on the surface and resuscitation efforts were unsuccessful. An autopsy was performed and disclosed changes associated with drowning as well as intravascular gas. The decedent also had moderate coronary artery disease noted at autopsy.
BMI = 30.4 kg·m^{-2}

06-35 Diver certified and experienced, medical history included diabetes, heart disease, obesity, smoker, made dive and experienced difficulty at depth, surfaced and found unconscious at surface.

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

This 64-year-old female was an experienced, certified diver. Her medical problems included obesity, diabetes, and heart disease. She was also a cigarette smoker. The diver made a dive to 130 fsw (40 msw), experienced an unknown difficulty on the bottom, and surfaced. The diver was found unconscious on the surface and could not be resuscitated. In addition to findings that corroborated drowning and air embolism, the autopsy also disclosed cirrhosis, coronary artery disease, cardiomegaly, and evidence of prior ischemic injuries to the heart.
BMI = 30.8 kg·m^{-2}

06-57 Diver with unknown certification and experience level, drysuit training, made rapid ascent and surfaced in distress, lost consciousness, towed to shore by buddy.

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

The certification status and experience level of this 34-year-old male is unknown. He was participating in a drysuit training class as a student when he made a rapid ascent and surfaced in distress. The victim lost consciousness and his buddy towed him back to shore where resuscitation efforts were unsuccessful. The case was signed out as a drowning with air embolism due to a rapid ascent.
BMI = na

06-59 Certified rescue diver and instructor, no diving in 15 years, made dive with buddies, overweighted, became separated and found floating unconscious on the surface, BC partially inflated and empty tank, computer indicated rapid ascent.

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

This 39-year-old male was a certified diver with rescue and instructor certifications but he had taken a 15 year break from diving. He and two buddies planned a dive to 40 fsw (12 msw) for 45 minutes but they became separated at about the 40 minute mark. The victim was found floating face down and unconscious on the surface with a partially inflated

buoyancy compensator and an empty tank. Resuscitation efforts were unsuccessful. The victim's computer indicated that a rapid ascent had occurred from a depth of approximately 33 ft (10 m). He was wearing 54 lb (24.6 kg) of ballast weight and prior to the dive said that was how much he typically used. The autopsy findings were consistent with drowning but the history is very characteristic for an air embolism, which may have been a contributing factor in this case.
BMI = na

06-68 Experienced technical diver, medical history of asthma, hypertension and obesity, on medication, third dive of day on rebreather, made rapid ascent then sank, pulled to surface by other divers, found to have defective rebreather.

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

This 47-year-old male was an experienced diver with technical diver certification. His medical history was significant and included asthma (for which he took medications), hypertension, and obesity. The diver was making his third dive of the day using a rebreather apparatus. After approximately 30 minutes the diver made a very rapid ascent from 49 fsw (15 msw) to the surface. The victim then called out for help and sank below the surface. He was pulled to the surface by other divers and resuscitation efforts were unsuccessful. An autopsy revealed focally severe coronary artery disease, cardiomegaly, fatty liver, an adrenal tumor, and gas in both ventricles of the heart. The rebreather was examined and was found to have a defective oxygen sensor. At some point the victim may have been breathing 3.0 atmospheres absolute (ATA) of oxygen. The victim's diluent tank was also empty. The medical examiner called this a cardiac death but the empty tank and rapid ascent combined with the finding of intracardiac gas make this most likely an air embolism. The possible exposure to high partial pressures of oxygen make the occurrence of an oxygen-induced seizure also a possibility.
BMI = 38.1 kg·m^{-2}

06-71 Certified diver with unknown experience, medical history positive for hypertension, diving to collect lobster with buddy, found by other divers at surface floating unconscious, buddy who drowned also was found four days later.

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

This 47-year-old female was a certified diver with an unknown amount of experience who was involved in a double diving-related fatality. Her medical history was significant for hypertension. She and another diver, a 53-year-old male, were diving from a boat to collect lobster. No one remained on the boat so it was not until other boaters came upon this diver's body floating face down in the water that anyone knew there was something wrong. The people initially on the scene attempted to resuscitate the diver but they were not successful. The victim's buoyancy compensator was inflated when she was found with 16 lb (7.3 kg) of ballast weight present. An autopsy revealed extensive intravascular and intracardiac gas and changes consistent with drowning. The medical examiner signed the case out as a drowning death that was due to an air embolism, which seems likely given the circumstances and autopsy findings. The body of the decedent's male dive buddy was found four days later. [See case 06-72.]
BMI = 24.0 kg·m^{-2}

06-75 Very experienced divemaster and rescue diver, assisting with AOW class, overweighted and could not leave bottom, assisted by buddy and instructor to surface where he was unconscious.

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

This 35-year-old male was a very experienced diver with divemaster and rescue diver certifications. He was assisting with an advanced open-water certification class and descended to 130 fsw (40 msw). The diver was overweighted and could not get off the bottom without his buddy's assistance. He was assisted to the surface by the instructor of the class. The diver may have lost consciousness during the ascent but was definitely unconscious at the surface. Resuscitation efforts were unsuccessful. In addition to changes associated with drowning, an autopsy demonstrated extensive intravascular gas, including involvement of the cerebral arteries. The decedent also had focally severe coronary artery disease and a patent foramen ovale. This drowning was most likely due to an air embolism secondary to a rapid ascent. The coronary artery disease present may have played a role in initiating the chain of events and certainly the excess ballast weight had an effect. Nitrogen narcosis may also have affected his judgment.
BMI = 25.0 kg·m^{-2}

Proximate Cause: Cardiac

06-20 Certified and experienced diver, history of heart disease and noncompliant with medications, completed uneventful dive, on boat he complained of chest pain and collapsed.

Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 55-year-old male was a certified, experienced diver making a dive on a wreck. He had a history of heart disease, including placement of a coronary artery stent, and was noncompliant with his medications. The diver completed his dive. The dive profile is unknown but the wreck sits as deep as 140 fsw (43 msw). The diver was back on the boat for an unknown period of time before he began to complain of chest pain and collapsed. Resuscitation efforts were unsuccessful. The medical examiner declined to perform an autopsy and the death was attributed to a cardiac event. A decompression event like an air embolism can not be excluded with the limited information available.
BMI = na

06-38 Unknown certification and experience, diving with buddy, possible cardiac event, limited information, heart disease on autopsy.

Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

The exact certification and dive experience status of this 59-year-old male is unknown but since he was on a dive vacation it might be presumed that he was a certified diver. He was diving in the ocean with a buddy when he suffered a fatal cardiac event according to the limited information available. An autopsy was performed that apparently noted the presence of atherosclerotic cardiovascular disease and the pathologist concluded that the diver died of a cardiac event, but the complete report was not made available.
BMI = na

06-41 Diver with unknown certification and experience level, second dive of day, buddy descended and victim lost consciousness before his descent, sank underwater and buddy pulled him to surface.

Cause of Death: Cardiac Dysrhythmia

The certification status and experience level of this 61-year-old male is unknown. He was making his second dive of the day with a buddy. The victim's buddy descended ahead of him and, according to witnesses present, the diver lost consciousness prior to descending. He sank below the surface and was pulled up by his buddy. Resuscitation efforts were unsuccessful. If an autopsy was performed the findings were not made available. Given the witnesses' accounts and other circumstances, the fatal outcome was most likely due to a cardiac event.
BMI = na

06-42 Certified diver with advanced experience level, poor physical condition including being overweight, diving on cruise ship excursion with buddy, signaled to surface and buddy stayed at bottom and saw victim getting CPR, unknown if autopsy done.

Cause of Death: Cardiac Dysrhythmia

The certification status and experience level of this 43-year-old male is not well documented but he was apparently a certified diver with approximately 45 lifetime dives. He and a buddy were on a dive excursion arranged by a cruise ship. The diver was overweight and in a state of poor physical conditioning. The two divers were on the bottom when the victim indicated that he was going to surface. He went up alone while his buddy stayed on the bottom. When the buddy ascended to the surface she saw the victim receiving cardiopulmonary resuscitation. Resuscitation efforts were unsuccessful. If an autopsy was performed the findings were not made available. The most likely cause of death in this case is air embolism but a cardiac event can not be excluded.
BMI = na

06-69 Experienced, obese public safety diver, made solo working dive in strong current and bad visibility wearing drysuit, tethered to line, surfaced in distress minutes into dive and lost consciousness.

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

This 40-year-old male was an experienced diver on a public service dive team performing a working dive in a river. The diver's only known medical problem was obesity. There was a strong current and visibility was poor. The diver wore a drysuit and entered the water alone, but was tethered by a line. After two minutes at a depth of 12 ft (3.6 m) the diver surfaced in distress and lost consciousness. He was pulled back to the boat and resuscitation was attempted but the diver was pronounced dead at a local medical treatment facility. The autopsy disclosed severe coronary artery disease and cardiomegaly. The death was ruled to have been the result of a cardiac event.
BMI = na

Proximate Cause: Drowning/Cardiac

06-13 Certified diver with intermediate experience level, overweighted, made shore entry dive in rough seas with buddy, surfaced and began swim to shore, became distressed and was towed to shore, lost consciousness.

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

This 49-year-old male was a certified diver with 25 lifetime dives and basic open-water certification. He and his 17-year-old son made a shore entry dive in rough seas. They dived to 80 fsw (24 msw) followed by a safety stop at 15 fsw (5 msw). The two divers surfaced and began to swim back to shore on the surface. The victim complained of difficulty breathing and his son began to tow him to shore. After the stricken diver lost consciousness his buddy had to leave him to get assistance. The diver was eventually brought to shore where resuscitation efforts were unsuccessful. The diver carried 31 lb (14.1 kg) of integrated weight that was not dropped at any time through the rescue/recovery. An autopsy revealed focally severe coronary artery disease, cardiomegaly, and changes consistent with drowning. The cause of death was drowning secondary to a cardiac event. Another possible contributing factor was the apparently excessive amount of ballast weight used by the diver.
BMI = 30.3 kg·m^{-2}

06-21 Student in open-water certification class, obese, on second dive, lost consciousness.

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

This 29-year-old male was a student in an initial open-water certification training class making his second open-water dive from a boat with a buddy. The only significant known health issue for this diver was obesity. As he began the second dive the instructor said that the victim made an unusual sound and then lost consciousness. The autopsy findings included focally severe coronary atherosclerosis as well as changes associated with drowning.
BMI = na

06-25 Diver certified and experienced with multiple medical conditions including heart disease and seizures while diving, on medications, made second solo dive of day to collect lobster while friends remained on boat, failed to surface and found unconscious on bottom.

Cause of Death: Drowning due to Cardiac Dysrhythmia due to Sick Sinus Syndrome

This 58-year-old male was an experienced, certified diver with multiple medical problems including chronic shoulder pain for which he took morphine and sick sinus syndrome for which he had an implanted pacemaker. The diver also had a history of migraines and had suffered episodes of seizures and blackouts while diving. He was obese as well. The diver was making his second dive of the day to 50 fsw (15 msw) to gather lobster. He was making solo dives while three friends waited in the boat. After approximately one hour of bottom time, the topside personnel noted a lack of bubbles and someone descended to check on the diver. He was found unconscious on the bottom. Resuscitation efforts were unsuccessful. The decedent's dive gear was examined and found to be in satisfactory condition. The autopsy revealed changes associated with drowning as well as fibrosis in the conducting system of the heart. Toxicological studies revealed a high level of morphine in both blood and gastric contents. Since the diver had been using morphine chronically and did not seem impaired to his colleagues, the medical examiner concluded that morphine intoxication did not likely play a large factor in

his death. The death was attributed to a cardiac dysrhythmia secondary to sick sinus syndrome.
BMI = 37.4 kg·m^{-2}

06-27 Open-water student diver, obese, training on second dive of day, lost consciousness.

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

This 29-year-old male was a student in an initial open-water certification class. His only known medical problem was obesity. The diver was making his dives under instruction as part of the course with a buddy and from a boat. The victim reportedly made a strange gurgling sound at the beginning of the second dive of the day and then lost consciousness. Resuscitation efforts were unsuccessful. An autopsy disclosed focally severe coronary artery disease. The medical examiner signed the case out as a cardiac event but the autopsy report described changes associated with drowning and the description of the event is most consistent with drowning resulting from an acute cardiac event.
BMI = 32.0 kg·m^{-2}

06-47 Diver with unknown certification and experience, made ocean dive with buddy, unknown problem at depth, lost consciousness.

Cause of Death: Drowning due to Cardiac Dysrhythmia

The certification status and experience level of this 60-year-old male diver are unknown. He experienced an unknown problem at depth while making an open ocean dive with a buddy from a boat. He was pulled from the water unconscious and could not be resuscitated. Investigators felt that the death was a drowning due to a cardiac event.
BMI = na

06-48 Experienced diver, past medical history of cancer, made dive with buddy to wreck, surfaced in rough seas, buddy descended briefly and returned to find diver unconscious at surface.

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

This 64-year-old male was a very experienced, certified diver making his third dive of the day with a buddy. His known past medical history included only prostate cancer. The divers were on a wreck at 60 fsw (18 msw) for 60 minutes before working their way up to 40 fsw (12 msw). The victim motioned to his buddy that he wanted to surface. The divers had trouble finding the chain that ran from the wreck to shore and they surfaced in rough seas. The buddy went down to 10 fsw (3 msw) briefly and when he returned to the surface the victim was unconscious. The buddy towed the stricken diver to shore where resuscitation efforts were unsuccessful. In addition to changes consistent with drowning, the autopsy revealed focally severe coronary artery disease. The death was likely a drowning secondary to a cardiac event.
BMI = na

06-52 Certified, experienced diver, multiple health problems, diving with group to collect lobsters, separated from buddy at depth, found floating unconscious at surface with inflated BC.

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

This 48-year-old male was an experienced, certified diver with multiple medical problems including severe coronary artery disease requiring stent placement, a previous myocardial infarction, obesity, elevated serum cholesterol, hypertension, and chronic back pain. He made a dive to 70 fsw (21 msw) with a group of divers in order to collect lobster. The victim became separated from his buddy and the group and was found floating on the surface unconscious by a member of the boat crew. The diver was pronounced dead at a local hospital. The diver had apparently inflated his buoyancy compensator prior to losing consciousness. The autopsy disclosed cardiomegaly and severe coronary atherosclerosis with a large scar on the lateral ventricle of the heart. He also had atherosclerosis of the aorta and its branches, fatty change of the liver, and arterionephrosclerosis. The death was appropriately certified as a drowning secondary to a cardiac event.
BMI = 29.8 kg·m^{-2}

Proximate Cause: Drowning/Insufficient Air

06-02 Recently certified, inexperienced diver, medical history of recent ruptured tympanic membrane, on cold medications, made night dive with buddy to collect lobster, surfaced low on air, buddy became entangled, diver assisted but lost weight belt, descended to retrieve it and separated from buddy, found next day.

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

This 24-year-old male completed an initial certification course three months earlier and had made 20 lifetime dives. He was on the fourth day of a multi-day dive trip, embarking on his first ever night dive. Significant dive medical history included a ruptured tympanic membrane three weeks earlier. He was also taking numerous over-the-counter cold medications. The diver and his buddy were collecting lobster during a night dive and surfaced after spending enough time at a maximum depth of 65 fsw (20 msw) to both be low on air. The buddy had become entangled in kelp shortly before the divers surfaced and the victim had apparently aided his buddy's disentanglement. The victim lost his weight belt in the process and both divers descended to retrieve it. The two divers became separated and the victim was not seen again until his body was recovered the next day. When the body was recovered, it was located on the bottom and in close proximity to the lost weight belt. An equipment evaluation revealed that the decedent was significantly over-weighted, using a total of 32 lb (15.5 kg), 8 lb (3.6 kg) on the weight belt and the rest in various pockets of the buoyancy compensator. The victim had also modified his fins so that they were reportedly less efficient for propulsion. The autopsy findings were consistent with drowning.
BMI = 32.3 kg·m^{-2}

06-03 Non-certified diver, with "diving experience," made dive with buddy to collect lobster, separated at depth but continued dive solo, buddy surfaced and victim did not, found unconscious at bottom, out-of-air, toxicology positive for cannabinoids.

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

This 36-year-old male was not a certified diver, but was reported to have "diving experience." He was gathering lobster with a buddy, making their second dive of the day. The two buddies became separated but both continued to dive solo. The buddy surfaced

when he ran low on air but the victim did not. The buddy was unable to locate the victim and a search team recovered the unconscious body from the bottom at 15 fsw (4.6 msw). At the time the body was recovered, all equipment was still in place except the regulator mouthpiece, which was not in his mouth. The autopsy findings were consistent with drowning. An examination of the equipment revealed that the tank and regulator were attached incorrectly, the purge button on the regulator stuck at times, there was a small leak in the buoyancy compensator, and the tank was empty. Toxicology was positive for pseudoephedrine (medication commonly used as a decongestant) and cannabinoids (active intoxicating compounds present in marijuana).

BMI = 29.1 kg·m^{-2}

06-06 Certified, experienced diver, planned repetitive dives, on second dive, buddies descended first, found unconscious at surface, weight belt dropped and empty tank.

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

This 72-year-old male was a certified, experienced diver making a set of repetitive dives. The first dive was a wreck dive to 112 fsw (34 msw) for 28 minutes and was reported to be uneventful. The second dive was planned to be shallow and the victim's three buddies descended ahead of him. The victim's body was later found floating on the surface, one half mile away from the initial descent area. One witness reported that the decedent had his snorkel in his mouth when his body was recovered. The decedent's weight belt was off and his tank was empty. The decedent's computer had recorded a nine minute dive to 29 fsw (9 msw). Apparently each diver in the group used one tank to make both dives. The autopsy findings were consistent with drowning.

BMI = na

06-12 Diver with unknown certification and experience level, shore entry dive into kelp, surfaced with buddy, descended again, became separated, found unconscious at surface, towed to shore.

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

The experience level and certification status of this 56-year-old male is unknown. He and his 19-year-old son made a shore entry dive into a kelp bed. They surfaced together after a period of time on the bottom, descended again, and became separated below the surface. The son found his father unconscious on the surface, with his buoyancy compensator inflated. The stricken diver was pulled to shore where resuscitation efforts were unsuccessful. Evaluation of the equipment revealed that the decedent's tank was very low on air. The autopsy disclosed changes associated with drowning, pulmonary emphysema, a simple renal cyst, and evidence of chronic hepatitis. The death was ruled a drowning.

BMI = 25.3 kg·m^{-2}

06-43 Experienced diver with instructor level certification, obese, making a wreck penetration dive with group wearing drysuit, separated from buddy, found unconscious on deck of the wreck, out-of-air. No autopsy done.

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

This 56-year-old male was an experienced, certified diver with instructor level certification. His medical problems included obesity. The diver was making a wreck penetration dive in freshwater off a boat and as part of a large group. He was diving on air and using a drysuit. The dive was to a maximum depth of 135 ffw (41 mfw). There were four divers in the group and the victim and his buddy became separated. At approximately the 25-minute mark of the dive the victim was found unconscious on the deck of the wreck. He was out of air and, because of his size, the other divers could not

bring him to the surface. The divers had to go through 37 minutes of staged decompression before reaching the surface to get help. Other divers went down to bring the body to the surface. The medical examiner declined to perform an autopsy so contributions of natural disease processes and medications or drugs can not be assessed. It seems fairly certain that running out of air at depth was the primary issue and the diver subsequently drowned. Nitrogen narcosis may have made a contribution. BMI = na

06-44 Experienced diver with advanced certification, made shore entry night dive with group to set personal depth record with single air tank, poor visibility, separated from buddy.

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

This 27-year-old male was an experienced diver with advanced open-water certification. He was making a shore entry, night dive with a group of divers and planned to set a personal depth record using a single tank of air. The victim had other divers staged at various depths to assist him. Visibility was poor and the victim's buddy became separated from him and aborted the dive at that point due to nitrogen narcosis. A third diver complained of vertigo at 200 fsw (61 msw) and the victim assisted that diver up to 160 fsw (49 msw) before turning to continue his descent. The decedent's partially skeletonized body was recovered nine months later by a diver making a solo dive to 200 fsw (61 msw). The death was signed out as a drowning and nitrogen narcosis likely played a role.
BMI = 30.9 kg·m^{-2}

06-56 Certified diver, unknown experience, made shore entry dive wearing drysuit with limited drysuit experience, overweighted, separated from buddy, found unconscious at 40 ffw (12 mfw), out-of-air.

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

This 39-year-old male was a certified diver using a drysuit for only the third time in order to dive on a wreck. It was a shore entry dive into a river and in very cold water. The diver was overweighted for the task and according to witnesses either the diver or his buddy "shot to the surface" during the dive. The dive profile was approximately 88 ft (27 m) for 35 minutes. The two divers became separated during the dive and the victim was found unconscious at 40 ft (12 m) with his regulator out of his mouth. The two other divers that came upon him were unable to inflate the stricken diver's buoyancy compensator because his tank was empty. They dragged the victim to shore where resuscitation efforts were unsuccessful. The death was signed out as a drowning but if the decedent was the diver seen making the rapid ascent, an air embolism may also have factored into this death. The actual autopsy report was not made available for review.
BMI = na

06-66 Certified diver with numerous certifications but moderate experience, medical history of hypertension and obesity, made dive with buddy in cold water and poor visibility, separated on ascent, body found next day, tank out-of-air.

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

This 51-year-old male was a certified diver with moderate diving experience. He possessed numerous specialty certifications but nearly all of his diving had been done in warm, open water. This was his first dive of the year and it was planned to be a night dive on a wreck in a freshwater lake. The diver's medical problems included obesity and hypertension. Visibility was poor, the water was cold and the victim forgot to bring a hood. He and his buddy entered the water and spent approximately 14 minutes at a max depth

of 97 ft (30 m). The victim signaled to his buddy that he was down to 1000 psi (69 bar) and planned to ascend. The two divers went up to 60 ft (18 m) but became separated at that point. The diver's buddy went to the surface but he could not locate the victim. A search began immediately but the body was not recovered until the next day. The deceased diver still had 20 lb (9.1 kg) of ballast weight in his buoyancy compensator that would have been difficult to drop. His tank was empty and an evaluation of the regulator showed that it took increased work to breathe through the second stage. The autopsy showed marked cardiomegaly and mild coronary artery disease. Toxicological studies were negative and the cause of death was determined to be drowning. A contribution from natural disease processes can not be excluded.
BMI = 32.7 kg·m^{-2}

06-70 Experienced instructor and technical diver, medical history included allergies and asthma, diving to explore wreck on rebreather, first dive with group, solo second dive in poor visibility and moderate seas, did not resurface, body found next day, rebreather found to be turned off for second dive.

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

This 40-year-old male was an experienced diver with instructor and technical diver certifications. The diver's medical history was significant for allergies and asthma. On this particular day he was using a rebreather apparatus, diving with a group of divers, with one other also using a rebreather. The dives were made from a boat and for the purpose of exploring a wreck. After an uneventful first dive the diver stated that he wanted to go off alone during the second dive so that he could maximize his bottom time. He also stated that it was his habit to turn off the electronics on his rebreather between dives and advised the other diver using a rebreather to do the same. The divers entered the water for the second dive and the victim went below the surface on his own. The seas were moderate and visibility was poor. After all of the other divers had returned to the boat and waited for a substantial period of time a search was initiated. The decedent's body was recovered the next day. The autopsy disclosed changes associated with drowning as well as intracardiac and intravascular gas. There were also pleural adhesions, mild coronary artery disease, and fatty change of his liver noted. The rebreather was in good working condition but a thorough investigation revealed that the victim failed to turn it on for the second dive. His diluent bottle was empty but a pony bottle he had for an alternate air source had plenty of air remaining in it. The victim did not have a computer and would not have been able to monitor depth or elapsed time. The intravascular gas noted at autopsy likely represented postmortem artifact but the occurrence of an air embolism can not be excluded.
BMI = 26.9 kg·m^{-2}

06-74 Instructor and technical diver, medical history positive for epilepsy, diving on rebreather with buddy in cold water and poor visibility, equipment problem at depth, made rapid ascent, separated from buddy, found unconscious at surface, inspection revealed faulty equipment.

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

This 47-year-old male possessed instructor and technical diving certifications and he experimented with modifications he made to a rebreather apparatus. The diver's medical history was significant for epilepsy. He and a buddy were performing a dive at a quarry using a shore entry into very cold water and with poor visibility. The victim had an equipment problem approximately 15 minutes into the dive after reaching a maximum depth of 105 ft (32 m). He and his dive buddy ascended rather quickly and then became separated at an 80 ffw (24 mfw) stop. The dive buddy made two more stops and went to the surface. Other divers on the surface heard someone yell and then saw the victim

floating unconscious on the surface. Resuscitation efforts were unsuccessful. According to the investigation the victim knew that his rebreather was malfunctioning and planned to use it in semi-closed-circuit mode to compensate. An examination of the equipment revealed that it was out of specifications, with malfunctioning sensors and an improperly packed carbon dioxide scrubber. The diluent gas tank was also empty. The report also stated that the victim had been drinking beverages containing alcohol until four o'clock the morning of this dive. An autopsy was performed but the report was not made available. The death was a drowning due to insufficient breathing gas. Possible contributions of a rapid ascent and the history of epilepsy can not be determined.
BMI = na

Proximate Cause: Drowning/Various Causes

06-05 Certified diver with limited recent experience, made research dives from shore with buddy, strong current, buoyancy problems on first dive, separated from buddy on second dive during descent, found unconscious on surface.

Cause of Death: Drowning due to Scuba Diving

This 50-year-old male was a certified diver who had taken a long break from diving and recently went back to it. He was making a set of research dives, using a shore entry, with a buddy. There was reportedly a strong current and the diver had some buoyancy problems during the first dive. During the second dive the diver and his buddy became separated during descent. The victim was found unconscious and floating on the surface by a passing boat. He was resuscitated and placed on life support but died the next day. The airways were noted to be filled with fluid during the resuscitation efforts. The medical examiner determined the cause of death to be drowning.
BMI = 24.9 kg·m^{-2}

06-07 Experienced diver, medical history included fainting spells and obesity, made dive with buddy (son) in kelp, breathing difficulty at depth, surfaced and lost consciousness, faulty equipment found on inspection, possible kelp entanglement.

Cause of Death: Drowning due to Scuba Diving

This 53-year-old male had been a certified diver for over 25 years and was very experienced. His recent medical history was significant for fainting spells for which he did not seek treatment. He was also obese. The diver and his buddy made a shore entry dive in a kelp bed to 40 fsw (12 msw). It was also significant that the victim's buddy was his 15-year-old son who was making his first ever open-water dive. It is not clear from the investigation if this was meant to be a training dive for the son. After a few minutes at depth the victim appeared to be having some breathing difficulties and pointed toward the surface. On the surface the victim was unconscious and his buddy struggled to keep the stricken diver's head out of the water. Bystanders arrived to render assistance but resuscitation efforts were unsuccessful. The autopsy findings were consistent with drowning and there was also mild coronary artery disease noted. Evaluation of the regulator revealed that it was in very poor shape and according to the investigator "should have been taken out of service years ago." It is unclear to what extent the equipment may have played a role in this mishap. There are mixed reports regarding the possibility of kelp entanglement playing a factor but according to the buddy it did not.
BMI = 33.6 kg·m^{-2}

06-09 Certified, inexperienced diver, training in advanced open water class, made shore entry dive with buddy, became separated on descent, found unconscious at surface.

Cause of Death: Drowning due to Scuba Diving

This 50-year-old male had been a certified diver for one year and had fewer than 20 lifetime dives. He was a student in an advanced open-water certification course making a shore entry with a buddy. The buddies became separated immediately on descent and the victim was found unconscious on the surface. The autopsy findings included changes associated with drowning and myxoid changes of the mitral valve of the heart (softening of the valve causing it to be floppy). It is unknown what role the mitral valve abnormality may have played but the condition has occasionally been associated with cardiac dysrhythmias.
BMI = 19.9 kg·m^{-2}

06-11 Diver with unknown certification and experience level, made shore entry dive with buddy (son) in rough seas and strong current, change of dive plan and never submerged, victim distressed and towed to shore.

Cause of Death: Drowning due to Scuba Diving

The experience level and certification status of this 36-year-old male is unknown. He and his 15-year-old son made a shore entry into rough seas and a strong current. From the investigation report it appears that the victim and his buddy never submerged. The two divers decided to head for shore after swimming out a moderate distance, but the victim ended up being towed by his buddy. Others eventually arrived to provide assistance. Resuscitation efforts were unsuccessful. The cause of death was determined to be drowning. An incidental renal cell carcinoma was discovered at autopsy but it was too small to have any role in this diver's death.
BMI = 27.5 kg·m^{-2}

06-14 Certified diver with unknown experience level, made dive with group in rough seas, returned to boat because air was not turned on, attempted descent multiple times, aborted dive, found unconscious on surface.

Cause of Death: Drowning due to Scuba Diving

This 46-year-old male was a certified diver with an unknown amount of diving experience. He was making a dive from a boat with a large group of divers in rough seas. The diver first entered the water but had to return to the boat because his air was not turned on. He then attempted to descend several times but finally aborted the descent because of the rough seas. The divemaster surfaced to find him but could not. The boat captain then spotted the diver unconscious and floating on the surface. He was brought into the boat but resuscitation efforts were unsuccessful. The autopsy disclosed changes consistent with drowning and minimal coronary artery disease. Toxicology studies revealed an elevated level of a prescription antidepressant, though the side effects of that medication are usually minimal. No evidence of pulmonary barotrauma was described in the autopsy report, but the multiple attempted excursions to depth would certainly be a risk factor for an air embolism. The attempted descent without turning on his air may indicate that the diver was an infrequent or inexperienced diver.
BMI = 28.0 kg·m^{-2}

06-15 Certified but inexperienced diver, made solo dive in cold water with drysuit to spearfish, did not return to surface, found next day.

Cause of Death: Drowning due to Scuba Diving

This 43-year-old male had been a certified diver for less than one year and had logged nearly all of his dives in warm water. He was using a drysuit to make a solo dive from a boat while others waited on the surface. The victim had little experience with a drysuit. After approximately 10 minutes the people on the surface noticed that the diver's bubbles had stopped. His speargun was found drifting approximately one half mile from the dive site. The body was recovered the next day at 75 fsw (23 msw). The cause of death was determined to be drowning. The decedent did not have the auto-inflator house connected and he wore a total of 37 lb (16.8 kg) of ballast weight, including ankle and pocket weights.
BMI = na

06-18 Certified diver with unknown experience level, diving on surface-supplied equipment to collect lobster, difficulty with fins and mask at surface, dropped lobster gathering equipment, buddy retrieved, surfaced and did not see victim, found on bottom.

Cause of Death: Drowning due to Scuba Diving

This 66-year-old female was a certified diver using surface-supplied equipment to collect lobster. The victim entered the water and had some difficulty putting her fins and mask on while she was on the surface. In the process of donning her gear, some of the lobster gathering equipment dropped and her buddy descended to retrieve it. When the buddy returned to the surface, the victim was not there and he assumed she had descended. The buddy found the victim unconscious on the bottom. The stricken diver was taken to a local hospital but resuscitation efforts were unsuccessful. In addition to changes associated with drowning, the autopsy revealed significant degenerative joint disease and mild arterionephrosclerosis. Toxicology was positive for diphenhydramine (generic name for prescription medication with common brand name of Benadryl). The death was ruled a drowning by the medical examiner.
BMI = 22.8 kg·m-2

06-24 Experienced diver, overweighted, made shore entry dive with buddy, panicked in shallow water, grabbed mask of buddy, lost consciousness and became separated, body recovered later that day.

Cause of Death: Drowning due to Scuba Diving

This 39-year-old male was an experienced, certified diver making a shore entry dive with a buddy. For unknown reasons the diver panicked in shallow water and grabbed at his buddy's mask. The diver then lost consciousness and became separated from his buddy. His body was recovered later that day by rescue divers. An equipment check revealed that the victim was markedly over-weighted. One report stated that 57 lb (25.9 kg) of ballast weight was found on the recovered body. An autopsy was performed and the death was certified to have been a drowning. The autopsy report was not made available.
BMI = na

06-26 Certified diver with unknown level of experience, diving with buddy in cold water and rough seas, caught in strong current at bottom, separated, found unconscious with no gear on but mask.

Cause of Death: Drowning due to Scuba Diving

This 39-year-old male became a certified diver two years previously but his diving experience level is not known. He was diving in rough seas off a boat with a buddy and in cold water. The divers went to 64 fsw (19 msw) for 33 minutes and became caught in a strong current on the bottom. The victim and his buddy became separated and the buddy went to the surface. When the victim did not surface the Coast Guard was notified and a search began. Another set of divers found the victim face down in the water and unconscious, with all gear off except his mask. Resuscitation efforts were unsuccessful. An autopsy was performed and the cause of death was determined to be drowning. BMI = 24.2 kg·m^{-2}

06-39 Diver with minimal experience, poor physical conditioning with heart disease, made dive with buddies to wreck, signaled low on air and ascended alone, called for help at surface, lost consciousness and drifted away from the boat, equipment not recovered.

Cause of Death: Drowning due to Scuba Diving

This 49-year-old male had been certified less than one year and he had minimal diving experience. He and two buddies went to 107 ffw (33 mfw) in a large lake to dive on a wreck. After approximately 30 minutes the victim signaled to his dive buddies that he needed to ascend because he was low on air and he ascended alone. The diver called for help on the surface and then drifted away from the boat after losing consciousness. He was brought to a local hospital where he was pronounced dead. The decedent's equipment was not recovered but it is known that he began the dive with less than a full tank. The victim was in poor physical shape and had a history of an elevated serum cholesterol level and other "heart issues." An autopsy was performed but the report was not made available. The cause of death was listed as drowning, but contributing factors could possibly include an air embolism or a cardiac event. BMI = na

06-45 Certified diver with unknown experience level, made shore entry dive with buddy, multiple attempts to descend, separated and found below the surface, unconscious.

Cause of Death: Drowning due to Scuba Diving

This 26-year-old male was a certified diver with an unknown amount of diving experience was making a shore entry into a freshwater pond with a buddy. The diver made three unsuccessful attempts to descend and became separated from his buddy. The buddy found the stricken diver unconscious with his regulator out of his mouth approximately 5-10 ffw (1-3 mfw) below the surface. The buddy pulled the victim to shore and performed cardiopulmonary resuscitation, but his efforts were unsuccessful. An autopsy was performed along with toxicological studies and the cause of death was determined to be drowning. The report was not made available for review. BMI = na

06-46 Certified diver with unknown level of experience, medical history includes obesity, limited information on diver and profile, went missing during dive, found 13 days later.

Cause of Death: Drowning due to Scuba Diving

There is little information about the circumstances surrounding the death of this 60-year-old female diver. She was a certified diver but her experience level and frequency of diving are unknown. The dive profile is also unknown. Known medical history includes only obesity. Her partially decomposed body was recovered 13 days after she went missing during a dive. An autopsy was performed that revealed no obvious natural disease processes, though the examination was limited. She had bitten her tongue, which often occurs with a terminal seizure. The death was ruled to be due to drowning. BMI = 27.4 kg·m^{-2}

06-49 Experienced diver, made shore entry dive with buddy, but planned to descend separately and meet at depth, did not happen and victim surfaced in distress, lost consciousness.

Cause of Death: Drowning due to Scuba Diving

This 34-year-old male, experienced, certified diver made a shore entry dive into a quarry. He and his dive buddy agreed to descend separately and meet up at depth. That did not appear to go as planned. The victim surfaced alone and called for help. He then lost consciousness. Resuscitation efforts at the scene were unsuccessful. The victim was obese but had no other known health problems. The autopsy findings were consistent with drowning and the medical examiner signed the case out as a drowning death. However, no special procedures were attempted to try to exclude pulmonary barotrauma and air embolism. The history as provided is at least suspicious for an air embolism contributing to drowning. BMI = 35.4 kg·m^{-2}

06-51 Student in open-water class, made third dive of the class into a river with strong current, poor visibility and cold water, using drysuit, surfaced in distress, disappeared below surface, body found three days later.

Cause of Death: Drowning due to Scuba Diving

This 23-year-old male was a student in an entry level open-water certification class making his third open-water dive. The planned dive was into a river with a strong current, poor visibility, and very cold water using a drysuit. The diver apparently surfaced in distress and then quickly disappeared below the surface. His body was recovered three days later. The coroner signed the case out as a drowning and according to witnesses the diver seemed to have panicked. A contributing air embolism from a rapid ascent can not be excluded. BMI = na

06-53 Diver with unknown certification and experience level, made shore entry dive with buddy to test new drysuit, descended alone, found upside down with tank hanging loose, pulled to surface.

Cause of Death: Drowning due to Scuba Diving

The certification status and experience level of this 60-year-old male is unknown. He made a shore entry dive in a lake with his buddy in order to test a new drysuit. The victim had some difficulty getting suited up and went into the water ahead of his dive buddy. During the descent he was seen upside down at 12 ffw (3.6 mfw) with his tank hanging loose but still attached by the regulator hoses. The diver was pulled from the water but could not be resuscitated. The death was ruled a drowning.
BMI = na

06-60 Experienced diver with technical certification, made trimix dive on rebreather with buddies, one buddy had trouble on descent, while others assisted victim sank below surface, body recovered four days later.

Cause of Death: Drowning due to Scuba Diving

This 65-year-old male was an experienced diver with technical diver certification. He and three other divers were using trimix in rebreathers to make a dive to 165 fsw (50 msw). Prior to the dive the victim had replaced the sensors in his rebreather. All four divers began the dive together but one had trouble descending and while the other two divers rendered assistance to him, the fatality victim sank below the surface. His dive buddies recovered his body four days later. An autopsy showed mild cardiomegaly and mild coronary artery disease. Toxicology was positive for antidepressant and diphenhydramine (generic name for prescription medication with common brand name of Benadryl). An evaluation of the equipment documented a few issues and also that some of the pre-dive checks had been skipped but there was nothing present that would explain the fatality. Some investigative reports attributed the death to "shallow water blackout." While the term is now more familiar as it is used to describe hypoxia of ascent in breath-hold divers, it was initially coined to describe impaired consciousness associated with the use of closed-circuit oxygen rebreathers, likely due to inadequate carbon dioxide scrubbing. The available information, however, makes it impossible to determine if this was involved in the current case. The death was signed out as a drowning, though it is possible that a natural disease contribution was present.
BMI = 28.0 kg·m^{-2}

06-61 Certified diver with experience, made shore entry solo dive in swift current to tie line to sunken boat, overweighted, returned to surface quickly in distress, sank below surface, body recovered two days later.

Cause of Death: Drowning due to Scuba Diving

This 26-year-old male became a certified diver one year earlier but was a fairly frequent diver. He made a shore entry, solo dive into a river to tie a line to a sunken boat. The diver was wearing 50 lb (22.7 kg) of ballast weight. There was a swift current and almost immediately upon descending he returned to the surface and called for help. He then sank back below the surface and his body was not recovered until two days later. Toxicology was negative and the equipment was in good working order. In addition to changes consistent with drowning, the autopsy disclosed the presence of a projectile from a past gunshot wound of the head.
BMI = na

06-65 Diver with unknown certification and experience level, made dive with group in rough seas and strong current, surfaced during rain storm, submerged again and body was recovered later.

Cause of Death: Drowning due to Scuba Diving

This 58-year-old male was diving with three other divers from a charter boat in rough seas and a strong current. His certification status and level of experience are not known. The diver surfaced after the dive in rough seas and a rain storm. He submerged again and his body was recovered an hour later. The autopsy findings were consistent with drowning. The decedent also had moderate coronary artery disease and mild left ventricular hypertrophy as well.
BMI = 24.7 kg·m^{-2}

06-63 Certified diver with limited experience, overweight and reckless diver, made dive with buddy to spearfish, surfaced early in distress, entangled in rope and attempted to share air, witnesses attempted rescue but line snapped, both divers sank below surface and both bodies were recovered later in day.

Cause of Death: Drowning due to Entangled (rope) due to Scuba Diving

This case represents a double fatality involving buddies. This 37-year-old male was a certified diver with limited diving experience and no dives in the previous year. He and another diver, a 35-year-old female, were making a dive from a boat in order to go spearfishing. The male diver was overweight and described as a reckless diver by individuals who were reportedly familiar with his diving habits. A third person waited back in the boat while the two divers entered the water. By all reports the current in the area of the dive was very strong that day. Shortly after beginning the initial descent the male diver surfaced and waved for help. The witness back in the boat observed the divers struggle on the surface and become entangled in the buoy line. The male diver panicked and used the female diver's alternate air source. Other individuals arrived at the scene and attempted to assist the divers by pulling in the buoy line but the line snapped. Both divers descended below the surface and their bodies were recovered approximately an hour later in 50 fsw (15 msw). The male diver still had ballast weights in place and was entangled in the line. The female diver had dropped her weights but was also entangled in the line and floating a few feet above her dive buddy. An autopsy of the male victim disclosed changes associated with drowning. Toxicology was positive for cocaine metabolites, antihistamines, ephedrine, and dextromethorphan. The victim's equipment proved to be in nearly unusable condition and the buoyancy compensator would not hold air. The air tank was nearly full. [See case 06-64.]
BMI = 38.1 kg·m^{-2}

06-64 Certified diver with unknown level of experience, made dive with buddy to spearfish in strong current, buddy surfaced early into dive in distress, entangled in rope and panicked, witnesses attempted rescue but line snapped, both divers sank below surface and both bodies were recovered later in day.

Cause of Death: Drowning due to Entangled (rope) due to Scuba Diving

This case represents a double fatality involving buddies. This 35-year-old female was a certified diver with an unknown amount of diving experience. She and another diver, a 37-year-old male, were making a dive from a boat in order to go spearfishing. A third person waited back in the boat while the two divers entered the water. By all reports the current in the area of the dive was very strong that day. Shortly after beginning the initial descent the male diver surfaced and waved for help. The witness back in the boat observed the divers struggle on the surface and become entangled in the buoy line. The male diver panicked and used the female diver's alternate air source. Other individuals

arrived at the scene and attempted to assist the divers by pulling in the buoy line but the line snapped. Both divers descended below the surface and their bodies were recovered approximately an hour later in 50 fsw (15 msw). The male diver still had ballast weights in place and was entangled in the line. The female diver had dropped her weights but was also entangled in the line and was floating a few feet above her dive buddy. Her mask was on her forehead. An autopsy of the female victim disclosed changes associated with drowning. Toxicology was positive for cocaine metabolites and nicotine metabolites. The victim's equipment was in poor repair. The air tank was nearly full. [See case 06-63.]
BMI = 27.1 kg·m^{-2}

06-67 Experienced instructor and technical diver, made dive on trimix to collect lobster with buddy, became separated at bottom, buddy found him at bottom.

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

This 40-year-old male was an experienced diver with instructor and technical diver certifications. He and two other divers were going into the water to gather lobster. One diver went off on his own and the victim and another diver went in as a buddy team. The victim was using trimix and also had an 80% oxygen mixture for shallow decompression stops. He recently had some maintenance performed on his regulators and both second stages were nearly identical for both breathing gas mixtures. The pair became separated on the bottom and the dive buddy found the victim unconscious with his regulator out of his mouth. The dive buddy brought the unconscious diver toward the surface but then inflated the victim's buoyancy compensator and sent him to the surface while he stayed at a decompression stop. The case was signed out as a drowning death but the equipment evaluation was revealing. The decedent's trimix tank was nearly full and his 80% oxygen decompression mix was empty. The decedent likely suffered a seizure from oxygen toxicity at depth that resulted in drowning.
BMI = 29.5 kg·m^{-2}

06-72 Diver with unknown certification and experience level, made dive with buddy to collect lobster, no witnesses, buddy was found unconscious at surface, and diver was recovered four days later.

Cause of Death: Drowning due to Scuba Diving

This 53-year-old male had unknown certification and experience levels and was involved in a double diving-related fatality. He and another diver, a 47-year-old female, were diving from a boat to collect lobster. No one remained on the boat and when the buddy was found floating unconscious on the surface, a search for this diver's body was initiated. His body was recovered four days later with decomposition and animal predation present. In addition to changes associated with drowning, the presence of coronary artery disease was noted during the autopsy. The medical examiner signed this case out as a drowning death but his findings were limited given the decomposition present. However, since the buddy had evidence of sustaining an air embolism, the possibility remains that this diver may have also had a pulmonary over-expansion injury. [See case 06-71.]
BMI = 26.2 kg·m^{-2}

Proximate Cause: Unspecified or Body Not Recovered

06-16 Diver with unknown certification or experience, went missing and found next day, limited information.

Cause of Death: Death, Unspecified Cause

There is very little information available on the death of this 40-year-old male. It is not known if he was a certified diver or not and whether he had any significant diving experience. It is not known if he was diving solo or had a buddy when he went missing. The body was found the day after he went missing during a dive. No cause of death was available.
BMI = na

06-17 Diver certified but unknown certification level and experience, history of anxiety attacks, made dive with buddy to wreck in poor visibility, separated, surfaced in distress, body found eight days later.

Cause of Death: Death, Unspecified Cause

The information regarding the death of this 36-year-old male is incomplete. He was a certified diver, but his diving experience level is unknown. The diver was known to be prone to anxiety attacks. He and a buddy made a dive from a boat, in poor visibility, down to a wreck. The divers became separated and the victim surfaced, visibly in distress. He removed his mask and sank back below the surface. The body was not recovered until eight days later. An autopsy was performed but the medical examiner's office would not release a report or even a cause of death. The case was likely signed out as a drowning death.
BMI = na

06-22 Experienced, certified diver, diving with group on second dive, possibly low on air, surfaced apart from group, buddy found diver unconscious at surface, unknown if autopsy done.

Cause of Death: Death, Unknown Cause

There is little information available regarding the circumstances of the death of this 58-year-old female. She was an experienced, certified diver with her most recent dive trip eight months earlier. The diver was with a group of divers making her second dive of the day to 60 fsw (18 msw). At least one report indicated that she was low on air. She surfaced apart from the other divers and her buddy swam over to her on the surface. The buddy reported that the diver was unconscious at that point and cardiopulmonary resuscitation was initiated in the water. The stricken diver was brought to the boat and then back to shore where she was pronounced dead at a medical facility. There is no information available regarding the cause of death or whether a postmortem examination was conducted. The possibilities include air embolism, drowning, or a natural disease process such as a stroke or a myocardial infarction.
BMI = na

06-23 Certified diver, experienced in warm water diving, made dive in cold water with buddy, separated, body recovered two days later, unknown if autopsy done.

Cause of Death: Death, Unknown Cause

There is little information available regarding the circumstances of the death of this 74-year-old male. He was an experienced, certified diver but nearly all of his diving had been performed in warm water. The diver was making an ocean dive from a boat and in cold water. He became separated from his buddy and his body was recovered two days later

in approximately 250 fsw (76 msw). There is no information available regarding the cause of death or whether a postmortem examination was conducted.
BMI = na

06-28 Certified diver, unknown experience level, no further information available.

Cause of Death: Death, Unknown Cause

There is nearly no information available about the death of this 27-year-old male. He reportedly was certified eight months earlier but his experience level is unknown. There is no other information available except that the fatality occurred outside of the United States.
BMI = na

6-30 Divemaster, unknown if body was recovered, no further information available.

Cause of Death: Death, Unknown Cause

There is no information available regarding the death of this 45-year-old male divemaster. It is listed as a diving-related death but it is unclear if a body was even recovered.
BMI = na

06-32 Experienced, certified diver, diving with group, separated from buddy, last seen on descent, mooring line broke and diver disappeared and never recovered.

Cause of Death: Death, Unknown Cause (Body not Recovered)

This 55-year-old male was an experienced, certified diver making a dive with five other individuals. The dive plan was for an excursion to 90 fsw (27 msw). While the victim's buddy dealt with mask problems the two divers became separated. The victim was last seen on descent at 70 fsw (21 msw). The mooring line of the boat broke and the divers were recalled but the victim did not return to the boat. His body was never recovered.
BMI = 27.3 kg·m^{-2}

06-33 Unknown certification and level of experience, diver experienced problem after descent, released belt but BC did not inflate, autopsy results not available.

Cause of Death: Death, Unknown Cause

There is little information available regarding the death of this 49-year-old female. It is unclear if she was a certified diver or whether she had diving experience. According to one report, the victim experienced some sort of problem soon after descent. She released her weight belt but the buoyancy compensator was not inflated. The body was recovered and an autopsy was performed but the findings were not made available.
BMI = na

06-34 Diver certified and experienced, medical history included morbid obesity, history of deep dives with decompression stops on ascent, surfaced unconscious, limited information for this dive.

Cause of Death: Death, Unknown Cause

This 50-year-old male was an experienced, certified diver. His medical problems included morbid obesity. The diver had a history of performing deep dives that required decompression stops. Little information is available about his final dive but he apparently surfaced from a shore entry dive unconscious and with foam coming out of his nose and mouth. The dive profile is unknown. While the final event appears to have been drowning,

contributing factors may include a cardiac event, air embolism, a seizure, or other possibilities.
BMI = na

06-36 Unknown certification and experience level, under instruction for unknown class, limited information.

Cause of Death: Death, Unknown Cause

There is almost no information regarding the diving-related death of this 59-year-old male. It is unknown if he was a certified diver or what level of experience he possessed. He was making a dive from a boat and was in some sort of class or under instruction for an unknown purpose. No other information is available.
BMI = na

06-37 Diver experienced and certified, made solo research dive, surface tenders on boat, unresponsive at depth and pulled to surface, autopsy not available.

Cause of Death: Death, Unknown Cause

This 56-year-old male was an experienced, certified diver making a research dive to 50 fsw (15 msw) using surface-supplied air. He entered the water without a buddy, but had tenders back in a boat on the surface. The diver apparently became unresponsive while at depth and was pulled to the surface. He was unconscious but breathing after cardiopulmonary resuscitation but later died at a local medical facility. There is no additional information available and if an autopsy was performed the findings were not made available. The most likely scenario for this fatality, given the limited circumstances provided, would be a cardiac event.
BMI = na

06-40 Diver with unknown certification and experience, diving with group, surfaced alone, distress on swim to boat, lost consciousness, autopsy not available.

Cause of Death: Death, Unknown Cause

The certification status and experience level of this 57-year-old male is unknown. He was diving in a large group and surfaced from the dive alone. His dive profile is unknown. He began to swim toward the boat but suddenly spat his regulator out and threw up his arms. The diver then lost consciousness and was pulled from the water. Resuscitation efforts were unsuccessful. If an autopsy was performed the findings were not made available. A newspaper article lists the cause of death as drowning but it was published before any autopsy information would have been released. Possible events contributing to this death include air embolism and cardiac event.
BMI = na

06-50 Experienced diver, solo dive to collect scallops, never resurfaced and body never found, limited information.

Cause of Death: Death, Unknown Cause (Body not Recovered)

There is limited information available about this diving-related death. He was a 38-year-old male, experienced diver who made a solo dive from a boat in order to collect scallops. Shortly after he descended, witnesses in the boat noted that the bubbles had disappeared. The diver's body was never recovered.
BMI = na

06-54 Diver with unknown certification and experience, diving with buddy, distress on descent, surfaced with trouble breathing, towed to boat, lost consciousness, unknown if autopsy performed.

Cause of Death: Death, Unknown Cause

The certification status and experience lever of this 41-year-old male is unknown and there is little information about the circumstances surrounding his death. The diver and a buddy entered a river from a boat and soon after descent the victim signaled to his buddy that he was aborting the dive. The diver had trouble breathing on the surface and was towed to the boat by his buddy. He lost consciousness and cardiopulmonary resuscitation was attempted without success. There is no information available to allow a determination of the cause of death. Often when a problem begins at depth it indicates that a medical problem may be present. If an autopsy was performed the findings are not known.
BMI = na

06-55 Diver with basic certification and unknown experience level, diving with group from boat, limited information regarding event or cause of death.

Cause of Death: Death, Unknown Cause

There is virtually no information available on the death of this 59-year-old male. He was believed to be an open-water certified diver but his experience level is unknown. According to the investigation report available the diver was in a group making a dive from a boat. He may have had some type of cardiac event and he received cardiopulmonary resuscitation unsuccessfully onboard the boat. No other information regarding the presumed cause of death is available.
BMI = na

06-58 Certified diver with moderate experience, medical history included heart disease, diving with buddy to collect lobster, separated from buddy and surfaced in distress, sank below the surface, body never found.

Cause of Death: Death, Unknown Cause (Body not Recovered)

This 34-year-old male was a certified diver with moderate experience. His medical history was significant for two previous myocardial infarctions. The diver and a buddy were making dives from a boat in order to collect lobster. The depth of the dive was approximately 80 fsw (24 msw). The two divers became separated and the victim was seen by topside witnesses to surface in distress and sink back below the surface. Despite diligent search efforts, the decedent's body was never recovered.
BMI = na

06-73 Student diver, open-water class incomplete, made an open water dive in rough seas and poor visibility, attempted descent, returned to boat for more weight, descended, last seen near bottom, body never found.

Cause of Death: Death, Unknown Cause (Body not Recovered)

This 28-year-old female was enrolled in an entry level open-water certification class and had participated in at least one pool lesson 10 days earlier but she had never made an open-water dive. She was making a dive from a boat in rough seas and poor visibility. The dive was planned to be to 28 fsw (9 msw) for 40 minutes. The victim entered the water and attempted to descend but she returned to the boat for more ballast weight. She then descended and was last seen near the bottom by her buddy. The diver did not surface from this dive and her body was never recovered. There are still suspicions

surrounding the disappearance of this diver but there has been no evidence of foul play discovered by the authorities to date.
BMI = 22.8 kg·m^{-2}

Proximate Cause: Other

06-19 Experienced technical diver, made deep dives to wreck on trimix rebreather, after dives he descended alone to free anchor, possibly missed decompression and rapid ascent, surfaced and lost consciousness, autopsy not available.

Cause of Death: Decompression Sickness due to Rapid Ascent due to Scuba Diving

This 49-year-old male was a very experienced technical diver making a dive to greater than 200 fsw (61 msw) on a wreck using a rebreather apparatus and trimix breathing gas. After completing earlier dives he descended to free the anchor of the dive boat. It is uncertain if he had a problem with his reel as he began his ascent (the reports vary on this point), but in any event it appears that he missed one or more decompression stops and made a rapid ascent to the surface. At the surface he called for help and then lost consciousness. He was brought to the boat and then airlifted to a local hospital where he was pronounced dead. The autopsy report was not made available but this appears to be one of those rare cases of fatal decompression sickness. It is also very possible that the diver sustained pulmonary barotrauma and perhaps an air embolism in addition to decompression sickness.
BMI = na

06-62 Certified, but inexperienced diver, made shore entry dive to join group, poor visibility, gear assembled by someone else, descended and had problem with air source, buddy could not help, victim sank and found at bottom, died five days later.

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

This 58-year-old female became a certified diver five years earlier but had only completed 40 lifetime dives. She was going to enter a lake to join a large group of divers, making a shore entry into poor visibility water. The diver was in a hurry and had someone else put her equipment together. She descended quickly and had an early problem with her air source. The diver's buddy rendered assistance, providing an alternate air source and trying to assist the diver to the surface but the grip on the stricken diver was lost and she sank back down. Two other divers brought the victim to the surface where resuscitation efforts were started. The diver spent five days in a medical treatment facility before she died. An autopsy revealed complications of near drowning, which included anoxic brain injury and bronchopneumonia, as well as focally severe coronary artery disease. An examination of the equipment showed that the tank valve was closed and the power inflator hose to the buoyancy compensator was disconnected. The person who assembled the gear stated that all was in order with the gas turned on when the diver entered the water. It is unclear when the air was turned off in this scenario, if it was ever turned on.
BMI = 24.8 kg·m^{-2}

APPENDIX C. BREATH-HOLD INCIDENT CASE REPORTS

06-01 - Non-Fatal

This 41-year-old male was one of a group of four, spearfishing during a vacation in Hawaii. The conditions were light seas, slight current, and visibility greater than 50 ft (15 m) on this first day of the trip. He completed 12 modest dives (12-44 fsw [4-13 msw] depth and 10-59 s duration) followed by one more aggressive dive (90 fsw [27 msw] and 1:43 min:s duration) - the incident dive. The diver reported doing no hyperventilation before the dive, but described "several slow full exhalations and inhalations before taking a full breath." He planned to descend to approximately 60 fsw (18 msw) but the bottom was deeper than anticipated and he was approaching 90 fsw (27 msw) before realizing it. He paused briefly at his maximum depth and then began his ascent. He reached the surface and then fell unconscious. He rapidly sank to a depth of eight feet (2.4 m) before being pulled to the surface by one of the other divers. He regained consciousness quickly, with residual symptoms including a transient headache, slight nausea and some difficulty concentrating persisted for the next hour. There were no other complications. Several issues influenced this case. The diver was unfamiliar with the diving area, overweighted, and overconfident in his capabilities. Members of the group were aware of the importance of direct supervision post-dive, but did not employ it uniformly. Finally, the poorly defined continuum between hyperventilation and 'deep breathing' or 'workup breaths' is subjective and potentially a poorly appreciated source of risk BMI - 24.0 kg$\cdot$m^{-2}

06-07 - Non-Fatal

This 71-year-old male suffered from severe lacerations to the buttocks after being struck by a motorboat while spearfishing with two others during daylight hours. It is believed the driver of the boat did not see the man in the water at the time of the accident. It is possible that the use of surface floats and brightly colored equipment would have improved the visibility and thus the safety of the divers.

06-11 - Fatal

This 29-year-old male deepwater spearfisherman disappeared while spearfishing with friends. His body was subsequently recovered from the bottom at 120 ft (37 m). The events were unwitnessed but it is likely that blackout was involved; either hypoxic blackout at the bottom or, more likely, hypoxia of ascent. The risk would have been lessened by direct supervision by other divers. The use of automatic freediver recovery vests might be an appropriate alternative for independently diving spearfishermen.

06-12 - Fatal

This 50-year-old female was snorkeling from a commercial boat when she developed breathing difficulties. She was assisted to the boat, given oxygen and then cardiopulmonary resuscitation while en route to shore. She was pronounced dead at the dockside after being met by emergency medical personnel. The conditions suggested contribution from an existing medical condition.

06-15 - Fatal

This 23-year-old female was snorkeling in shallow water (approximately three feet [one meter] of depth) in an isolated spring with three others. The group was separated in pairs and then the victim was separated from her partner. After a brief search in the water and from shore by the three, the victim was found in the jaws of a seven to nine foot (two to three meter) long alligator. The risk of human-animal interactions increases as the range of animal territory is reduced.

06-16 - Fatal

This six-year-old male was snorkeling with two family members next to their 22-foot motorboat. A passing 18-foot skiff struck the victim and the boat. The risk of vessel-diver interactions can be reduced with the use of surface dive floats and brightly colored equipment.

06-21 - Fatal

This 22-year-old male was in the water with three friends; sharing a single set of snorkel gear and a flashlight to explore underwater caves. The victim was the last to go in and did not come up. His body was recovered from an underwater cave five hours later. Solo diving eliminates the possibility of buddy support in case of emergency.

06-26 - Fatal

This 37-year-old male graduate student was using a well-established technique to hand capture turtles for surface study. A freediver grabs the carapace fore and aft from above and behind, levers the aft end down, and directs the swimming turtle upwards. Additional swimmers are usually available to provide assistance. Scuba is not worn, as it makes the divers too slow to complete the capture. In this case, the experienced 170 lb (77 kg) victim jumped into the water from a small boat when he saw an estimated 300 lb (136 kg) green sea turtle just below the surface. The events occurring underwater are unknown since there were no other swimmers or divers in the water to observe or render assistance. Emergency services were contacted when the victim did not surface within four minutes. The victim's body was found four days later, with no wounds evident. It is possible that the lack of immediate assistance contributed to this outcome.

06-30 - Fatal

This 42-year-old male was spearfishing alone from a jetski in about 25 ft (8 m) of water. He speared a 40-inch fish which apparently bolted into a hole, in the process entangling the diver's wrist in the line. The diver was pinned at a depth of 17 ft (5 m) until he drowned. The presence of a partner and/or a knife easily accessible to either hand may have changed the outcome of this event.

06-37 - Fatal

This 59-year-old male was solo diving for octopus from a boogie board. A search was initiated when he failed to return home. His body was found in 8 fsw (3 msw), still tied to his boogie board. He had pre-existing cardiac disease. The medical examiner concluded that he had a stroke while diving and probably fell unconscious and then drowned.

06-39 - Fatal

This 41-year-old male was snorkeling with his wife on a reef. Friends on a nearby boat noticed that he was unmoving in a face down position at the surface. Attempts to resuscitate him were unsuccessful. The conditions suggested contribution from a pre-existing medical condition.

APPENDIX D. PROJECT DIVE EXPLORATION DATA COLLECTION

DAN Interns Collecting PDE Data

Intern	Center	Dives Collected
2006		
Kristin Lyons	Ocean Frontiers, Grand Cayman	2,959
Juliana Belolloti	Atlantis Divers, Fernando De Noronha, Brazil	934
Catherine Sincich	Institute of Nautical Archaeology, Bodrum, Turkey	854
Mairead Conneely	Scapa Flow, Scotland	765
Lucas Keenan	University of California, Santa Cruz	547
Brett Anderson	Aquatic Safari & Diver's Emporium, Wilmington, NC	390
Eric Little	Utila Lodge, Bay Island, Honduras	275
Andrea Krzystan	South Florida dive shops	109
2005		
Robert Conway	Ocean Frontiers, Grand Cayman	1,222
Aaron Mishkin	Cozumel, Mexico	1,130
Jessica Begyn	Sunset House, Grand Cayman	1,079
Matt Horton	Global Underwater Explorers, High Springs, FL	921
Lisa Zuckerwise	Aquatic Safaris, Wilmington, NC	338
Steve Hardy	Nautilus Explorer, Canada / Silent World, WA	191

Independent FRCs - Top collectors (over 100 dives submitted)

Peter Berende
Patrick Murphy
David Grenda
Robert Eichholtz, Jr.
Brian Basura
Dave Valaika

APPENDIX E. PUBLICATIONS

2007

Refereed Articles (primary literature)

Longphre JM, Denoble PJ, Moon RE, Vann RD, Freiberger JJ. First aid normobaric oxygen for the treatment of recreational diving injuries. Undersea Hyperb Med. 2007; 34(1): 43-50.

INTRODUCTION: First aid oxygen (FAO_2) has been widely used as an emergency treatment for diving injuries, but there are few studies supporting its efficacy. METHODS: 2,231 sequential diving injury reports collected by the Divers Alert Network (DAN) Injury database from 1998 to 2003 were examined. RESULTS: 47% (1,045) of cases received FAO_2. The median time to FAO_2 treatment after surfacing was four hours and after symptom onset was 2.2 hours. Persistent complete relief (14%) or improvement (51%) was seen with FAO_2 alone (65% overall response; n = 330). After one recompression treatment 67% of FAO_2 patients reported complete relief compared to 58% of the no FAO_2 group (OR = 1.5, 95% CI = 1.2 -1.8). FAO_2 given at any time after surfacing significantly reduced the odds of multiple recompression treatments (OR = 0.83, 0.70-0.98). When FAO_2 was given within 4 hours of surfacing, the OR decreased to 0.50 (0.36-0.69) yielding a number needed to treat of 6. Case severity affected urgency of FAO_2 treatment. Individuals with more prominent symptoms received prompt treatment. Cardiopulmonary, skin, and serious neurological symptoms had shorter delays to FAO_2 ($p<0.001$). CONCLUSIONS: FAO_2 increased recompression efficacy and decreased the number of recompression treatments required if given within four hours after surfacing.

Pollock NW, Natoli MJ. Performance characteristics of the second-generation Remote Emergency Oxygen ($REMO_2$) closed-circuit rebreather. Wild Environ Med. 2007; 18(2): 86-92.

OBJECTIVE: Closed-circuit oxygen rebreathers may provide high concentrations of oxygen at extremely low flow rates appropriate for field use with limited oxygen supplies. The performance of the preproduction, second-generation remote emergency medical oxygen (REMO2 system developed for Divers Alert Network was evaluated. METHODS: The unidirectional circuit was made up of a solid, prepackaged CO2 scrubber canister (984 ± 14 [SD] g scrubber mass), standard 22-mm-inside-diameter anesthesia circuit hoses, 5-L breathing bag, 5-cm H2O positive end-expiratory pressure valve, and oronasal mask. Oxygen flow, inspired oxygen, expired CO2, peak inspired and expired mask pressures, time to reach scrubber canister saturation or "breakthrough" (postscrubber CO2 concentration reaching 3.8 mm Hg), and subject tolerance were measured under standard laboratory conditions. RESULTS: Six trials were completed using healthy volunteers (94.7 ± 19.6 kg). Five of the 6 completed trials did not reach breakthrough at the planned trial limit of 8 hours. Mean average oxygen flow rate was 1.00 ± 0.17 L·min-1. Mean peak inspired and expired mask pressures were -5.0 ± 1.9 and 6.5 ± 1.9 cm H2O, respectively. Subjects generally reported good tolerance to circuit breathing. CONCLUSIONS: The second-generation REMO2 was well tolerated by healthy subjects during 8-hour laboratory evaluation trials. The device provided high mean inspired oxygen fractions at low mean oxygen flow rates, relatively modest mean maximal inspired and expired pressures, and excellent scrubber canister duration. Further evaluation of field performance with a patient population is warranted.

Vann RD, Pollock NW, Freiberger JJ, Natoli MJ, Denoble PJ, Pieper CF. Influence of bottom time on preflight surface intervals before flying after diving. Undersea Hyperb Med. 2007; 34(3): 211-220.

Previous trials of flying at 8,000 ft after a single 60 fsw, 55 min no-stop air dive found low decompression sickness (DCS) risk for a 11:00 preflight surface interval (PFSI). Repetitive 60 fsw no-stop dives with 75 and 95 min total bottom times found 16:00. Trials reported here investigated PFSIs for a 60 fsw, 40 min no-stop dive and a 60 fsw, 120 min decompression dive. The 40 min trials began with a 12:05 PFSI (USN guideline) which was incrementally reduced to 0:05 (three DCS incidents in 281 trials). The 120 min trials began with a 22:46 PFSI (USN guideline) which was reduced to 2:00 (nine incidents in 281 trials); 2:00 was rejected with six incidents. Low-risk PFSIs for the 40 min dive were nearly 12 hours shorter than for the 55 min dive, and low-risk PFSIs for the single 120 min decompression dive were 12 hours shorter than for the 75-95 min repetitive dives. With the dry, resting conditions of these dives, low-risk PFSIs appeared to be sensitive to dive profile characteristics such as

bottom time, repetitive diving, and decompression stops. Whether this is so for wet, working dives is unknown.

Review Articles (secondary literature)

Pollock NW. Aerobic fitness and underwater diving. Diving Hyperb Med. 2007; 37(3): 118-124.
Physical fitness is necessary to ensure that the normal and emergent needs of diving can be met. Reserves of both strength and aerobic capacity are important. Aerobic capacity (aerobic fitness or VO2 max) is defined as the maximum amount of oxygen that can be consumed per unit time. Alternatively, it can be described as metabolic equivalents (MET), dimensionless multiples of the oxygen consumption of assumed resting metabolic rate (3.5 mL·kg-1·min-1), yielding a range of 5-25 MET in the healthy population. A minimum capacity as high as 13 MET has been proposed for diving qualification. While limited, the available research data suggest that this is an unrealistically high threshold. A minimum capacity in the range of 7-10 MET may be more appropriate. Recognizing the importance of physical fitness and the decline associated with normal aging, training programs should promote awareness of the problems and risks that may be associated with low levels of fitness and the benefits of enhanced fitness. Training to understand and increase aerobic capacity should be encouraged.

Pollock NW. Scientific diving in Antarctica: history and current practice. Diving Hyperb Med. 2007; 37(4): 204-211.
Diving has served as an important research tool in Antarctic science for the past 50 years. Equipment, techniques and oversight have developed to make it a mainstream function in many polar programmes. The safety record is encouraging, particularly given the unforgiving nature of the environment.

Pollock NW. Use of ultrasound in decompression research. Diving Hyperb Med. 2007; 37(2): 68-72.
Techniques for ultrasonic assessment of decompression stress continue to evolve in concert with technological development. While aural Doppler remains a staple, imaging techniques are gaining in popularity. Current initiatives to increase the resolution of three-dimensional and dual-frequency imaging hold promise to expand our monitoring capabilities. An appreciation of the limitations and strengths of ultrasonic assessment is important to interpret existing work on decompression and to appropriately design new studies.

Editorial Articles

Pollock NW. Diabetes and recreational scuba diving. Pract Diabetol. 2007; 26(3): 30-32.

Books

Dear GdeL, Douglas E, Pollock NW, Freiberger JJ. DAN Pocket Guide to First Aid for Scuba Diving. 2nd ed. Durham, NC: Divers Alert Network; 2007; 35 pp.

Orr DL, Douglas EL. Scuba Diving Safety. Champaign, IL: Human Kinetics; 2007; 196 pp.

Book Chapters

Douglas EL, Moon RE. Emergency Oxygen Administration. In: Auerbach, PS, ed. Wilderness Medicine, fifth edition. Philadelphia, PA: Mosby/Elsevier; 2007: 1590-1598.

Nord DA. Scuba diving. In: Arguin PM, Kozarsky PE, Reed C, eds. Centers for Disease Control and Prevention Health Information for International Travel 2008. Atlanta, GA: US Department of Health and Human Services, Public Health Service, 2007: 464-468.

Edited Proceedings

Godfrey JM, Pollock NW, eds. Diving for Science 2006. Proceedings of the 25th American Academy of Underwater Sciences Symposium. ISBN #978-0-9800423-0-6. Dauphin Island, AL: AAUS; 2007; 104 pp.

Pollock NW, Godfrey JM, eds. Diving for Science 2007. Proceedings of the 26th American Academy of Underwater Sciences Symposium. ISBN# 0-9800423-1-3. Dauphin Island, AL: AAUS; 2007; 197 pp.

Proceedings Articles

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.

Pollock NW. Evolving standards for diabetes and diving: implications for scientific diving. In: Godfrey JM, Pollock NW, eds. Diving for Science 2006. Proceedings of the American Academy of Underwater Sciences 25th Symposium. Dauphin Isl, AL: AAUS, 2007: 25-38.

Pollock NW. Scientific diving safety: integrating institutional, team and individual responsibility. 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: 45-50.

Vann RD. The history of Divers Alert Network (DAN) and DAN Research. In: Moon RE, Piantadosi CA, Camporesi EM, eds. Proceedings of Dr. Peter B. Bennett Symposium. Durham, NC: Divers Alert Network; 2007: 81-120.

Vann RD, Pollock NW. Rebreather fatality investigation. 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: 101-110.

Edited Reports

Pollock NW, Vann RD, Denoble PJ, Freiberger JJ, Dovenbarger JA, Nord DA, McCafferty MC, Caruso JL. Annual Diving Report, 2007 Edition. Durham, NC: Divers Alert Network, 2007; 118 pp.

General Articles (lay literature)

Douglas EL. Swept away. Scuba Diving. 2007; Dec: 81.

Douglas EL. Four reasons divers die. Scuba Diving. 2007; Oct: 66-68.

Douglas EL. No-hassle night diving. Scuba Diving. 2007; Sept: 71-74.

Douglas EL. Emergency oxygen: provide the highest concentration as soon as possible. Alert Diver. 2007; Mar/Apr: 16-18.

Douglas EL. New Zanzibar chamber furthers DAN mission. Alert Diver. 2007; Jan/Feb: 44-45.

Douglas EL, Ange, MR. Finding proper trim. Scuba Diving. 2007; Nov: 91-96.

Douglas EL. Nord DA. Stop, in the name of safety. Alert Diver. 2007; Nov/Dec: 20-23.

Held HE, Pollock NW. The risks of diving while pregnant - reviewing the research. Alert Diver. 2007; Mar/Apr: 48-51.

Pollock NW. Bubbles and ultrasound. Alert Diver. 2007; Nov/Dec: 48-51.

Pollock NW. Testing the $REMO_2$ closed-circuit oxygen rebreather. Alert Diver. 2007; Sept/Oct: 48-51.

Pollock NW. Hypothermia - the cold facts. Midwest Scuba Diving. 2007; Summer: 20-21.

Pollock NW. AAUS publications - repositories and availability. Slate. 2007; 2: 25.

Pollock NW. Diabetes and the teenage diver - collecting the data. Alert Diver. 2007; July/Aug: 45-47.

Pollock NW. Practical thoughts on physical fitness and a return to diving. Alert Diver. 2007; Jan/Feb: 27-29.

Vann RD, Pollock NW, Denoble PJ, Freiberger JJ. Flying after diving. Alert Diver. 2007; Nov/Dec: 36-39.

Abstracts

Denoble PJ, Caruso JL, Dear GdeL, Pieper CF, Vann RD. Application of the pareto principle to recreational diving deaths. Undersea Hyperb Med. 2007; 34(suppl): 281.

Denoble PJ, Ellis J, Vann RD. Fatalities in divers using rebreathers. Undersea Hyperb Med. 2007; 34(4): 282-283.

Freiberger JJ, Flachofsky E, Dear GdeL, Moon RE, Piantadosi CA. Long term follow up for hyperbaric oxygen treatment of osteoradionecrosis of the mandible. Undersea Hyperb Med. 2007; 34(4): 293-294.

Howle LE, Weber PW, Vann RD. A parameter estimation system with computational advantages for fitting probabilistic decompression models to empirical data. Undersea Hyperb Med. 2007; 34(4): 230.

Uguccioni DM, Natoli MJ, Comfort BJ, Justus MA, Freiberger JJ, Vann RD. Nasopharyngeal pressure during middle ear equalization: A device to support investigation of aural barotrauma. Undersea Hyperb Med. 2007; 34(4): 252.

Vann RD, Denoble PJ, Caruso JL, Dear GdeL, Pieper CF. Statistical validation of the pareto principle as applied to recreational diving deaths. Undersea Hyperb Med. 2007; 34(suppl): 282.

Weber PW, Howle LE, Denoble PJ, Vann RD, Pieper CF. Probability models of mild and serious decompression sickness (DCS). Undersea Hyperb Med. 2007; 34(4): 229-230.

Audiovisual Material

Vann RD. "Breathing Underwater is an Unnatural Act." Divers Alert Network Web-Based Training Program. http://www.diversalertnetwork.org/training/seminars/bubbles/index.asp.
First accessible: January 4, 2007.

2006

Refereed Articles (primary literature)

Pollock NW, Uguccioni DM, Dear GdeL, Bates S, Albushies TM, Prosterman SA. Plasma glucose response to recreational diving in novice teenage divers with insulin-requiring diabetes. Undersea Hyperb Med. 2006; 33(2): 125.133.

> A growing number of individuals with insulin-requiring diabetes mellitus (IRDM) dive, but data on plasma glucose (PG) response to diving are limited, particularly for adolescents. We report on seven 16-17 year old novice divers with IRDM participating in a tropical diving camp who had recent at least moderate PG control (HbA1c 7.3 ± 1.1%) (mean ± SD). PG was measured at 60, 30 and 10 min pre-dive and immediately following 42 dives. Maximum depth (17 ± 6 msw) and total underwater times (44 ± 14 min) were not extreme. Pre-dive PG exceeded 16.7 mmol·L-1 (300 mg·dL-1) in 22% of dives. Males had significantly higher pre-dive levels (15.4 ± 5.6 mmol L-1 [277 ± 100 mg·dL-1] vs. 12.8 ± 2.9 mmol·L-1 [230 ± 52 mg·dL-1], respectively) and greater pre-post-dive changes (-4.3 ± 4.4 mmol L-1 [-78 ± 79 mg·dL-1] vs. -0.5 ± 4.3 mmol·L-1 [-9 ± 77 mg·dL-1], respectively). Post-dive PG was <4.4 mmol·L-1 [<80 mg·dL-1] in two dives by two different males (3.4 and 3.9 mmol L-1 [61 and 70 mg·dL-1]). No symptoms or complications of hypoglycemia were reported. These data show that in a closely monitored situation, and with benign diving conditions, some diabetic adolescents with good control and no secondary complications may be able to dive safely. The impact of purposeful elevation of PG to protect against hypoglycemia during diving remains to be determined.

Review Articles (secondary literature)

Vann R. The year in review: a synopsis of diving literature: 2005. Jap J Hyperb Undersea Med. 2006; 41(4): 257-264.

   [No abstract available.]

Books

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

Dear GdeL, Pollock NW, (with Moon RE, Uguccioni DM, Myers J, Douglas E). DAN America Dive and Travel Medical Guide. 4th ed. Durham, NC: Divers Alert Network; 2006.

Edited Proceedings

Lindholm P, Pollock NW, Lundgren CEG, eds. Breath-hold diving. Workshop Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21. Durham, NC: Divers Alert Network, 2006:165 pp.

Proceedings Articles

Modi SJ, Pollock NW. DAN breath-hold incident database: 2004-2005 records. In: Lindholm P, Pollock NW, Lundgren CEG, eds. Breath-hold Diving. Proceedings of the Undersea Hyperbaric Medical Society/DAN 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network, 2006: 56-59.

Pollock NW. Development of the DAN breath-hold incident database. In: Lindholm P Pollock NW, Lundgren CEG, ed. Breath-hold diving. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network, 2006: 46-55.

Published Reports

Vann RD, Freiberger JJ, Caruso JL, Denoble PJ, Pollock NW, Uguccioni DM, Dovenbarger JA, Nord DA, McCafferty MC. Annual Diving Report. Durham, NC: Divers Alert Network; 2006: 99 pp.

General Articles (lay literature)

Adams JB, Pollock NW. Increasing diver confidence and ability with muscular fitness. Alert Diver. 2006; May/June: 36-39.

Douglas EL. New first aid and CPR guides: changes are coming to DAN courses. Alert Diver. 2006; Mar/Apr: 26-27.

Douglas EL. On-site neuro assessment: the next step in diver care. Alert Diver. 2006; Mar/Apr: 28-29.

Douglas EL. Safety is good for business. Alert Diver. 2006; Mar/Apr: 30-31.

Donnawell KR, Pollock NW. Careers in diving. Alert Diver. 2006; Jan/Feb: 38-39.

Pollock NW. Developing a personal fitness program. Quest. 2006; 7(1): 13-15.

Pollock NW. Flying after diving. Ask the WMS Experts, Wild Environ Med. 2006; 23(3): 28.

Pollock NW. Hypothermia. Alert Diver. 2006; Sept/Oct: 40-43.

Pollock NW. Perception and cold-water diving. Alert Diver. 2006; Sept/Oct: 38-39.

Pollock NW. Scientific diving in Antarctica - the U.S. program. Quest. 2006; 7(2): 27-29.

Pollock NW. Sport diving and diabetes. Alert Diver. 2006; July/Aug: 12.

Vann RD. MCPO Don Rose, USN, Ret.: a career in diving in the Underwater Demolition Teams. The Blast. 2006; 38(4): 44-48.

Vann RD. The year in review: a synopsis of diving literature 2005. Japanese J Hyperb Undersea Med. 2006; 41(4): 257-264.

Abstracts

Dear GdeL, Freiberger JJ, Denoble PJ, Uguccioni DM, Moon RE, Vann RD. Older divers and outcomes after the treatment of decompression illness. Undersea Hyperb Med. 2006; 33: 358.

Denoble PJ, Freiberger JJ, Uguccioni DM, Vann RD. Correlation of tympanometric findings with equalization problems and symptoms of middle ear barotrauma during seven-day dive trip. Undersea Hyperb Med. 2006; 33: 364.

Denoble PJ, Pollock NW, Dear GdeL, Uguccioni DM, Vann RD. Diving fatalities involving divers with diabetes mellitus. Undersea Hyperb Med. 2006; 33(5): 364.

Howle L, Lebental S, Vann RD. An object-oriented system for optimizing probabilistic decompression models to empirical decompression data. Undersea Hyperb Med. 2006; 33: 328.

Modi SJ, Pollock NW. Development of the DAN breath-hold incident database: 2004-2005. Undersea Hyperb Med. 2006; 33(5): 371.

Nishi RY, Pollock NW. Sensitivity and specificity as related to Doppler bubble data. Undersea Hyperb Med. 2006; 33(5): 328.

Pollock NW, Natoli MJ. Performance Characteristics of the Divers Alert network Remote Emergency Oxygen (REMO$_2$) Closed-circuit Rebreather. Wild Environ Med. 2006; 17(1): 57-58.

Vann RD, Lebental S, Howle L. The relative roles of surface tension and the oxygen window in bubble resolution. Undersea Hyperb Med. 2006; 33: 327.

Audiovisual Material

Moon RE. "Pathophysiology of Decompression Illness." Divers Alert Network Web-Based Training Program. http://www.diversalertnetwork.org/training/seminars/pathophysiology/index.asp. First accessible: March 05, 2006.

Pollock NW. "Diabetes and Recreational Diving." Divers Alert Network Web-Based Training Program. http://www.diversalertnetwork.org/training/seminars/diabetes/index.asp. First accessible: November 08, 2006.

Vann RD. "Inert Gas Exchange, Bubbles, and Decompression Theory." Divers Alert Network Web-Based Training Program. http://www.diversalertnetwork.org/training/seminars/bubbles/index.asp. First accessible: July 27, 2006.

APPENDIX F. GLOSSARY

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

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

Acute
Of short or sharp course, not chronic; said of disease.

Aerobic Capacity (VO2 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.

Aerophagia
Excessive swallowing of air.

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

Alveolus, Pulmonary
Terminal dilations of the bronchioles where gas exchange occurs.

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.

Apnea
Absence of breathing.

Arrhythmia, Cardiac
Loss of heart rhythm.

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 of the large branches of the renal artery.

Asphyxia
Impaired or absent ventilation and, subsequently, gas exchange.

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.

Barodontalgia
Dental pain caused by either increased or reduce atmospheric pressure.

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

Blackout
Temporary loss of consciousness.

Bleb
A large flaccid (relaxed, without tone) vesicle (sac).

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. Body composition 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.

Bronchitis
Inflammation of the mucous membrane of the bronchial tubes.

Bronchus
One of the primary subdivisions of the trachea that convey air to and from the lungs.

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)
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 status 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.

Chronic
Of long duration; denoting a disease of long continuance.

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

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

Constitutional
General; relating to the system as a whole; not localized.

Coronary Artery Disease
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 gas tension dissolved in a diver's tissue exceeds ambient hydrostatic pressure and gas bubble formation occurs. The 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 also 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.

Diuretic
Promoting the excretion of urine.

Dive Computer
Personal electronic devices that continually measure time and pressure during the dive, calculate remaining dive time, monitor ascent rate and provide instructions for decompression. Dive computers may employ any one of a number of mathematical models to compute decompression status. Some dive computers are integrated with breathing gear and may measure the pressure in gas dive cylinders.

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 of interest for PDE.

Dive Log-7 (DL-7)
A standard computer format for recording information about divers, their dive profiles and medical outcomes.

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. For use in PDE, the recording interval should be five seconds or less.

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 similar to Project Dive Exploration developed and conducted by DAN Europe, with shared goals and methodology.

Dive Series
As applied to PDE, all the dives between a period of 48 hours without diving and 48 hours without diving or flying.

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.

Dysrhythmia, Cardiac
Defective rhythm of the heart.

Edema
An accumulation of an excessive amount of watery fluid in cells, tissues, or serous cavities.

Electrocardiogram
The graphic record of the heart's electrical activity.

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)
A nitrogen/oxygen breathing gas mixture containing more than 21% oxygen, usually made by mixing air and oxygen. Also known as nitrox and oxygen-enriched air.

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

Facial Baroparesis
A reversible paralysis of the facial (seventh cranial) nerve resulting from pressure introduced through the middle ear. Also known as alternobaric facial nerve palsy.

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 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 traditionally used by the Navy and was adopted by the dive industry. For metric conversions, the term 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 PDE.

First Aid Oxygen (FAO$_2$) – See Surface Oxygen Treatment

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

Flying After Diving (FAD)
Flying after diving involves exposure of divers to a secondary decompression. 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. In the first few hours after a dive, a diver may still have enough excess nitrogen dissolved in his body to allow the secondary decompression stress of flying to cause decompression sickness. Unpressurized aircraft may reach altitudes in excess of 8,000 ft. For this report, all flights within 48 hours after diving are considered "flying after diving." Practically, divers will also be exposed to reduced atmospheric pressure by mountain travel.

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.

Gait
Manner of walking.

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).

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 40-55% for males and 35-45% for females.

Hemoptysis
The spitting of blood derived from the lungs or bronchial tubes.

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

Hypoxia
Condition of lower-than-normal oxygen partial pressure in the blood. Also 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. Commonly called shallow water blackout in North America, but not desired since this name 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.

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)
AIDA is the Worldwide Federation for breath-hold diving, established in 1992. The association 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.

Lung Barotrauma – See Pulmonary Barotrauma

Lymphatic
Pertaining to lymph, a vascular channel that transports lymph, or a lymph node.

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)
1.0 msw = 3.28084 fsw (arithmetic conversion). See Feet of Seawater (fsw).

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.

Mottling
An area of skin comprised of macular lesions of varying shades or colors.

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.

Neurological
Involving the nervous system.

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

Otoscope
An instrument for examining the tympanic membrane (ear drum) or auscultating the ear.

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

Oxygen-Enriched Air – See EAN

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

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.

Pleura
The serous membrane enveloping the lungs and lining the walls of the pleural cavity.

Pneumomediastinum – See Mediastinal Emphysema

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

Prophylaxis
The prevention of disease.

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). 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.

Quadriplegia
Paralysis of all four limbs.

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 be permanent.

Resolution of Symptoms
Symptoms resolving (disappearing) after appearance. Resolution may be spontaneous or in response to treatment.

Reverse Block
Overpressure developing in a closed air space during ascent as ambient pressure falls and internal pressure cannot be equalized.

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.

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 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 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. 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 to maintain 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 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.

Stroke
A sudden neurological affliction usually related to a cerebral blood supply disruption.

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 (dumping exhaled gas) or closed (reusing exhaled gas after it is scrubbed of carbon dioxide). 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 more serious type of DCS that is sometimes seen after long deep dives with a rapid ascent. Type III DCS is thought to be caused by the occurrence of 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 deteriorating clinical picture that becomes rapidly worse.

United States Navy Treatment Table 5 (USN TT5)
A 2:15 h:min oxygen with air breaks recompression protocol used 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 oxygen with air breaks recompression protocol commonly used 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 either 60 fsw or 30 fsw (9 msw).

Upper Respiratory Infection (URI)
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)
The waist-to-hip ratio is 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.