RECREATIONAL DIVING FATALITIES WORKSHOP PROCEEDINGS

APRIL 8-10, 2010

DURHAM, NORTH CAROLINA

DAN

Recreational Diving Fatalities Workshop Proceedings

April 8-10, 2010

Richard D. Vann, Ph.D.

Michael A. Lang, B.Sc.

Editors

Recommended Citation:

Vann RD, Lang MA, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011. ISBN #978-0-615-54812-8.

This book is available for download at no cost as a PDF file from the Divers Alert Network website: *www.DAN.org*.

Design by Diana Palmer, DAN Communications.

ISBN #978-0-615-54812-8

CONTENTS

Acknowledgements

Naval Sea Systems Command

Office of Naval Research

Additional thanks to Patty Seery for skillful logistics management.

Special thanks to Dr. Simon Mitchell for preparation of the cardiovascular session summary.

Editors:

Richard D. Vann, Ph.D.
Divers Alert Network
Center for Hyperbaric Medicine and Environmental Physiology
Duke University Medical Center
Durham, N.C. USA

Michael A. Lang, B.Sc.
Smithsonian Institution
Washington, D.C. USA

Recreational Diving Fatalities Workshop Summary*

Richard D. Vann, Ph.D.
Divers Alert Network
Center for Hyperbaric Medicine and Environmental Physiology
Department of Anesthesiology
Duke University Medical Center
Durham, N.C., USA

Michael A. Lang, B.Sc.
Smithsonian Institution
Washington, D.C., USA

The risks of dying during recreational diving are small. The purpose of this workshop was to consider how the risks might be reduced further. Topics included investigation, surveillance, training and operational safety, and cardiovascular disease. Investigations involve on-scene inquiry, forensic examination of the deceased and life-support-equipment testing. These are essential to determine causes but are often inadequate. Independent annual fatality rates were presented and reviewed for diving, jogging and motor vehicle accidents and for divers in training. Common factors associated with diving fatalities included running out of gas, entrapment or entanglement, buoyancy control, equipment misuse, rough water and emergency ascent. Asphyxia by drowning, air embolism and cardiac events were the principal injuries or causes of death. About one-quarter of the deaths were associated with cardiac events, mostly in older divers. Revised procedures were recommended for identifying occult cardiovascular disease in candidate divers who warrant further investigation, but older, previously certified divers may be at greatest risk.

"Common factors associated with diving fatalities included running out of gas, entrapment or entanglement, buoyancy control, equipment misuse, rough water and emergency ascent."

Introduction

The risk of dying during recreational diving is small, but no activity is completely risk-free, and deaths occasionally occur. Improved countermeasures might be devised if contributing factors were identified. Studies of the causes and annual rates of recreational diving fatalities suggested this might be feasible (Denoble, Caruso et al. 2008; Denoble, Pollock et al. 2008), and this workshop was convened to explore the possibilities. Topics addressed included investigation, surveillance and data analysis, training and operations, and cardiovascular disease. The workshop findings are summarized below. The four cardiovascular papers published in these proceedings (Bove 2011; Thompson 2011; Douglas 2011; Mitchell, Bove 2011) were reprinted with permission from *Undersea and Hyperbaric Medicine.** The proceedings (Vann, Lang 2011) and presentation videos from the workshop are available on the DAN website *(www.DAN.org)* at no cost.

Workshop participants were encouraged to base their comments on evidence rather than opinion, and this approach was generally observed. During planning, one individual offered to present his opinion but declined to attend when asked to provide supporting data. The absence of evidence makes judging the validity of opposing opinions difficult, can lead to personal animosity and is counterproductive to useful public discussion.

Participants in the training panel were concerned in advance that the discussions might increase their liability, and several training agencies declined to attend.

*This summary and the four cardiovascular papers listed below are reprinted with permission from *Undersea and Hyperbaric Medicine*.

Bove A. The cardiovascular system and diving risk. *Undersea Hyperb Med.* 38(4):261-269; 2011.

Douglas P. Cardiovascular screening in asymptomatic adults: lessons for the diving world. *Undersea Hyperb Med.* 38(4):279-287; 2011.

Mitchell S, Bove A. Medical screening of recreational divers for cardiovascular disease: consensus discussion at the Divers Alert Network Fatality Workshop. *Undersea Hyperb Med.* 38(4):289-296; 2011.

Thompson P. The cardiovascular risks of diving. *Undersea Hyperb Med.* 38(4):271-277; 2011.

Vann R, Lang M. Recreational diving fatalities. *Undersea Hyperb Med.* 38(4):257-260; 2011.

To allay these worries insofar as possible, the training panel was not recorded as the other sessions were, although the topics discussed are presented in these proceedings.

Unsupported opinions were most common in the training and operations discussion and occasionally resulted in sharp exchanges. Some of the topics raised were useful, but the acrimony was not. Accordingly, a summary of the key points from the training and operations discussion is presented rather than a verbatim transcript as for the other sessions.

Investigation

In the United States, the Coast Guard and/or state law enforcement agencies have authority over diving fatalities that occur in most U.S. waters. Law enforcement organizations are charged with determining criminal culpability but not investigating causes. A local coroner or medical examiner may be responsible for establishing the cause of death (COD) but is frequently unfamiliar with the special requirements of diving autopsies that differentiate among causes such as drowning, air embolism and decompression sickness (Caruso 2011). Often, agencies are not well coordinated nor do they have the resources or capabilities for comprehensive investigation.

"A local coroner or medical examiner may be responsible for establishing the cause of death (COD) but is frequently unfamiliar with the special requirements of diving autopsies that differentiate among causes such as drowning, air embolism and decompression sickness."

The ideal investigation would begin immediately with a trained individual conducting an on-scene inquiry that included equipment inspection, a dive site survey and interviews with witnesses, dive professionals and public safety personnel (Barsky 2011). Life-support equipment should be impounded and preserved at once. A factual written report should summarize the findings with additional documentation by still photography. Videos of the site and/or equipment may supplement the report as needed. Forensic examination of the deceased would identify the COD and contributing medical factors in the context of operational reports (Caruso 2011).

Life-support equipment for compressed-gas diving is generally robust and reliable, but poor maintenance, improper use or design flaws can compromise its operation and contribute to events leading to death (Bozanic, Carver 2011). Equipment should be treated as evidence rather than personal property, and standard chain-of-custody procedures followed to minimize loss or damage. Forensic testing can determine if equipment was a contributing factor, but testing is expensive, few qualified personnel and facilities are available, and testing may be futile if equipment deteriorates due to long delays.

Investigations are often at the behest of an insurance company, which hires a private investigator with the objective of determining liability (Concannon 2011; Jaeck 2011). Inadequate investigation is a source of distress to the deceased's family and an impediment to understanding the causes of death. The probability of litigation increases when the events and causes are not discovered. Both U.S. and European courts are requiring strict adherence to evidence preservation such as data contained in a dive computer.

Thorough investigations are unusual because there are few trained investigators, but improvements should be achievable. These include: (a) readily available investigation protocols and checklists that are published in these proceedings (see Pages 223-282) and can be downloaded from the DAN website *(www.DAN.org)*; (b) chain of custody procedures for equipment; (c) training of first responders in investigation procedures; (d) collaboration among investigative organizations; (e) standardized equipment test protocols; and (f) national and international case reporting.

Diving Fatality Surveillance

Diving is not unique in its capacity to cause injury, and surveillance is an essential epidemiological tool to identify associated factors (Kucera, Marshall 2011). These factors are the basis for countermeasures to improve safety with regular follow-ups to assess countermeasure effectiveness. Diving fatality surveillance programs were described for the United States, Canada and Europe (Denoble et al. 2011); Australia and the Pacific region (Lippmann 2011) and the United Kingdom (UK) (Cumming et al. 2011). Annual per capita fatality rates among DAN America (16.4 deaths per 100,000 persons per year) and the British Sub-Aqua Club (BSAC) members (14.4 deaths per 100,000 persons per year) were similar and did not change during 2000-2006, the period examined (Denoble et al. 2011). Annual per capita fatality rates during jogging (13 deaths per 100,000 persons per year) and motor vehicle accidents (16 deaths per 100,000 persons per year) were comparable and within the range where reduction is desirable by UK Health and Safety Executive (HSE) criteria (Denoble et al. 2011).

Richardson reported data for 17 million student-diver certifications during 63 million student dives over a 20-year period (1989-2008) during which no trend in annual fatality rate was apparent (Richardson 2011). The mean per capita death rate during this period was 1.7 deaths per 100,000 student divers per year. This was lower than for insured DAN members during 2000-2006 at 16.4 deaths per 100,000 DAN members per year (Denoble et al. 2011), a statistically significant difference ($p<0.0001$ by chi-square test). Per capita fatality rates are poor measures of exposure risk, however, and may not be informative of true risk. Thus, the tenfold lower per capita rate between student divers and DAN members may not represent a tenfold lower exposure risk.

Fatality rate per dive is a better measure of exposure risk, and Richardson reported a mean annual fatality rate of 0.48 deaths per 100,000 student dives per year (Richardson 2011), while Cumming et al. (2011) reported 0.54 deaths per 100,000 BSAC dives per year and 1.03 deaths per 100,000 non-BSAC dives per year during 2007. Naïve comparison of these per-dive rates suggests the difference in risk between diving during organized courses and during non-course dives is less than tenfold, but this conclusion could not be tested statistically since the BSAC rates were based on survey estimates rather than on logged dives as reported by Richardson.

The above review indicates that the difference in risk of death between organized training-course dives and non-course dives was difficult to distinguish in data presented at the workshop. This argues for independent information, and diving training agencies and diver membership organizations are encouraged to publish data similar to that described by Richardson (Richardson 2011). Moreover, the total size of the diving population is important for determining overall fatality rates, and the population estimates from the 1990s of several million U.S. divers need to be updated (Hornsby 2011).

Fundamental problems associated with diving fatalities have not changed significantly in recent history (Denoble et al. 2011; Lippmann 2011; Cumming et al. 2011; Richardson 2011). The most frequently cited root cause among the independent population samples was insufficient gas or running out of gas. Other common factors included entrapment or entanglement, buoyancy control, equipment misuse or problems and rough water. Emergency ascent was also common. The principal injuries or causes of death included drowning or asphyxia due to inhalation of water, air embolism and cardiac events. Older divers were at greater risk of cardiac events, with men at higher risk than women, although the risks were equal at age 65 (Denoble, Pollock et al. 2008).

"The principal injuries or causes of death included drowning or asphyxia due to inhalation of water, air embolism and cardiac events."

Operational Diving Safety

A discussion of diving safety based on operational experience cited many of the risk factors mentioned above (Vann, Lang 2011). Divers are taught to avoid most of these during training, but many who died seemed not to have acted in accordance with instruction. It was unclear why this was so. Suggested countermeasures included skill refreshers with check-out dives, buoyancy control rehearsals and gas management and alternate air source practice. Fatal entanglement might be prevented by carrying a cutting device. Obstructed overhead environments should be avoided (without proper training) to prevent entrapment.

Unsubstantiated opinions concerning contributing factors were common, and although many seemed plausible, validation by empirical evidence is needed. Suggested contributing factors included inexperience, infrequent diving, inadequate supervision, insufficient predive briefings, buddy separation and dive conditions beyond the diver's training, experience or physical capacity.

Given that divers who died often seemed to forget their training, the editors created a diving safety "quiz" (see Appendix C) as a reminder to recreational divers of key safety factors. It is offered for general community use without permission as a handout, dive magazine filler, website post, poster, etc.

Cardiovascular Risk Assessment

Given that cardiac events are associated with about a quarter of recreational diving fatalities that were investigated (Denoble, Caruso et al. 2008), current screening methods appear inadequate for identifying divers at risk of sudden cardiovascular death. The most common causes of sudden death in the general population are arrhythmia and acute myocardial infarction (Thompson 2011), usually due to occult cardiovascular disease with little prior indication of abnormality (Douglas 2011). Divers face additional stresses from immersion and cold, which cause a central shift of blood and can lead to acute volume overload and decompensated heart failure (Bove 2011). Ischemia and arrhythmia may be aggravated during exercise due to increased blood pressure and sympathetic activation. Dive site survival might improve if divers and diving personnel were trained to recognize the signs and symptoms of cardiac events and to offer basic emergency assistance.

"Given that divers who died often seemed to forget their training, the editors created a diving safety 'quiz' as a reminder to recreational divers of key safety factors."

Prevention is preferred to emergency response, however, and two groups are potentially at risk. The first is candidate divers who seek to enroll in initial diving training. For this group, medical screening is generally based on a questionnaire such as the Recreational Scuba Training Council (RSTC) form on which an answer indicating a possibly disqualifying medical condition requires physical examination (RSTC 2010). The workshop reviewed the RSTC form and suggested revisions to its questions based on the AHA preparticipation questionnaire for competitive athletes (Maron et al. 2007). Risk factors discovered during subsequent examination were categorized as contraindications for diving or as grounds for further investigation. Further investigation included a stress test to demonstrate that a candidate diver can sustain exercise at an intensity of 6 MET (multiples of assumed resting metabolic rate) (Mitchell, Bove 2011).

The second at-risk group is established older divers who have developed occult cardiovascular disease in the years since initial training and appear to be at greatest risk (Denoble, Caruso et al. 2008; Denoble, Pollock et al. 2008). Appendix G is a "Divers Self-Assessment Checklist for Cardiovascular Health" that might be used before charter boat dive trips, prior to continuing diving education courses, etc.

References

Barsky S. On-scene diving accident investigation. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Bove A. The cardiovascular system and diving risk. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Bozanic J, Carver D. Equipment testing. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Caruso J. The forensic investigation of recreational diving fatalities. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Concannon D. Legal issues associated with diving fatalities: panel discussion. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Cumming B, Peddie C, Watson J. A review of the nature of diving in the United Kingdom and of diving fatalities, Jan. 1, 1998-Dec. 31, 2009. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Denoble P, Caruso J, Dear Gde L, Pieper C, Vann R. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med.* 35(6):393-406; 2008.

Denoble P, Pollock N, Vaithiyanathan P, Caruso J, Dovenbarger J, Vann R. Scuba injury death rate among insured DAN members. *Diving and Hyperbaric Medicine* 38(4):182-188; 2008.

Denoble P, Marroni A, Vann R. Annual fatality rates and associated risk factors for recreational scuba diving. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Douglas P. Cardiovascular screening in asymptomatic adults: lessons for the diving world. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Hornsby A. Models for estimating the diver population of the United States: an assessment. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Jaeck F. Collecting data and investigating a diving accident: focus on the European law. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Kucera K, Marshall S. Developing and evaluating interventions using surveillance data. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Lippmann J. Diving deaths down under. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Maron BJ, Thompson PD, Ackerman MJ, Balady G, Berger S, Cohen D, Dimeff R, Douglas PS, Glover DW, Hutter AM, Jr., Krauss MD, Maron MS, Mitten MJ, Roberts WO, Puffer JC. Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. Circulation. 2007 Mar 27; 115(12):1643-45.

Mitchell S, Bove A. Medical screening of recreational divers for cardiovascular disease: consensus. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Recreational Scuba Training Council (RSTC) Medical Statement. [cited 12 December 2010]; Available from: *http://www.wrstc.com/downloads/10%20%20Medical%20Guidelines.pdf/*.

Richardson D. Training scuba divers: a fatality and risk analysis. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Thompson P. The cardiovascular risks of diving. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Vann R, Lang M. Training and operations. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

On-Scene Diving Accident Investigation

Steven M. Barsky
Marine Marketing & Consulting
2419 E. Harbor Blvd. #149
Ventura, CA 93001 USA

When a diving accident occurs, an investigation of some type usually follows. In many cases, there are multiple investigators, each with a different agenda. If the police become involved, their approach is to look for any evidence of a homicide. The U.S. Coast Guard (U.S.C.G.) normally performs some type of investigation any time there is a death that occurs when diving takes place from a vessel in U.S. coastal waters. In the event of an accident during an organized dive through a dive store, such as a travel event or training, the certification agency's insurance carrier will normally dispatch an investigator under the direction of an attorney to research the case, interview those involved and collect the equipment. Unfortunately, in most cases, the investigation takes place some time after the event has occurred. The quickest response in some cases may be the U.S.C.G., if they fly an investigator out to a vessel. In most cases, the police will meet a boat, or travel to a beach site. In the diving industry, the investigation may not take place until weeks or even months after the event has taken place. It depends on how fast the persons involved report the event, how long it takes the paperwork to move through the legal department of the training agency and how proactive the insurance carrier is in dispatching an investigator. If the investigator is tied up with other work or cannot make contact with the persons who were involved in a timely manner, there may be further delays in the investigation. No matter how quickly an investigation is launched, in almost every case, the body has been recovered and resuscitation attempted, equipment has been removed and possibly damaged or lost, and the people at the site have returned to their homes. The equipment may be mishandled by the authorities who are unfamiliar with the gear and have stored it improperly. This paper addresses the steps involved in a recreational diving accident investigation as performed by the author. They cover personal interviews with witnesses and those involved, equipment inspection (not testing), sequestration of the equipment, site inspection and document collection. Equipment used in the course of an accident investigation will also be discussed.

Introduction

Scuba diving is an adventure sport, and because of this, there is always some risk in diving. Whether a person is snorkeling on a shallow tropical reef in warm, clear water, or performing a penetration dive using a rebreather inside a deep wreck in the North Atlantic, risks are always present.

When a diving accident takes place, an investigation of some type almost always follows. Investigations may be of several different kinds, depending on the organization performing the investigation. While most recreational diving accidents are usually straightforward, if the incident takes places in an extended-range environment or using special equipment, the investigation may require additional expertise that is beyond the scope of the investigator. In the investigation of diving accidents, it is important to remember that there is nobody who is an expert in all types of diving or all pieces of equipment.

"In the investigation of diving accidents, it is important to remember that there is nobody who is an expert in all types of diving or all pieces of equipment."

In the recreational scuba diving industry, the insurance company for the organizer of the dive is normally the main driving force in dive accident investigations.

Figure 1: In some municipalities, there may be no one from the police or coroner's office who has the experience to investigate a diving accident.

In most cases in the United States, the investigator will normally be working under the direction of an attorney for the insured.

In some municipalities, there may be no one from the police or coroner's office who has the experience to investigate a diving accident. In other locations, there may be detailed investigations if there are qualified personnel to conduct the work.

In the United States, the job of the investigator is normally to gather the facts of the case, collect any relevant documents, secure and inspect the equipment, visit the site and take statements from the persons involved in the case. It is generally not the job of the investigator to form opinions about the incident or arrive at conclusions, rather merely to report the facts, usually in the form of a written report.

If there is litigation, the expert witness will examine all the documents collected by the investigator, inspect or test the equipment and offer testimony as to what he believes took place either in deposition, court or both. The expert may also assist with developing lines of inquiry for the attorneys who are handling the case, perform re-creations of the incident or other tasks as directed by the attorneys. Investigators need a wide range of skills and equipment to do their job and must be conversant with the latest technology.

"Investigators need a wide range of skills and equipment to do their job and must be conversant with the latest technology."

Protocol

Appendix D is a checklist to guide on-scene investigations. The tables shown here represent a baseline dive accident investigation protocol. The protocol should be expanded to cover the specific equipment that is involved in a particular accident

Motivations for Investigations

Different agencies have their own reasons for conducting diving accident investigations. For a police department, their motivation normally is to determine whether a homicide took place. In the United States, the Occupational Safety and Health Administration (OSHA) will usually investigate if they feel there was a workplace violation. The U.S. Coast Guard is mandated to investigate any fatality that involves a vessel in U.S. waters, particularly a vessel that is carrying passengers for hire.

In the sport-diving industry, risk managers are normally concerned with instructional dives or organized dives conducted by a dive store. Most insurance companies are aggressive in investigating diving accidents and will investigate any accident or claim that takes place in an instructional setting.

Timeframe for Investigations

In many diving accidents, some type of rescue/recovery usually takes place within a brief interval from the time the dive organizer discovers there is a problem. When this occurs, the person is normally stripped of his or her equipment, and the diving suit, if worn, is usually cut away to aid with life-saving efforts. In most cases, the investigator arrives on the scene hours, if not days, weeks or even months later. This is particularly true when the accident takes place in a remote location.

Figure 2: In most cases, the victim's body has been moved and stripped of equipment long before the diving accident investigator arrives on the scene.

It is truly the exceptional case in which a police diver qualified in underwater crime scene investigation arrives on the scene within a short period of time and conducts a thorough crime scene analysis. This is not the fault of law enforcement but simply the reality of sport diving, as well as the intense efforts usually made by those present to rescue their fellow divers.

Conversely, in other cases, the body may not be recovered until some time after the event has occurred, or the victim may die after rescue. In one case handled by this writer, the body could not be located by the police, and friends of the deceased were prevented by weather for searching for the body until more than a week had gone by. When the body was recovered, the well-meaning amateur divers were unable to drag the diver with all of his gear back into their small inflatable and towed the body back through several miles of kelp before dragging the body across a boulder-strewn cove to deposit it on the beach.

Tasks in an Investigation

There are numerous tasks that normally take place in a diving accident investigation. These tasks include, but are not limited to:

- Interview of witnesses and anyone who may have been involved in the incident.
- Inspection of the site, which may include a beach, a boat, a dive store and/or a swimming pool. This may or may not involve diving the area, depending on your knowledge of the site and the details of the incident.
- Inspection of the equipment, including emergency/rescue equipment. The equipment is normally photographed and secured for holding by the attorneys representing the defense.
- Collection of documents from the instructor, dive store, vessel and other public or private agencies. (Other documents that may be included in the final report include charts, 911 logs, U.S.C.G. reports, etc.)
- Interaction with public agencies

Some attorneys may prefer that interviews be recorded on video, while others may prefer an audio recording and transcript. Still others may insist on a narrative report written by the investigator.

In some jurisdictions public agencies may be very cooperative, while in others obtaining documents such as an autopsy report may require a subpoena obtained by the attorney who is overseeing the work of the investigator.

"It is truly the exceptional case in which a police diver qualified in underwater crime scene investigation arrives on the scene within a short period of time and conducts a thorough crime scene analysis."

The end result for most investigations is a comprehensive report that will allow a risk manager, who may not even be a scuba diver, to make a decision on how the loss should be handled.

Skills and Traits for Dive Accident Investigators

There are a number of skills that are vital to conducting an effective investigation, no matter what format the final report may take. An effective investigator must have the following talents and abilities:

- The ability to elicit people's trust and help
- The capacity to write clear narrative reports
- The skill to take good photographs
- The ability to think critically and shift gears as new information presents itself
- Sensitivity to nonverbal cues from people being interviewed
- Tenacity

The investigator must be compassionate and nonjudgmental while conducting interviews. The people you will be interviewing will have gone through a traumatic experience. In all likelihood they will be experiencing some form of survivor guilt and will sometimes blame themselves, even if there was nothing they could have done to prevent the accident. It is not uncommon for the interview to be a very emotional experience for most people, including the investigator himself.

"To ensure that you gather all of the information available, it is imperative that you be tenacious in your determination to secure interviews with all of the people who were directly involved in the incident."

To ensure that you gather all of the information available, it is imperative that you be tenacious in your determination to secure interviews with all of the people who were directly involved in the incident. In many cases, people who you think may only be peripherally involved may have important information. In addition, it is vital to follow up all leads on any documents that may relate to the incident.

Tools of the Dive Accident Investigator

There are many tools that are used by the skilled dive accident investigator. At a minimum, any person conducting an investigation will probably need the items listed here:

- A digital camera capable of taking high-resolution photos that can be enlarged for courtroom presentation (Some digital cameras also shoot acceptable video, but it may be difficult to use for extended video captures.)
- A video camera capable of taking widescreen video (Frame grabs are possible from HD video cameras that may be acceptable for court use.)
- Laptop computer with network card for conducting Internet searches, sending email, etc.
- Smartphone with capability to send email and access web
- Color printer for printing reports
- Flatbed scanner for scanning student documents, charts, reports from other agencies, etc.
- Nautical charts/maps of the region where the incident took place (Maps are used to locate hospitals, fire department stations, etc.)

- Voice recorder for recording interviews (always ask permission first)
- Magnifying glass for reading very small serial numbers etched into equipment
- Chalk to help make serial numbers readable, especially when stamped into black plastic equipment (Chalk is rubbed into numbers to increase readability.)
- Handheld GPS for precisely locating sites, especially those that have no name
- Oxygen analyzer to ensure gas mixture in cylinder is as purported to be
- Gas sample kit, which will usually be rented from a lab capable of gas analysis to test for carbon monoxide, oils, etc., in the victim's air supply
- Fiberglass measuring tape for taking dimensions on vessels, on beaches, at swimming pools or other locations
- Vernier calipers to measure small pieces of equipment, damage to gear, depth of gouges, etc.
- Electronic scale, which is required for weighing diving weights, especially if they have been hand poured
- Jumpsuit to help protect your clothes and body in the event that you must inspect equipment that has been exposed to a biohazard or is very dirty
- Latex gloves are desirable for handling equipment contaminated by blood or vomit
- Gear inspection checklist with a list of the equipment you expect to encounter and notes to remind you to check serial numbers, pockets or other features
- Interview questions based upon your understanding of events surrounding the incident

An investigator may not need all of these items on every investigation, but the more prepared one is when he enters the field, the easier it will be to conduct a thorough investigation.

If the investigator is an experienced diver, unless there is something especially unusual about the site or the circumstances of the accident, it is usually not necessary to dive the site. Exceptions might include cases where a diver is struck by a propeller on the dive vessel and the geometry of the vessel is not known, or the site has unusual underwater features, such as a wreck or cavern, that the investigator has not previously explored.

"If the investigator is an experienced diver, unless there is something especially unusual about the site or the circumstances of the accident, it is usually not necessary to dive the site."

Conducting Interviews

Whenever possible, interviews with people who have been involved with a diving accident should be conducted in person rather than over the telephone. This allows the interviewer to establish better rapport and to gauge the person's facial expressions and body language while discussing what transpired.

Figure 3: A fiberglass measuring tape is essential for taking measurements on vessels and sometimes at dive sites.

Normally, the investigator will need to set up personal interviews in advance, which takes time and schedule coordination. However, some people will want to complete their interview upon initial contact by telephone. Should this occur, as long as the interviewee is not one of the principal parties to the incident, the investigator should be prepared to conduct the interview on the spot. Unfortunately, it's not uncommon for people to change their mind and be unwilling to cooperate at a later date, unless compelled to tell their story under the force of a subpoena.

Although the investigator's basic list of interview questions will normally be prepared in advance, he must always be prepared to ask new questions as the information from the incident unfolds. In many cases, interviews may be back-to-back, and it will be important to add new questions on the fly.

One technique that is often helpful in preparing interview questions is to create a chronology of events. This will often reveal information that is missing. However, it is essential to realize that not everyone's timekeeping devices will be synchronized. Just because one person's account of when events took place is different from another's does not necessarily indicate that a particular person is not telling the truth. It's also vital not to "cue" the witness based upon information the investigator my already know.

Investigators must be discrete and cannot discuss their investigations with people beyond the offices of the law firm supervising their work. In the United States, their activities are normally considered "attorney/client work product."

"Although the investigator's basic list of interview questions will normally be prepared in advance, he must always be prepared to ask new questions as the information from the incident unfolds."

Sequence of Interview Questions

The sequence of questions asked by the investigator usually follows the normal sequence of events that took place during the accident. The interview will usually include questions about the diver's training, events leading up to the dive and the incident, any attempts made at rescue and resuscitation, and any other postdive events that may have relevance.

In an instructional accident, typical questions will include the history of the diver's training, any unusual events that occurred during training, the source of the gear used by the diver, any use of drugs or alcohol by the deceased or instructional staff, and the plan for the dive. If the diver completed training at more than one facility, it is important to interview any instructional staff who may have interacted with the diver under different circumstances.

The interview will then normally segue into the events of the dive itself. Questioning will include issues such as sea conditions topside, underwater visibility at the site, buddy separation, instructional supervision and problems the victim experienced during the dive. When and where the victim was last seen, as well as their actions at the time should be covered in detail.

The details of the rescue and/or recovery will be very important. It is always essential to interview the person who recovered the body, the people who participated in administering CPR as well as any other bystanders who may have observed the event. The investigator must keep in mind that new divers or nondiving bystanders may not understand exactly what they saw or may not be able to describe the events in terms used by the diving industry.

People to Interview Following a Sport Diving Accident

There are usually many people to interview following a diving accident. This list will vary, depending on whether it was a training incident or merely organized recreational diving. Some of the people to interview might include:

- Any instructional staff if the dive was being conducted for purposes of training
- Vessel crew, if the dive was conducted from a vessel, including captain, deck-hands, etc.
- Other divers who may have been on site
- Any rescue personnel who may have been involved in the incident

In other types of diving incidents, there will usually be other individuals who may be relevant to the investigator's inquiry. For example, in a public safety diving accident there will normally be a dive team leader, and there may be a line tender who is tending a tethered scuba diver. There will also usually be other dive team members on site.

Figure 4: If possible, you will want to interview any public safety personnel who may have participated in the rescue or recovery.

Inspecting Diving Equipment

Although the investigator may have a preliminary list of what equipment to expect, it is not uncommon to be confronted with other unlisted equipment. Visually inspect each piece of equipment, and note any serial numbers or other marks (such as rental numbers). Note any obvious defects, such as a torn mouthpiece or a broken drysuit zipper. Investigators do not normally disassemble any equipment.

As an investigator, equipment inspection rather than testing is normally the rule. Testing may be destructive and may change the amount of air remaining in the cylinder(s) or cause other changes. Testing is normally conducted when all parties that may be involved with any pending litigation are present.

It must be kept in mind that equipment that has been stored for any length of time will usually not be in the condition that it was in at the time of the accident. Batteries in dive lights and dive computers may not be functional, O-rings and diaphragms may have deteriorated, and salt water may have caused corrosion or metal parts to "freeze," making them inoperable.

If the investigation calls for the assessment of gear with which the investigator has no direct experience, such as a particular model of rebreather, it will be necessary to find someone with the required knowledge to help examine this gear. In these circumstances, it behooves the investigator to learn as much about the gear as possible prior to the inspection. Make sure that the person assisting with the exam proceeds slowly and explains each step they plan to take prior to taking any action. Be sure to check the records of the Consumer Product Safety Commission (CPSC) to see if any of the equipment has been recalled.

Vessel Inspection

In some cases, the vessel itself may be directly involved in the accident. It is not unusual for a vessel to strike a diver. In some cases this may lead to death due to unconsciousness or serious bleeding. When insufficient safety equipment is present, such as side rails or safety chains, or the diver performs an unsafe act, such as leaning out over the side, divers have been known to fall over the side and be run down by the vessels they were traveling on.

In cases involving a vessel, the investigator will want to try to obtain any drawings of the vessel. If these are not available, it's vital to take the measurements of the vessel. If the vessel involved was backing down to pick up a diver, the investigator will want to be sure to measure the line of sight from the helm to the stern (or swim step if visible). If the diver was struck by the prop(s), it may be necessary to make a dive to take measurements on the diameter of the prop(s), their placement on the hull and any other hardware present. Underwater photos or video will be very helpful in these cases.

Dive Store Inspection

If the incident involved rental equipment provided by a dive store, then a visit to the store is in order. Particular attention must be paid to the repair department, records of rental gear maintenance, compressor testing and all training records. Copies of any receipts for credit card transactions made by the victim must be obtained.

"Particular attention must be paid to the repair department, records of rental gear maintenance, compressor testing and all training records."

Compiling the Report

The end result of a dive accident investigation is normally a written report containing all of the materials collected by the investigator in one document. This report is normally delivered to the attorney who has been assigned to handle the case on behalf of the insurance carrier.

A good report will include all of the following documents:

- Table of contents
- Narrative summary of the events of the incident
- Chronology of the events
- Individual interviews
- Nautical chart (or map) locating where the event took place
- Photographs of the equipment and the site, vessel (if applicable) and dive store
- Photographs of the equipment
- Documents from public agencies (police, fire, U.S.C.G.)

Conclusion

Conducting a diving accident investigation is never a fun task. At best, the investigator can only pursue his work with compassion and take solace in the knowledge that his investigation may help to prevent similar events from occurring in the future.

Acknowledgement

The author would like to express his appreciation to Stephen Hewitt, Esq., who served as a mentor for him through many diving accident investigations.

Recommended Reading

Barsky S and Neuman T. *Investigating Recreational and Commercial Diving Accidents.* Ventura, Calif.: Hammerhead Press, 2003.

DiMaio V. *Forensic Pathology.* Boca Raton, Fla.: CRC Press, 2001.

Dix J, Graham M and Hanzlick R. *Asphyxia and Drowning: An Atlas*. New York, N.Y.: CRC Press, 2000.

Flook V and Brubakk A. *Lung Physiology and Diver's Breathing Apparatus*. Aberdeen, Scotland: University of Aberdeen, 1995.

McBride W. *High Pressure Breathing Air Handbook*. Sub-Aquatics Inc., 1996.

Neuman T and Brubakk A. *Bennett and Elliott's Physiology and Medicine of Diving, 5th Edition.* London, England: Saunders, 2003.

Nuckols M, Tucker W and Sarich A. *Life Support Systems Design*. Needham Heights, Mass.: Simon and Schuster Custom Publishing, 1996.

Discussion

KEN KURTIS: I am scuba consultant with the LA County coroner. How many fatality investigations do you do a year?

STEVEN BARSKY: Right now I do them as part of my expert witness work, so they are a little bit different. As an accident investigator you get to go out and directly talk to the people. As an expert witness, you do not get to directly talk to the people in most cases. So now I am probably doing two or three cases a year, but back in the '90s and late-'80s, I probably did a total of about 80 cases. Again, it is all industry driven, and it is driven by a lot of politics.

DR. SIMON MITCHELL: Who usually instructs you in these matters? Who brings you into this situation in a typical case?

BARSKY: In a typical case if it was direct, only accident investigation, then your case is going to usually come through the insurance company. The insurance company may call you directly, or maybe the attorney's office may call you. As an expert witness, it is always through the attorney's office.

MITCHELL: Do you find that your terms of reference make a difference to the way people react to you in your investigations?

BARSKY: In the insurance-driven investigation, the people who are involved who are insured have an obligation to talk. They have to share what happened. I have had people who have been less than forthcoming. The worst-case scenario I can think of is I had a guy set up to do an interview — a very busy guy, assistant instructor, divemaster in Los Angeles in the entertainment business. We had set up this interview. I got to his office. I could see him sitting there; there was a glass wall. He did not want to talk to me. I told the secretary, "Look, just tell him if he does not talk to me in the next five minutes — we have an appointment — I am going to have to call the insurance company and tell them he did not cooperate." But that is rare. That is really rare.

CAPT. JOHN MURRAY, U.S. Navy: You implied with looking at the gear that if you reached a point or if there was something about the particular investigation that made you question maybe the BC malfunctioned or maybe you did not drop weights as the person intended to, that you sort of would be careful not to alter the piece of gear, that you sort of would inspect it but not actually detach the weights if they were detachable. So how do you figure out where you are going to send it in that situation? For me the answer is easy because I send it to NEDU [Navy Experimental Diving Unit]. How do you figure that out?

BARSKY: The way I would figure that out is I would talk to the attorney and say, "This is the situation I believe we have. This is the way it appears to me, and how do you want me to proceed?" And let it go from there. Because it is always going to come back to — if it goes to litigation, and the assumption is in our society here in the United States it probably is going to go to litigation, particularly if there was a death involved — if you have altered it from the way it was, all bets are off. And it is very, very difficult to establish a defense. Again, if this is done on behalf of the dive industry, it is going to be a defense case. Did I answer your question?

MURRAY: I guess I am concerned at getting to obviously root cause and trying to make sure you prevent future diving accidents. So if the Diamond brand of BC has a problem, I want that to be found and to be fixed; fix future BCs if there is a problem with a particular gas mix or something. So ultimately somebody who is competent to actually evaluate how this particular device functioned or did not function seems like it is important. Are you implying that ultimately — if you are driven by the insurance industry — that they are going to know how to actually get the definitive answer, that when you contact them, they are going to say, send this BC to the manufacturer or send this drysuit back to Bare?

BARSKY: Generally what is going to happen is at some point there possibly is going to be a joint inspection by both parties, by plaintiffs and the defense. So, for example, I get a rebreather investigation with a semi-closed-circuit rebreather. Most people in the room can probably figure out which one that was in the case that took place in Hawaii. We had a joint inspection of the equipment as it was received from the police department by myself and Joe Dituri, who was representing the plaintiff's side. At that particular time we went through and tested the rebreather and found certain issues with it. That is all at that point in time we could come up with. That is as far as it went. It was videotaped. Everybody saw what happened. There were attorneys there from both sides. It really depends upon the circumstances.

GREG SHULTZ, U.S. Coast Guard: Getting back to the discussion of root cause, does DAN take a look at — if we have multiple accidents — events tied in with pieces of equipment? We can associate that through our investigations. But on the recreational side and specifically within the insurance side you have fragments of pieces of information. Is anyone collecting those and trying to see if there is causal analysis that will drive to a certain piece of gear? Is there anybody that is doing that?

DR. RICHARD VANN: It is an important question. Somebody needs to do that. DAN has done that, but DAN is not an investigative agency, so DAN cannot go out and do studies of equipment. What we do is just contact the coroners, Coast Guard, family members and so forth and request that information be sent in. Then we will analyze that information based on what we can get. But there is definitely a need for a central collection agency to do it, if it is DAN or somebody else. Somebody needs to do it and it needs to be formalized.

DAVID CARVER, Los Angeles County Sheriff's Department: Dealing with multiple jurisdictions around the country and other parts of the world, where have you found that most of the equipment that needs to be looked at is kept in the interim months and years between the time of the accident or fatality occurs and you get called?

BARSKY: That really depends. Usually what happens is it normally goes to the police department, and it's in the police evidence locker for a period of time, which may or may not be well stored. For instance, in this rebreather case I was talking about, the rebreather was stored in an un-air-conditioned evidence locker after it had been dragged across the beach through the sand, and it was unrinsed. So it was full of sand. It was in a hot place, and it had been stored there for two months. So what sort of shape do you think it was in? Typically what happens is — when I was doing field investigations, I was doing lots of those — I would try to get there as soon as possible and take custody of the equipment. Normally what happens is, in a case where there is a training agency involved, the equipment is going to go to the attorney's office who will be defending the case, theoretically if there is a case, if a case occurs. So that equipment will be stored at their offices, and that is usually what happens. But there is a period of time usually where it is in the hands of law enforcement. It may or may not be inspected. I know, for instance, Ken, you were doing gear inspections in LA. There was a dive shop in Monterey that for a long time did gear inspections and issued reports and proclamations. It just really depends upon where it takes place. Some places it's just turned right back out. You are in the middle of Minnesota or Michigan, some of those places, small towns, and there may be nobody there who knows what to do with it.

Equipment Testing

Jeffrey E. Bozanic
Next Generation Services
P.O. Box 3448
Huntington Beach, CA 92605-3448 USA

David M. Carver
Emergency Services Detail
Los Angeles County Sheriff's Department
1060 North Eastern Avenue
Los Angeles, CA 90063 USA

Equipment testing is an important part of dive accident and fatality analysis. Stakeholders in the community have different and occasionally conflicting needs when it comes to such testing. Current practices are poorly standardized, including when testing is conducted, who is responsible for testing and what tests should be performed. This paper briefly examines current practices and proposes suggestions for future direction. Key among these is the need for rapid testing to occur, overseen by impartial investigators. A law-enforcement model is advanced, with all equipment being treated as evidence as opposed to personal property. Challenges inherent with this proposal include training of first responders, timely analysis, education of law enforcement agencies, access to testing resources, development of sufficiently detailed and standardized procedures, and funding to conduct such testing. A sample equipment evaluation procedure form for open-circuit scuba equipment is provided as Appendix E. A second form for the testing of rebreathers is also provided.

Introduction

Many stakeholders have an interest in scuba fatality investigations. Law enforcement, medical examiners and coroners, training agencies, liability insurance companies, equipment manufacturers, dive professionals, equipment retail establishments, dive-travel providers, victims' families, research groups and others have an interest in determining the cause of any incident. Essentially, all groups want more information to prevent future accidents and make scuba diving a safer activity.

Life-support equipment is an integral part of scuba diving. Generally, dive equipment is robust and functions as designed. However, poor maintenance, design flaws, improper use or other factors may contribute to, or cause, an incident. Even when equipment issues are not contributory to an incident, it is important to rule them out so that the cause may be determined from other factors.

Currently, equipment investigations are conducted in a variety of manners. There is no consistent community or national standard for such testing: who does it, what is done, how it is done or even why it is done. This paper will briefly examine such questions and suggest possibilities for future standardization of the above. Key questions and challenges will also be addressed, which will require further community discussion and development.

"There is no consistent community or national standard for such testing: who does it, what is done, how it is done or even why it is done."

Why?

Multiple reasons exist as to why an examination of the equipment involved in diving incidents is desirable. Each of the interested parties has their own set of needs, which are often complimentary but not always congruent. Law-enforcement authorities and medical examiners are charged with determining the mode and manner of death and investigating any criminal culpability. Victims' families want to understand what happened and why, often so that other families do not have to suffer the same pain and grief. Training agencies want better instructional programs to prevent similar future occurrences. Manufacturers want to improve equipment design. Insurance companies want to limit financial exposure. Research groups, like universities and nongovernmental organizations such as DAN, want access to better data.

Law-enforcement agencies are tasked with investigating dive-related fatalities with several goals in mind. The first is to determine if any criminal culpability exists on the part of another party. That party might be a dive partner, wife, boyfriend, girlfriend, dive instructor, divemaster, dive shop, boat crew or another party entirely. The criminal culpability could range from premeditated homicide to gross negligence leading to a diver's death. If dive fatalities are automatically assumed to be accidents, then criminal conduct will never be expected.

The second goal of the investigation is to determine or assist in determining why, how and when the fatality occurred. This information is very important to family members who cannot understand how their loved one died doing what most families consider a safe outdoor sport. Many families are not satisfied with a medical examiner's finding of drowning. This leaves too many unanswered questions. Families want to know why and how their loved one died. In most cases, families have difficulty accepting that their loved one might have made a mistake or otherwise been at fault. Often they want to assign blame elsewhere — for example, with the equipment, instruction or dive or boat professionals. If a complete investigation is not done by a law-enforcement investigator, many families will have trouble coping with the unanswered questions. This can lead families to file lawsuits that might have been avoided if a complete investigation was conducted.

"If a complete investigation is not done by a law-enforcement investigator, many families will have trouble coping with the unanswered questions."

Training agencies develop instructional programs in which equipment use and handling are incorporated. Much of this body of knowledge has been developed over years of instructional practice and subsequent operational use. However, new equipment, modifications to current equipment and usage in a variety of environments may lead to unforeseen issues or problems. While every attempt is made to identify potential problems before instructional programs are approved, not every circumstance can be anticipated. A dive fatality may be the first indication that a problem exists. Thus, analysis of a dive fatality may lead to changes in instructional certification programs or training practices.

Likewise, information gleaned from post-incident equipment testing may be used by manufacturers to improve equipment design. Often unanticipated usage by customers results in scenarios that were not expected. This may result in substandard equipment performance or suggest equipment design modifications extending the range of use. In other cases, broad, extended use of new equipment in the field may unearth problems that do not manifest themselves during research, development and testing phases of new product introduction.

Insurance agents want to limit financial liability regarding any given incident. The issue here is that many of the insurance companies may have conflicting viewpoints. A company providing instructional liability protection may welcome a finding that equipment might have been at fault. Another firm providing product liability would prefer a finding that shows the diver caused the incident by practicing improper dive procedures. The firm insuring the regulator used by the decedent would rather that the design of the BC used (which they do not insure) be determined to be deficient.

Finally, many individuals and organizations conducting research into dive safety would benefit from better information regarding equipment testing. Such test results might have significant impact regarding the evaluation of incidents and examination of their underlying causes. The quality of results or findings might be significantly improved with accurate post-incident equipment evaluation.

As can be seen from the above, a multiplicity of viewpoints surrounds any dive incident. All would benefit from an equipment review, but not necessarily from the same type of review. Our premise is that the greater needs of the entire dive community would be better served if detailed, timely and unbiased equipment testing was conducted on all dive fatalities. Currently, this is not the norm.

Current Practices

A wide range of practices currently exists as to what happens to dive equipment after an incident. Each of these has various advantages and deficiencies. Broad areas of concern in post-incident equipment testing include who (1) directs testing (direction), (2) conducts testing, (3) funds testing and (4) when such testing occurs. Each of these will be discussed in the following section.

"Since the cause of death is often taken for granted to be 'drowning' due to a 'misadventure,' frequently both homicide and medically driven investigations are simply not conducted. This leaves equipment testing to be pursued by other groups."

Direction is defined as establishing the scope of testing, selecting who will physically conduct the tests and determining when testing will be conducted. In general, equipment testing is directed by one of three broad groups: public agencies, plaintiff attorneys or defense attorneys. Public agencies may include law enforcement, medical examiners or coroners. Generally these personnel are less biased in their approach to directing testing because they have no vested interest in the outcome or results. However, public agencies are usually the least likely to institute equipment testing because their motivation to do so is narrowly defined, i.e., the need to rule out homicide or determine a cause of death. Since the cause of death is often taken for granted to be "drowning" due to a "misadventure," frequently both homicide and medically driven investigations are simply not conducted. This leaves equipment testing to be pursued by other groups.

If not initiated by public agencies, equipment testing is generally directed by attorneys. The attorneys involved may be working for plaintiffs or for the defense, but obviously in either capacity they have an interest in furthering their clients' objectives. Thus, testing may be incomplete, often restricted toward achieving or defining a particular result. As an example, plaintiff goals might be to demonstrate that a particular regulator has inherent design flaws, was improperly serviced or adjusted by a repair facility or failed from manufacturing defects. The same regulator testing might be directed by defense attorneys to show that the regulator worked fine in practice, that the victim had possession of the equipment for a significant time post-servicing and may have either advertently or inadvertently altered key mechanical adjustments, or just used the regulator in an improper manner. In either case, even though they probably are not directly conducting the testing, their respective needs and objectives establish the limits of the personnel conducting the tests, leading to incomplete or biased results. All other equipment used during the incident may be virtually ignored, as it falls outside the scope of the narrowly defined needs of the client. Unfortunately, the majority of equipment testing is directed by these parties.

Most of the time the individuals directing the testing are not the same persons who conduct the tests. Instead, another group is tasked with actually performing testing. Groups currently used include dive stores, repair facilities, manufacturers, U.S. Navy, law-enforcement personnel, universities, independent consultants or insurance investigators. One of the primary concerns with all of these groups is that there is no standardized training or qualifications for conducting scuba equipment testing specific to incident analysis. While any given category may be well suited for one aspect of such testing, such as a repair facility regulator expert being trained how to service and maintain regulators, that same individual may have no or only limited knowledge in identifying problems that might lead to an incident and properly documenting the same. Law-enforcement personnel have extensive training in investigative procedures but limited, if any, knowledge of scuba equipment. Unfortunately, scuba-equipment testing requires knowledge of procedures, analysis, specific testing protocols, broad multimanufacturer knowledge base, documentation skills and report writing.

Nor is there a standard for what tests should be conducted. Current practices may range from a visual examination of the equipment to full disassembly, possibly including open-water trials in an environment similar to that experienced by the decedent at the time of the incident. Some testing is purely qualitative, while other testing is quantitative. No generally accepted standards exist.

Another issue again deals with bias. The most knowledgeable person on any given piece of equipment is probably a manufacturer's employee. However, that same individual will generally have an overt or subconscious desire to protect their employer, especially if they were involved in the design and production of the equipment. Other common sources of bias include personal equipment preferences of the individuals conducting the testing, institutional bias toward or away from a particular piece or brand of equipment, and again the needs of those financially supporting them in their investigative capacity.

"While rapid evaluation is conducted in some jurisdictions, more common current practice is that equipment is not examined or tested until the perceived 'need' arises."

As with test direction, funding typically comes from three primary avenues: public agencies (law enforcement, medical examiner and coroner), plaintiff attorneys or victim's families, or defense attorneys, frequently funded by the insurance company who wrote the liability protection on the equipment. The same issue of perceived need, bias and limited scope previously discussed all apply to funding as well.

Finally, we must consider the problem of when testing occurs. The best time to examine and evaluate equipment is immediately after the incident occurs. The longer equipment sits, the higher the likelihood of data being lost. While rapid evaluation is conducted in some jurisdictions, more common current practice is that equipment is not examined or tested until the perceived "need" arises. This typically is defined as when a lawsuit is being contemplated or filed. Since it may be months before a suit is filed, the interval between the incident and testing is substantial. Further postponements are frequently caused by motions and disagreements between plaintiff and defense attorneys during the discovery process. It is not uncommon for equipment testing to be delayed by several years after the incident, making such testing much less effective and much harder to interpret.

Future Direction

It should be apparent that current practices are inadequate for the optimal level of information capture and maintenance with regards to post-incident scuba-equipment testing. We believe that the process could be improved, providing benefits to all constituent groups, by implementing a different process for such testing. This recommendation is not without its own challenges, specifically associated with training and funding issues. However, it may provide a stepping stone to a gradual change of a long-term plan that would accomplish the job even more effectively. Components of our proposal may be summarized as follows:

- Public agency personnel should provide the direction associated with equipment testing. They generally are the most impartial and have the greatest training in conducting investigations. Generally speaking, law-enforcement personnel would probably be the most able to provide this function, but in some jurisdictions coroners or medical examiners may be in a better position to provide this direction.
- Equipment involved in incidents should be treated as evidence, not as personal property. Proper chain-of-custody procedures should be followed.
- Information preservation must begin at the scene: We must teach dive professionals and first responders the initial steps required to preserve data.
- Equipment testing should occur within 24 hours of the event.
- Testing should be conducted by an independent professional but overseen by law enforcement.
- Standardized testing procedures and protocols should be developed and followed.
- When indicated, manufacturers' agents may be asked to participate, but if so should be directly overseen by a knowledgeable third party.
- All testing should be photo-documented using both still photography and video.

"Equipment involved in incidents should be treated as evidence, not as personal property. Proper chain-of-custody procedures should be followed."

Chain of Custody

Different law-enforcement evidence procedures exist throughout the world, but there are certain fundamental protocols that almost all law-enforcement agencies adhere to. For an item to be considered a reliable piece of evidence, the following conditions must exist:

- A handling officer or agent must document the dive item at the time the item is collected. This usually involves documenting the item in a notebook or report at the time of collection and placing some type of evidence tag on the object. This documentation should include the manufacturer's name, serial number, color and condition of the item, where the item was found or recovered and who had contact with the item before being secured by a handling officer or agent. In most jurisdictions, photographs are taken of items involved in fatalities even before the item is collected. This provides a visual image of the item when it is first found, collected or received.
- All dive equipment associated with the fatality should be held as evidence, as would be the case with any other object (firearms, knives, narcotics) that could have been involved in a fatality. Dive gear should be properly documented in a notebook, photographed and secured like any other relevant item associated with a law-enforcement investigation.
- Once the dive item has been collected, the item needs to be packaged or transported to a secure location in a manner that does not damage or change the item or its evidentiary value (e.g., allowing a regulator mouthpiece to be damaged in transport). Before placing the item in an evidence locker or room, the officer or agent will list the items held in either an evidence computer database or handwritten logbook. The information placed into the computer or logbook usually includes a description of the item, when the item was recovered, who recovered the item, the name of the decedent and a specific number assigned to the case.

- Placing dive gear into evidence solves several issues that arise if dive gear is held as "personal property." Once in evidence, any piece of dive gear removed for any reason will be documented. This documentation includes when an item was removed, who removed it, why it was removed and when the item was returned to the evidence locker. Without this vital documentation or security, an item being relied on in court years later as "evidence" could be deemed unreliable. Placing items into evidence minimizes the chances of the dive gear being misplaced, lost, stolen or handled improperly by untrained individuals.

The above procedures could be simplified if the agency has only one dive investigator who is the only person who has access to a "dive-evidence locker" as compared to an agency that might have a large evidence room run by a specific evidence custodian in charge of many different types of evidence and cases.

Most of the time, the only gear that is retained as evidence or personal property is the gear worn or used by the decedent, but this possibly should include some or all of the dive partner's dive gear as well. Items such as a dive partner's computer can verify or disprove the statement of a partner. The partner's dive computer could be more advanced and provide a better dive profile then the decedent's dive computer. In out-of-air cases, the decedent might have used the dive partner's octopus or bailout bottle, in which case that equipment will need to be identified and tested.

In all cases, every piece of dive equipment must have a documented chain of custody, especially if the fatality was found to have criminal or civil liability. All gear should be secured in an evidence locker until the equipment is determined to have no civil or criminal relevance or is ordered released by a court of law.

"Most of the time, the only gear that is retained as evidence or personal property is the gear worn or used by the decedent, but this possibly should include some or all of the dive partner's dive gear as well."

Evidence Preservation

Upon arrival at a dive fatality the investigator should interview any personnel that might have had contact with the dive equipment. This list includes dive partners, on-scene rescuers, bystanders, instructors, divemasters, lifeguards, firefighters, chamber crews and law-enforcement personnel. These interviews will provide the investigator with an idea of how the fatality might have occurred and what specific equipment testing might need to be done. These initial interviews also will help the investigator document any changes that occurred to the equipment prior to their arrival. This is vitally important because any findings that are based on altered equipment could lead to a wrong conclusion on why the fatality occurred. This means specific questions must be asked of on-scene personnel to determine what changes were made to the equipment and who made the changes. Any and all changes must be determined and documented.

Photographs of the dive equipment should be taken at the scene to show the condition of the equipment as it was found or recovered. This includes photographs of the cylinder, buoyancy compensator, regulator, gauges, dive computers and any other relevant piece of gear.

Before transporting the gear to a secure location, the investigator should document in his notes the type of equipment and the overall appearance of the equipment. The notes should also document any major issues that are apparent that could have led to the fatality. This includes noting specific aspects of the equipment that could change while the gear is in transport or waiting to be tested (e.g., the volume of gas contained within the buoyancy compensator).

If the cylinder valve is still on, the pressure of the cylinder(s) should be noted and then the valve turned to the off position after noting the starting position of the valve knob and how many turns were needed to close the valve. If the cylinder had been turned off prior to arrival and was not empty, the valve should be opened to note the cylinder pressure. If the cylinder was recovered empty or close to empty, the valve must remain in the off position for transport to conserve any remaining gas for analysis.

First-Responder Training

Equipment investigation begins before the fatality occurs. Training needs to be conducted for first responders on how to properly handle and document equipment that has been used in a dive fatality. This training should be geared toward rescue divers, divemasters, instructors, lifeguards, firefighters, recompression-chamber crew, law-enforcement personnel, U.S. Coast Guard personnel and dive boat crews. These are the personnel who will most likely have contact with a dive fatality and the decedent's dive equipment. If the decedent's dive equipment is altered without the handling investigator's knowledge, then any equipment findings could lead to a wrong conclusion or analysis.

"Training needs to be conducted for first responders on how to properly handle and document equipment that has been used in a dive fatality."

First responders, instructors, divemasters and boat crews should be advised of the following procedures or similar adopted procedures if a decision is made to turn off the cylinder valve prior to the equipment being held as evidence.

- Record and photograph the cylinder pressure from the submersible pressure gauge with at least one other person as a witness.
- Mark the cylinder valve and cylinder, and then count how many turns it takes to close the valve. After the valve is closed, record the cylinder pressure again.
- If transport of the gear to a testing location will be delayed or the travel will be rough, tape the valve shut to prevent it from being accidentally opened during transport.
- Attach a tag to the valve with the date and time the valve was closed and the name and phone number of the person who closed it. The tag should also include the cylinder pressure noted on the gauge and how many turns it took to close the valve.

Similar procedures should be followed for any other piece of equipment in which the original status may be altered during rescue or recovery operations. These may include but are not limited to turning off dive computers; turning off lights, strobes, cameras or other battery-operated accessories; switching off rebreather electronics; rewinding or respooling line that may have come off a reel; unclipping accessory equipment; or removal of any equipment such as weights or accessories.

Timely Evaluation and Testing

Dive equipment needs to be examined as soon as possible after the dive fatality occurs, preferably within 24 hours. Even gear not used in salt water can be damaged if left wet in a dive locker. Metal parts can rust or freeze, rubber can deteriorate, and plastic pieces can be break. Data contained on certain gauges and in dive computers could be lost if the batteries were allowed to drain or become compromised. Dive equipment that has been left unsecured or allowed to deteriorate over an extended period of time might make later equipment evaluation difficult or even pointless. Testing a regulator used in the ocean that was left drying in a plastic bag would not render the same results if secured properly and tested immediately.

Standard Test Protocols

Each piece of equipment associated with the dive fatality should be examined, evaluated and tested to make sure the equipment works as designed. Efforts should be made to locate any piece(s) of equipment that had been ditched or lost during the rescue phase of the incident. Without complete equipment, assumptions are sometimes made that might not be correct.

Evaluate the equipment in a manner that maximizes the information gained without sacrificing important information that will be needed later. Equipment should be examined in a systematic manner using established protocols that allows the investigator to examine each piece of gear as it relates to the other pieces of equipment as a functioning life-support system. Later in the testing process each piece of equipment can be tested individually.

At the end of the evaluation process, the investigator should have notes and photographs of each piece of equipment and how that equipment was connected to, or interacted with, the other gear being tested. This includes the size and volume of items like the cylinder and buoyancy compensator to the smaller pieces that make up the equipment like the O-rings.

The investigator should also know if the equipment was owned by the decedent, borrowed from a friend or instructor, or rented from a dive shop or boat. Without this basic information, it would be difficult to ascertain when the gear was purchased or last serviced or who is actually responsible for the gear being used. If possible, purchase receipts and maintenance records should be obtained on all serviceable pieces of equipment.

"Equipment should be examined in a systematic manner using established protocols that allows the investigator to examine each piece of gear as it relates to the other pieces of equipment as a functioning life-support system."

Certain pieces of equipment might need to be tested in the water and at the same depth or pressure where the fatality occurred. For example, a regulator might appear to be working on dry land but breathe very wet while underwater. This could cause a diver to aspirate water, leading to panic. If this were not discovered, then the possible trigger factor would never actually be known.

If possible, regulators and other types of equipment should be tested at the same cylinder pressure noted when the fatality occurred. They should also be tested in multiple orientations while underwater.

Only qualified personnel in an environment that can be reasonably controlled should do underwater testing. Safety divers should be deployed during the testing process. Items like regulators should be decontaminated and then placed on a pony bottle, unless the quality of the gas in the original cylinder has already been verified.

Any camera or video equipment that was being used by the decedent, dive partner or person in the dive party should be obtained or the contents downloaded as photographic evidence. The photographs or video images should be downloaded as soon as possible to gain a better understanding of what occurred before, during or even after the dive. A video showing divers fighting against a strong current could be very helpful in understanding why a middle-aged diver with a history of heart disease was later found dead on the bottom. The images could show the gear being used by the diver and what that gear looked like before being removed during the rescue.

Similarly, any dive computers worn by the decedent and possibly the dive partner should be downloaded as soon as possible. A detailed dive profile will often provide information that makes a reconstruction of the events leading to the incident much more likely.

Appendix E of these proceedings contains sample equipment evaluation forms to aid in the equipment testing process. Forms for both open-circuit and closed-circuit scuba equipment are included. The closed-circuit forms were drafted with input from many individuals. Gregg Stanton provided the initial effort and draft with further input on subsequent drafts provided by Joerg Hess, Kevin Gurr, Mike Ward, Gavin Anthony, David Cowgill, Jon Conard, Jeffrey Bozanic, Richard Vann, Petar Denoble and others.

Manufacturer Agents

If a manufacturer is needed in the testing process, the equipment should be tested in the presence of, and under the supervision of, the assigned investigator. It would also be prudent to make a video of any testing or evaluation done by the manufacturer so it could be reviewed later if needed. The manufacturer's agent should be asked to provide a running commentary of all actions taken so the record is clear upon later review.

Photographic Documentation

High-quality photographs should be taken of each piece of dive gear at the testing location. This should occur prior to any equipment manipulation. The photographs should clearly show any gauges, hoses, connections, buckles or attached gear and note any damage. There should also be photographs showing the equipment manufacturer's name, model and the serial number.

"The testing process begins by taking detailed notes and high-quality photographs of each piece of equipment as it has been found."

The testing process begins by taking detailed notes and high-quality photographs of each piece of equipment as it has been found. Make sure to have multiple photographic views of any piece of equipment that is damaged, is thought to have been a factor in the fatality or is found connected or assembled incorrectly (e.g., low pressure hose not connected to the buoyancy compensator).

All testing and evaluation procedures should be documented by video. Such documentation may be used to resolve discrepancies or ambiguities in the actual testing practices long after the tests have been completed.

Long-Term Future Possibilities

We recognize that the proposals above do not offer a complete solution to the problems and issues facing us today. We regard them as an interim solution that may improve the current practices. It is expected and desired that such practices continue to evolve and improve. Some possibilities include the following:

1. *Formation of a national investigating authority.* This investigative body might be modeled after the National Transportation Safety Board (NTSB). A body such as this would offer the benefits of concentrating knowledge and experience in a single unit, which could be expected to quickly improve during a relatively short period of time. It could also offer the greatest resource efficiency by providing a centralized data storehouse (repair manuals, disks, downloading software, etc.) and capital equipment facility (test benches, ANSTI test machines, apparatus, etc.) in a single location without widespread or regional redundancy. However, the perceived need for such an agency is minimal, as the impact of scuba fatalities or injuries is not nearly as widespread as the need for investigation of national transportation issues. Scuba diving does not impact a broadbased citizenship like transportation does.

2. *Establishment of a nongovernmental organization (NGO) to coordinate and provide testing.* This could have similar benefits to the national investigative body considered above, but instead of being governmental, it would be supported by

those interested in the information and results: divers and associated members of the dive community. Divers Alert Network (DAN) could be considered as a model for this suggestion. Because of the direct interest of the community members, an NGO might be more successful than a similar governmental agency. Challenges include a lack of funding, no universal acceptance, ownership and access of documents and findings, and problematic issues associated with post-testing requirements (depositions, law suits, court appearances, etc.)

3. *Vendor list.* A list of competent testing and investigative resources should be developed and made available to all parties involved in testing. Such a resource base might include core competency data and contact information for scuba equipment testing facilities, qualified individuals, scuba equipment manufacturers, test equipment manufacturers and governmental and NGO agencies involved in testing. Such a resource could be web-based and openly available. Challenges include designating an individual or group to establish and maintain the site, providing criteria for inclusion on the site and general acceptance of the persons responsible for maintaining the information.

4. *Information library.* A similar database could be established to provide documentary resources to persons or agencies responsible for conducting equipment testing. The primary resource on such a database might be a standardized evaluation protocol or protocols such as those provided in Appendix E of these proceedings. It could be expanded to include a broad library of manufacturers' repair and service manuals for different types of scuba equipment, notices of finding from previous investigations, courtroom and depositional documentation from previous incidents, operations manuals of test equipment and other similar articles. Challenges include the time and effort needed to amass such a collection, access security and setting criteria for inclusion. It may be that an organization involved in providing similar functions in the dive industry, such as the Rubicon Foundation, might be approached to fulfill this function.

5. *Qualifications determination.* We need standards that would qualify an individual, group or agency as testing personnel. Such a program might take the form of a certification or qualification evaluation, a grandfathering program or a training class. While we are unsure of the format, it is apparent to us that we need some type of criteria to qualify testing personnel. We may also need criteria that would prohibit certain classes of individuals from conducting testing. These might be necessary to prevent conflicts of interest, biased reviews or other currently unforeseen issues.

Conclusion

We do not suggest that we have all of the answers to the problems and issues facing the industry in the area of post-incident equipment testing. We offer some suggestions that we feel would benefit the industry, as well as a series of equipment-testing protocols for general use. It behooves all of us to continue to examine this issue, make improvements to such protocols and share information on equipment testing. Broad community input can only help us all.

"It behooves all of us to continue to examine this issue, make improvements to such protocols and share information on equipment testing."

Discussion

DR. PETER BENNETT, UHMS: We have not really had, in the beginning of this meeting anyway, a documentation of the incidents of fatalities that we have. Certainly when I was running DAN and was involved with some of this data collection and presented some of it, I seem to remember that most of the accidents did not involve equipment. It was human error in using the equipment perhaps, not the equipment itself. I am wondering just how big a number it is. We are told comparisons with fatalities on the roads. Well, you have 45,000 deaths a year in the United States on the roads, and maybe 10 to 15 deaths in the United States in the diving world. So, obviously, resources are going to be very hard to obtain.

JEFFREY BOZANIC: That is a really good point. Steve made that point as well, and I did not mention that. The reality is that equipment is not generally the root cause of the incidents that are going on. Although it may be a contributing factor to many incidents, it is usually not the root cause. In fact, as Peter just mentioned, the reality is that pilot error is what typically causes most of the problems as it relates to equipment, either through improper use, improper setup or improper maintenance. Usually it is pilot error that causes the problem to begin with, improper dive practices. But apart from that, there are numerous incidents in which dive equipment has been directly contributory to the particular incident. For example, there was an incident off San Diego involving bent pins of an integrated weight system; the bent wires prevented the diver from being able to adjust the weights, resulting in an inability to reach the surface, causing a fatality. We have had buttons switched off by hydraulic machines underwater that have turned off life-support equipment. We have had valve disintegration or valve problems causing leakages. We have had torn drysuit problems leading to hypothermia being a contributing factor to fatalities. We have had improper use of diver propulsion vehicles or buttons not turning off on diver propulsion vehicles. In one case I worked on somebody was holding a DPV. Turned it on, it didn't work mainly because of where the switch was placed, pivoted on their hand, hit them in the forehead, is what we believed happened, knocked them unconscious underwater, and they sank to the bottom and drowned. But you are right, the majority of the incidents that occur underwater are not due to equipment faults themselves but may be related to the equipment in terms of other scenarios. And I don't have a good number for you. I have not looked at that particular issue. Even trying to do it in a small field such as rebreathers is really difficult to do. We have less than 200 fatalities to look at worldwide over the last 10 years. With most cases we do not have enough information to evaluate what is going on, and even when you do, the data capture is not good enough to be able to look at what is happening.

DR. JAKE FREIBERGER: In my experience, diving equipment problems are a small subset of most fatalities. What are the key questions you would ask during an investigation? When would you call in an accident investigation, since there are lots of times that we have an incident rather than a fatality? What are the things that we can use practically when we are consulting on these cases to decide that this is a case that actually needs an equipment investigation? Please address this for both open-circuit and rebreathers.

DAVID PARKER: I will do my best on at least one of those; I'll leave the second one for Jeff. In Los Angeles County any time there is a fatality there is going to be an investigation. The gear is going to be held as evidence. That is just not disputed at this time. So nobody has to request it; it is going to be taken care of. Then hopefully it is done correctly so everybody has that information. Other agencies are not quite that way. When it comes to — and the second part of your question, sir, I think was dealing with what DAN would do with that information or if they were requested?

FREIBERGER: No. We have a lot of diving incidents, and not all of them end up as fatalities. Some of them do. Most of them, in fact, are primarily medical problems or, like Mr. Bozanic said, operator error. But what would be the things that would push you to have an equipment investigation? Should we investigate them all?

PARKER: It is my belief, at least in Los Angeles County — I am tasked with that particular field now — that, yes, every time we have a fatality, the equipment is going to be tested. I could get a call tomorrow and be told that the gentleman definitely had a heart attack, but I am going to go through and test all of the equipment, including the gas, to rule out any other factors that might have contributed to that fatality.

FREIBERGER: Do you have an estimate of what percentage of the times that actually occurs?

PARKER: Sir, I have not been in the field long enough to tell you. I just know in the past year and a half there are at least three — of the seven fatalities last year, in three of them equipment had something to do with the death, either the flow-restricting orifice…. There was one gentleman who decided to place shoelaces on his integrated weight pouches, thus making them nonfunctional and then ran his cylinder dry. Those are things that the equipment had an effect on why he did not survive the incident. It was not an equipment malfunction, it was an operator malfunction.

BOZANIC: So that was about 45 percent of the incidents in a small sample set. It is pretty high, but I don't think it is generally that high. Your second half of the question was looking at rebreathers in particular. One of the things that we need to recognize is the fact that as technologies are developing, we know less about new technologies than we do older technologies. So we all have a fairly reasonable understanding of open-circuit dive gear and the things that happen with it, either deficiencies or the way it is misused. Generally the level of development within this part of the community is probably higher in terms of knowledge base than it is with new technologies. My belief is that with newer technologies, things like rebreathers or mixed-gas diving being done recreationally, that those types of incidents suggest that we should have a much more in-depth investigation into the incident and the equipment involved in general because we have the most to learn there. Our knowledge base is not as well established. There may, in fact, be numerous and significant unknown factors that are taking place and causing some of these fatalities. We are not going to find out what those are unless we spend the time looking at them. So with rebreathers in particular, my suggestion would be that we look at all of these incidents.

KARL HUGGINS: We have a very good working relationship with the sheriff's deputies on Catalina Island and the Emergency Services Detail (ESD) where Dave comes from. In terms of answering when an investigation should occur, one of the things we do is to contact ESD if we have a diver who has the potential of being a fatality. So if we have somebody brought in in cardiac arrest or somebody being brought in in respiratory arrest, they will be notified so they can actually start the investigation. Even though the person may survive, they have actually started the investigation right then because there is the potential that is there.

PARKER: Extremely helpful. Karl called the other day, and we were able to get things going much more quickly than if I waited for an official call after somebody passes away.

GORDON BOIVIN, U.S. Coast Guard: I find it intriguing that this morning collectively we are talking about equipment, and the sport is so heavily dependent on equipment, yet everybody has so far has said the equipment is not that big of a deal because it is not causing the problems. I have to back Dave up. We have crossed paths on the last two fatalities. What causes a 32-year-old physically fit male to die? He is on the bottom, and he is dead. If you do not look at the equipment, what caused him to have the heart attack? Truly and honestly, Dave and I have worked on a couple now, we have to get the equipment. Then the second point, one of the interesting things is the last case we worked on together, he meets the diver in the chamber. I met the commercial divers on the dock. The equipment is in two different places, all of a sudden in two different jurisdictions. At the end of the day when I turned around, the dive buddy walked away with the dive bag. So the dive buddy took all the personal effects and went home, and Dave was left with the just gear at the other end. It was kind of like, oops, we made a mistake. We work in a very close relationship between the LA sector and ESD. But when we step out of Los Angeles County and we go to Santa Barbara County, we walk in, the sheriff's department slides everything across the table and says, there you go, it is yours. But equipment, to me, is the root cause, some of it.

BOZANIC: Something that Gordon just said is something that I wanted to mention during the talk as well. It is not just the equipment being worn by the victim that needs to be examined. It is any of the equipment that was potentially involved in the incident. So, for example, if somebody signals out of air and goes to his buddy for air and that regulator gets offered to the person, the person puts that regulator in his mouth and perhaps there is a small tear in the mouthpiece. That permits water into the breathing chamber, he aspirates water and panics and bolts to the surface. It is any equipment that is involved. So when you look at this equipment and do an investigation into this type of incident, you also need to look at the buddy's equipment, and you may need to impound that as evidence as well because that may also have been contributory to the incident or the root cause of the incident and how things occurred. So that is also an important part of what should get looked at. It is not just the victim's equipment but that of the buddy as well.

GREG STANTON: Who in the past has determined the standards of our investigations? That may be the core issue.

BOZANIC: I think that for the most part that has been a haphazard development of practice, primarily developed by the insurance companies to either protect or pursue a particular claim within the legal arena. There really is no standard in terms of an investigative practice that is nationally accepted of which I am aware.

STANTON: Could the courts not be the ones determining that standard?

BOZANIC: That is what I am suggesting. Right now it is being done through the legal process. What I am suggesting is that is not the best way because it is not looking at the global needs of our community, which is development of dive safety.

The Forensic Investigation of Recreational Diving Fatalities

James Caruso
Regional Armed Forces Medical Examiner
Navy Recruiting Command
5722 Integrity Drive
Millington, TN 38054 USA

Diving using scuba, or any type of diving using compressed breathing gas, remains a popular pastime in the United States and worldwide. Present estimates place the number of active recreational divers in the United States at between 2.7 to 3.5 million (Hornsby, Page 165). The number of fatalities involving U.S. citizens performing recreational dives averages 90-100 each year. From a dive safety perspective, these deaths should be thoroughly investigated to determine a trigger, or root cause, for the mishap. Proper data collection and analysis allows identification of the most common triggers and contributing factors associated with fatal diving mishaps.

Introduction

Monitoring the epidemiology of diving fatalities allows diver training organizations and dive safety organizations to make recommendations for improved instruction and safer diving habits. It is hoped that such changes in training and dive protocol will result in fewer fatal diving accidents and fewer diving-related injuries overall.

From a forensic pathology point of view, these fatalities challenge the investigators and pathologists who must investigate and certify these deaths. Except in a select few jurisdictions, such as Miami and San Diego, diving fatalities are rare enough that most forensic pathologists have little experience in this area. There are a few specialized techniques that can be utilized during the performance of the autopsy to help maximize the amount of information obtained. At least a basic understanding of diving physics and diving physiology is required to properly interpret the findings of a postmortem examination. The forensic pathologist also needs to understand the limitations of autopsy findings in diving-related deaths and realize that there are common postmortem artifacts that can be misinterpreted, resulting in erroneous conclusions.

"The forensic pathologist also needs to understand the limitations of autopsy findings in diving-related deaths and realize that there are common postmortem artifacts that can be misinterpreted, resulting in erroneous conclusions."

Another item that cannot be overlooked is the fact that recreational diving fatalities are often litigated in civil court and occasionally in a criminal court. It is in the public's best interest that any lawsuits or criminal charges resulting from a diving-related death be based on sound conclusions from a properly investigated mishap.

The most important step in investigating a fatal diving mishap is obtaining a complete history. Certainly a detailed dive profile is essential, but also the decedent's past medical history and the decedent's health status and behavior prior to the dive are extremely important components of the investigation. A thorough postmortem medicolegal autopsy along with toxicological testing should be the standard of care. Dive equipment used by the deceased diver needs to be impounded immediately and examined by an expert who has no stake in the results. If there is any breathing gas remaining, it should be analyzed in accordance with industry standards.

Diving medical professionals are an invaluable resource for the proper investigation of diving-related fatalities. A savvy medical examiner should seek out clinical colleagues with expertise in dive medicine when faced with investigating diving-related fatalities. As a corollary, medical professionals with expertise in dive medicine should offer to assist in the investigation of diving-related deaths, and being present during the autopsy would be ideal.

The proper investigation of diving-related deaths and public dissemination of the most common health issues, dive practices and behaviors that result in or contribute to a fatal dive mishap are fundamental to improving dive safety. Collaboration is required among the authorities responsible for investigating these deaths, the clinical dive medicine community and the dive training and dive safety organizations.

Forensic Investigators and Forensic Pathologists

Forensic investigators are individuals who possess special training and experience in the field of death investigation. While there are a variety of training pathways and backgrounds that lead to a career in death investigation, many forensic investigators have prior law enforcement or military experience. A significant number have college degrees, and some even have advanced degrees. Most will seek national certification in death investigation.

Forensic pathologists are physicians who after completing medical school go on to complete an additional three to five years of training in pathology, the medical specialty that focuses on diseases and disease processes. After training in general pathology, an additional year of training in forensic pathology is required. Board certification by formal examination is typical.

"The proper investigation of diving-related deaths and public dissemination of the most common health issues, dive practices and behaviors that result in or contribute to a fatal dive mishap are fundamental to improving dive safety."

Forensic pathologists and forensic investigators are extremely skilled at evaluating deaths that are sudden, non-natural, unexpected or suspicious in any way. Much of the casework centers on violent deaths, such as assaults and accidents, and unattended deaths that appear to be natural. Diving-related deaths are rare compared to other types of deaths that come to the attention of the medical examiner's office. Another individual who may be involved in the investigation of a diving death is a coroner. Coroners do not have to be medically trained, though some are. States have different systems for the certification of deaths. If a state has a coroner system, the coroner typically certifies the death and signs the death certificate, but he or she would have a forensic pathologist perform the postmortem examination on the remains. Most, but not all, forensic autopsies are performed by forensic pathologists. Occasionally, a general pathologist who has not completed formal forensic training will be tasked with performing a postmortem examination on someone whose death appears to be non-natural. Fortunately, that is the exception rather than the rule.

Select offices have significant experience with diving-related deaths. Dade County (Miami), San Diego County, Honolulu and Monroe County (Key West) are examples of jurisdictions that typically investigate several diving-related deaths each year. Other jurisdictions may see as few as one diving-related death every few years, and the experience with certifying cause and manner of death for these cases would be minimal.

Death Certification

Death certificates are legal documents that list very detailed demographic information about the deceased, important chronological data such as the date and time of the death, and, most important, the cause and manner of death. Cause of death is defined as the injury or disease that produces a physiological derangement in the body that results in the death of the individual. Examples include a gunshot wound, lung cancer, blunt-force injuries and drowning. The list is extensive, and the possibilities are innumerable. Manner of death is the category of circumstances under which death occurred and can only be one of five possibilities: natural, accident, homicide, suicide and undetermined. Manner of death essentially explains how the cause of death came about. Typically, the cause of death is determined by the autopsy, and the manner of death is determined by the investigation.

The Medicolegal Autopsy

A complete medicolegal autopsy consists of several steps, all of which are important to the ultimate goal of determining an appropriate and correct cause and manner of death. A proper investigation of the events leading up to the death is essential. If the autopsy is the final physical examination on a deceased individual, the investigation is the history component. A pathologist should not perform an autopsy without at least reviewing a preliminary investigative report. Prior to beginning the autopsy, some cases warrant radiographic studies. These range from postmortem CT imaging to simple head and neck radiographs.

"While standard hospital autopsies focus on a detailed description of the internal organs and the natural disease processes that affect them, forensic autopsies stress a thorough external examination looking for injuries, injury patterns, trace evidence and clues to how the body and the environment may have interacted."

While standard hospital autopsies focus on a detailed description of the internal organs and the natural disease processes that affect them, forensic autopsies stress a thorough external examination looking for injuries, injury patterns, trace evidence and clues to how the body and the environment may have interacted. It is not unusual for the external examination portion of a medicolegal autopsy to take every bit as long as, or longer than, the internal examination. Extensive photodocumentation plays a significant role in the external examination, and digital photography has made this part of the postmortem exam infinitely easier.

Once a thorough external examination is completed, the internal examination portion of the autopsy begins. Organs are examined in situ, removed, weighed and thoroughly examined. An important component of the internal examination is obtaining adequate toxicology samples, including blood, urine, vitreous fluid, bile, gastric contents and portions of various solid organs such as liver, spleen, kidney and brain. Once the organs have been removed and examined, the autopsy concludes with an inspection of the skeleton, particularly the ribs, spine and skull.

After the autopsy examination is completed the pathologist releases the remains of the deceased individual to the next of kin. Depending on what the pathologist finds during the autopsy examination, some ancillary studies may be indicated. Microscopic slides of select organs, particularly the lungs, heart, liver and brain, may be prepared. In some cases the pathologist may choose to retain complete organs, such as the brain or heart. An official consultation on these organs may be requested. There are subspecialists, neuropathologists and cardiovascular pathologists, who concentrate on diseases of one specific organ system. Toxicological testing was already mentioned, and for all medicolegal autopsies this is an essential part of the examination. It would be important to know if the diver had been under the influence of any sedating medications or illicit drugs, for example. In diving-related deaths the blood should be tested for the presence of carbon monoxide as that would point the investigation toward tainted breathing gas and also suggest the possibility that other divers may be affected if other cylinders containing impure gas are circulating.

Of course, no death investigation that concerns a diver is truly complete without an evaluation of the equipment. Guidelines concerning the evaluation of dive equipment are covered in this volume (Barsky 2011; Bozanic, Carver 2011), but the forensic pathologist needs to know if the equipment played a significant contributing role in the death of the diver. Equipment problems seldom directly cause the diver's death, but the diver's response to an equipment malfunction, especially if the response is panic and perhaps a rapid ascent to the surface, may be the catastrophic event in the sequence that results in a diving-related fatality.

Once all of the investigative reports, the equipment evaluation and all of the components of the postmortem examination, including toxicological testing, are available to the pathologist, a final autopsy report can be generated. Such a report should provide a detailed description of the autopsy findings and include a synopsis of the circumstances surrounding the death as well as the results of all ancillary studies. A good autopsy report also includes a summary and interpretation section that cites the professional opinion of the pathologist who performed the autopsy.

Specialized Autopsy Techniques for Diving-Related Deaths

A recommended protocol for performing a postmortem examination on an individual who died while involved in a dive is included in Appendix F of these proceedings. While most forensic pathologists will have a similar approach to performing a medicolegal autopsy to what was outlined above, there are a few techniques that can be employed to maximize the yield of a postmortem examination in a diving-related death. There are also areas that warrant special attention. The investigative report must include important pieces of information such as the diver's certification status and level of training and experience. Knowing the dive profile and the circumstances surrounding the death are essential. With the near universal use of dive computers, they become an invaluable resource for the investigation. Not only can the final dive or dive series be reviewed, but many computers have large memories that store hundreds of dives. The diver's experience and dive habits can be reviewed. If the death occurred in the ocean, the external examination should include documentation of any evidence of a bite, sting or other possible means of envenomation.

The diagnosis of fatal air embolism rests as much or more upon the dive profile than on the autopsy findings. However, corroborating evidence of pulmonary barotrauma found during the autopsy can substantiate the diagnosis of air embolism. Subcutaneous emphysema can be appreciated during the external examination. Mediastinal emphysema and pneumothorax can sometimes be appreciated with postmortem radiographic imaging. There are recommended alterations in the internal examination that may also yield useful information. The pathologist should always check for a pneumothorax and intracardiac/intravascular gas during the postmortem examination of anyone who died while breathing compressed gas.

Two approaches are commonly used to check for a pneumothorax. During the initial incision to open up the chest, the pathologist can make a pocket of soft tissue over the chest wall, fill that pocket with water and check for escaping gas as the chest wall is opened. A technique that I find more useful and far less messy is to carefully make the initial entry into each pleural cavity by teasing away the intercostal muscles with the scalpel. As the pleural cavity is breached, careful observation of the parietal and visceral pleura will be enlightening. If a pneumothorax has occurred, the lung volume would have already been decreased, and as the parietal pleural is cut, the lung will be observed down in the pleural cavity. In the normal situation, the visceral and parietal pleura are up against each other and the lung does not fall away from the chest wall until the pathologist's scalpel gets through the parietal pleura.

"Not only can the final dive or dive series be reviewed, but many computers have large memories that store hundreds of dives. The diver's experience and dive habits can be reviewed."

Careful observation for gas in the coronary arteries and in the arteries at the base of the brain should be made. Gas in the superficial veins of the cerebral cortex or the venous sinuses is not nearly that helpful. Tying off the arteries in the neck prior to opening the head and removing the brain decreases the chances of air being introduced into the cerebral arteries as an artifact.

The observation of intravascular and/or intracardiac gas during the autopsy of someone who died after breathing compressed gas can be very confusing and certainly does not indicate that an air embolism has occurred. Postmortem off-gasing does occur when the body sits at surface atmospheric pressure. Gas can be present in blood vessels and in the chambers of the heart after any type of dive, but the chances increase with long dives of sufficient depth resulting in large quantities of dissolved gas, typically nitrogen, in the body. Interpretation of intravascular gas at autopsy must be carried out with great care. The postmortem interval affects the amount of intravascular gas present at autopsy as gas is produced during the decomposition process. It is most important to take into account the dive profile. If the dive profile did not include an ascent, there is no possibility of an air embolism. I have seen experienced forensic pathologists erroneously decide than an air embolism contributed to a diver's death, even though the body was recovered from a deep cave system or a wreck without any possibility of an ascent during the dive.

Diving Professionals and the Medical Examiner's Office

Diving-related deaths, because of the circumstances under which they occur, nearly always fall in the domain of the medical examiner or coroner. How a case is handled once the medical examiner's office gets involved is highly variable and is influenced in no small part by the experience level that office has with these types of cases. Offices that handle diving-related deaths with some frequency often have a protocol in place for the evaluation of the equipment and the handling of the remains. It is not unusual for an office that sees very few diving-related deaths to treat them as presumptive drowning, and in some cases an autopsy will not even be performed. This is very unfortunate as an autopsy is an essential piece in the thorough investigation of a diving-related death and in my opinion needs to be performed in all suspected drowning deaths, let alone diving-related deaths.

"The observation of intravascular and/or intracardiac gas during the autopsy of someone who died after breathing compressed gas can be very confusing and certainly does not indicate that an air embolism has occurred."

The diving professional, whether dive instructor, divemaster, dive shop owner or dive medicine expert, can play a very significant role in the medicolegal investigation of a diving-related death. It is the rare forensic investigator who possesses a background in diving physiology that is sufficient enough so that the right questions are asked. As is the case for all death investigations, the first few hours after the death occurs is the best time for interviews and data collection. Likewise, few forensic pathologists have a thorough enough grasp of diving physiology to completely understand the possible contribution of the deceased diver's training and experience, the dive profile or equipment issues to a diving-related death.

For all of the reasons cited, it is extremely advantageous for the medical examiner or coroner to accept the assistance and input of experienced divers. The goal of correctly certifying the cause and manner of death can best be achieved by a collaborative effort. The diving community benefits by having diving-related deaths thoroughly and properly evaluated so that risky behaviors, poor decision making or, in rare cases, equipment problems may be identified and publicized. Generating "lessons learned" with the hopes of decreasing the number of future diving-related deaths will make diving a safer endeavor for all of us.

Additional Reading

Barsky S. On-scene diving accident investigation. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Bozanic J, Carver D. Equipment testing. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Brubakk AO and Neuman TS. *Bennett and Elliott's Physiology and Medicine of Diving.* Philadelphia: W.B. Saunders, 2003.

Busuttil A and Obafunwa J. A review of the forensic investigation of scuba diving deaths. *Sci Justice* 35: 87-95; 1995.

Calder IM. Use of postmortem radiographs for the investigation of underwater and hyperbaric deaths. *Undersea Biomed Res.* 14:113-32; 1987.

Edwards L. Autopsy features in scuba diving fatalities. *Med J Aust.* 27:1305-1306; 1970.

Findley TP. An autopsy protocol for skin- and scuba diving deaths. *Am J Clin Path* 67: 440-443; 1977.

Goldhahn RT. Scuba diving deaths: a review and approach for the pathologist. *Leg Med Ann* 1976:109-132; 1977.

Kindwall EP and Pellegrini J. Autopsy protocol for victims of scuba diving accidents. Appendix G In: *1990 Report on Diving Accidents and Fatalities,* Durham, N.C.: Divers Alert Network, pp. 94-100; 1990.

Plattner T, Thali MJ, Yen K, Sonnenschein M, Stoupis C, Vock P, Zwygart-Brügger K, Kilchör T and Dirnhofer R. Virtopsy-postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) in a fatal scuba diving incident. *J Forensic Sci* 48: 1347-1355; 2003.

Roobottom CA, Hunter JD and Bryson PJ. The diagnosis of fatal gas embolism: detection by plain film radiography. *Clin Radiol* 49: 805-807; 1994.

U.S. Department of the Navy. *U.S. Navy Diving Manual.* Washington, D.C.: United States Navy; Revision 6, 15 April 2008.

Warren LP, Djang WT, Moon RE, Camporesi ET, Sallee DS, Anthony DC, Massey EW, Burger PC and Heinz ER. Neuroimaging of scuba diving injuries to the CNS. *AJR Am J Roentgenol* 151: 1003-1008; 1988.

Williamson JA, King GK, Callanan VI, Lanskey RM and Rich KW. Fatal arterial gas embolism: detection by chest radiography and imaging before autopsy. *Med J Aust* 153: 97-100; 1990.

Discussion

MARK HRUSKA: I would like you to comment on the unwillingness of a lot of medical examiners to entertain a diagnosis of sudden cardiac death. By that, I mean when you have a situation where somebody does not really have a lot of pathological evidence that really rules it in, but the surrounding circumstances of the death do not allow for any other conclusion; but in our experience they always put down drowning even though it is clear that the person was, say, at the surface conscious and then just slumps over and that is it. I know that you have spoken probably with Tom Newman about that. He is willing to make that kind of diagnosis, but most of the medical examiners just will not do it.

DR. JAMES CARUSO: I would agree with you, there is some stubbornness. Cardiac arrhythmia is an actual cause of death. A study by a group of Brazilian scientists a few years back looked at the long QT syndrome and whether some of the cases that were signed out as drowning might have been a result of a long QT syndrome that had been previously undiagnosed. I will agree with you, there is some reluctance in the medical examiner community. I think forensic pathologists as a rule like to have clean causes of death. And some of them go back to the old dogma, which is hard to get changed: "Went into the water alive, dragged out of the water dead. They are wet, they are dead, must be a drowning." That is unfortunate, because certainly a cardiac event in many cases did precipitate the final outcome. Even if the final outcome is a drowning, it was a drowning due to the cardiac issue, and you do no one a service just by signing out as drowning.

DR. RICHARD SADLER: Assuming that there is gas in the arterial tree, how long will it remain detectable before you are able to do a postmortem examination?

CARUSO: Usually for at least a few days, but it depends on the condition of the remains. Unfortunately, gas is also produced by the decomposition process. Some of the gas is going to get added to. That is why I consider it an artifact in most cases but worth noting in all cases. I will do the exam appropriately, document your postmortem interval and look for gas. If it is there, great. If it is not there, great, document that. But go back to history. History is by far the most important component to a case where you are presuming air embolism to have occurred.

DR. DAVID COLVARD: I am a psychiatrist. That is the first case of definite suicide I have heard. I get contacted around the world from agencies and dive shops who wonder if they should allow a diver who is on psychiatric medicines to dive. Usually the interesting thing is they think they are going to commit suicide. I have had many contacts from divers who had depression who said it is the best they ever felt. You did not mention any psychological factors in this. Do you ever look at any of the background other than that one case that apparently was suicide?

CARUSO: We do. There probably is at least one or two others in my recollection over the last 15 years that I have entertained death being suicide. There was one gentleman who had severe end-stage liver disease. The dive professional described him as catastrophic prior to the dive. I think he went down and kept going down. Nobody ever saw him again. Perhaps that was his way to go, just narcosis and then some. It sounded like he was a chemotherapy patient, end stage at that point, who went diving. There are probably a few others out there. There is a case in the Croatian literature that a dive school classmate of mine, Capt. Petri, published where the individual supposedly stabbed himself during a dive. So we see a few. Most of the people who are on antidepressant medications probably are not actively suicidal. In fact, it has become a vitamin in some certain circles. We get calls at DAN all the time about diving on Prozac. There are probably a few well covered up suicides where the insurance maybe pays better for accidental death.

Legal Issues Associated with Diving Fatalities: Panel Discussion

David G. Concannon
Law Offices of David G. Concannon, LLC
200 Eagle Road, Suite 116
Wayne, PA 19087 USA

A panel of five attorneys — David G. Concannon, Stephen L. Hewitt, François Jaeck, Craig S. Jenni and Mark A. Hruska — discussed common legal issues associated with diving fatalities. The panel addressed the personal and financial costs associated with scuba diving fatalities, major factors leading to scuba fatality litigation, shortcomings of accident investigations and suggestions for improvement, how the lack of investigative information can be problematic in litigation, cooperation with first responders and medical examiners to facilitate effective incident investigation, the collection of data for research and education of the diving community, the impact of fatalities on liability insurance, changing legal standards in Europe, and methods for enhancing international training and diver education to reduce future fatalities. The panel discussed ways to improve information gathering, from the collection of evidence at an accident scene through the litigation process. A lack of solid information about the underlying causes of diving fatalities creates uncertainty, which leads to litigation, higher insurance premiums, massive costs and ultimately the continued loss of life. More and better data must be collected to determine exactly what is causing divers to die.

"Lack of solid information about the underlying causes of diving accidents and fatalities creates uncertainty, and this is the principal factor leading to litigation, higher insurance premiums, massive litigation costs and ultimately the continued loss of life."

Introduction

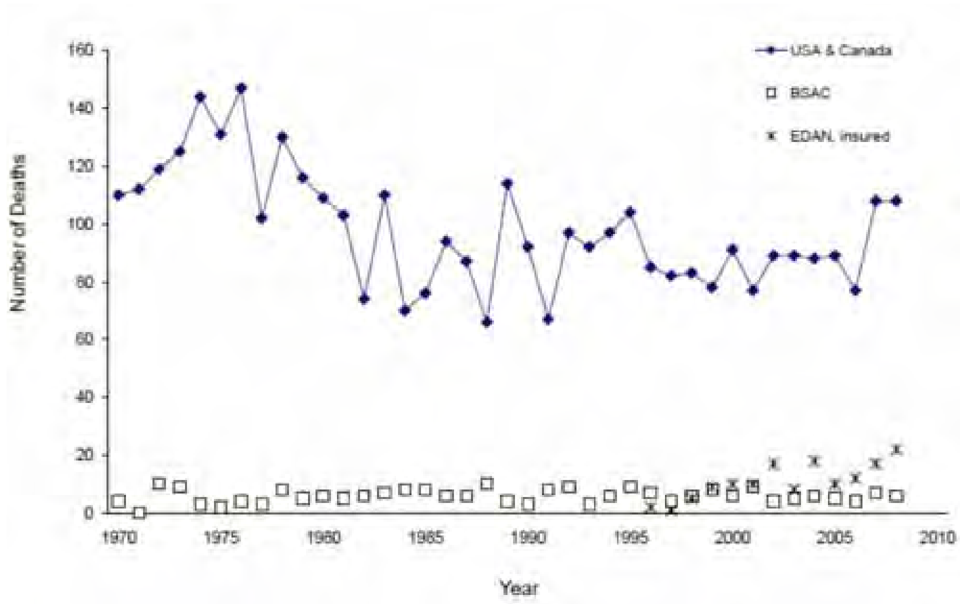
A panel of five attorneys, representing several decades of experience investigating scuba fatalities and litigating dive accident cases, included David G. Concannon (Law Offices of David G. Concannon, LLC, Wayne, Pa.), Stephen L. Hewitt (Hewitt & Truszkowski, North Hollywood, Calif.), François Jaeck (DAN Europe, Blois Cedex, France), Craig S. Jenni (Dive and Marine Consultants International, Fort Lauderdale, Fla.) and Mark A. Hruska (Schwartz & Horwtiz, PLC, Boca Raton, Fla.). The panel shared the members' collective experience and observations about the cause of diving fatalities, major factors leading to litigation and common legal issues associated with diving fatalities.

This paper summarizes the individual presentations and provides additional information to assist in identifying potential causes of scuba fatalities, but more information is needed to better address the associated legal and financial issues.

The Problem

Scuba diving fatalities have a toll that exceeds the unfortunate loss of human life; fatalities also have a major financial impact in the form of lost income, lost business, higher insurance premiums and massive litigation costs. Every year, approximately 125 divers die in North America, Europe and Asia (Denoble, Vann 2009). Of this number, between 50 and 60 scuba divers die in the United States (Denoble et al. 2008). Figure 1 shows the number of scuba fatalities is trending upward after remaining static for several years.

Figure 1: Diving deaths by year in North America, the United Kingdom and Europe (from Denoble, Vann 2009)



"The problem is there is no systematic collection of data performed to determine exactly how or why scuba divers are dying."

But what exactly is causing divers to die? Without knowing the answer to this question, it is difficult to make progress toward reducing the number of diving fatalities and related costs. The problem is there is no systematic collection of data performed to determine exactly how or why scuba divers are dying. Instead, information is collected, with varying degrees of accuracy, from a variety of different sources. Lack of solid information about the underlying causes of diving accidents and fatalities creates uncertainty, and this is the principal factor leading to litigation, higher insurance premiums, massive litigation costs and ultimately the continued loss of life.

Shortcomings of Scuba Fatality Investigations

Chris Acott, the founder of the comprehensive and ongoing Diving Incident Monitoring Study (DIMS) in Australia, has observed: "An accident is often the product of unlikely coincidences or errors occurring at an inopportune time when there is no 'system flexibility'" (Acott 2001, 2003). It is never just one event that causes a diver to die; instead, there is often a series of events, beginning before a diver ever enters the water, that leads to a fatal accident. Unfortunately, the series of events leading to an accident is rarely investigated completely, leading to a lack of critical information about what caused a particular accident.

Furthermore, the Pareto principle, also known as the "80-20 rule" or "the law of the vital few," states that, for many events, roughly 80 percent of the effects come from 20 percent of the causes. Therefore, the proper investigation of diving-related deaths, and public dissemination of the most common health issues, dive practices and behaviors that result in or contribute to a fatal dive mishap ("the vital few"), are fundamental to improving dive safety. Without proper investigation of diving fatalities, these common problems cannot be identified or fixed.

Scuba fatality investigations attempt to determine the cause of death by identifying causative factors, primarily focusing on three areas: medical, equipment and procedural. Medical investigation looks at a diver's health and medical factors leading to the cause of death. Equipment investigation addresses potential hardware issues that may have contributed to a cause of death. Procedural investigation focuses on whether the diver followed his or her training, properly prepared themselves and their equipment before diving, or went diving in conditions beyond their training and experience level.

It is important to note that all three areas are typically examined in a scuba fatality investigation, with varying degrees of competence and thoroughness. Procedural problems appear to be more common than equipment problems, but they are often difficult to identify. Proper medical investigation depends on whether protocols for conducting a proper "diving autopsy" are followed, but often they are not. In the vast majority of cases, the primary causative factors are never identified, leading to uncertainty about the cause of death.

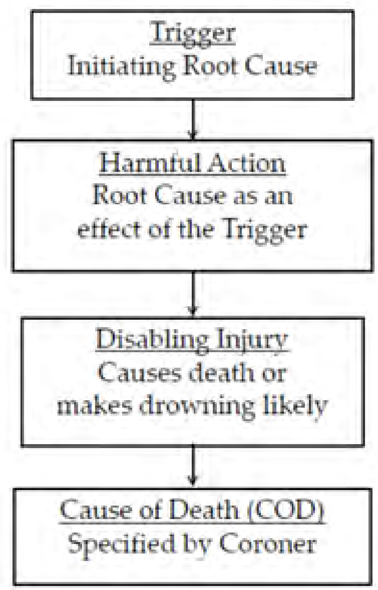
Furthermore, it is not uncommon for investigators to rule out one area, typically medical, and then point to another area as the most likely cause of death even though the investigator has no experience investigating this area and did not do so because they have excluded their area of expertise as a contributing factor. In such cases, a victim's wife may be told by a medical examiner, "Your husband was the picture of health, so it must have been his equipment," when, in fact, the medical examiner did not conduct a proper diving autopsy or was unaware that actual equipment problems account for less than 10 to 15 percent of all fatalities (Acott 2001; Vann et al. 2007).

"Scuba fatality investigations attempt to determine the cause of death by identifying causative factors, primarily focusing on three areas: medical, equipment and procedural."

Proper scuba fatality investigations are conducted using a root cause analysis to determine the four distinct events shown in Figure 2 (Denoble et al. 2008; Vann et al. 2008). The first event, the "trigger," is the earliest identifiable root cause that transformed an unremarkable dive into an emergency. The second event, the "disabling agent" or "harmful action" is an effect of the trigger that leads to the third event, the "disabling injury." The disabling injury caused death or rendered an incapacitated diver susceptible to drowning. The final event is the "cause of death" specified by the medical examiner, which might be the same as the disabling injury or drowning secondary to the disabling injury. It is not unusual for one or more of the four events to be unidentifiable.

The panel presented information derived from 947 recreational open-circuit scuba diving deaths from 1992 to 2003 (Denoble et al. 2008). Diving deaths were identified by active search of news reports, the Internet and a cooperative network of individuals and organizations developed by DAN over many years. Following notification of a death, DAN contacted official investigative agencies, medical examiners, hyperbaric chambers, witnesses and the decedents' families by telephone, mail or email. DAN reported: "These contacts could be helpful to a greater or lesser degree. Reports might include scant details or a full analysis of equipment, breathing gases and a description of a complete medicolegal autopsy" (Denoble et al. 2008). The causes of death, which DAN identified in only 814 of 947 cases, are shown in Figure 3.

Figure 2: Root cause analysis for diving fatality investigations (Denoble et al. 2008)

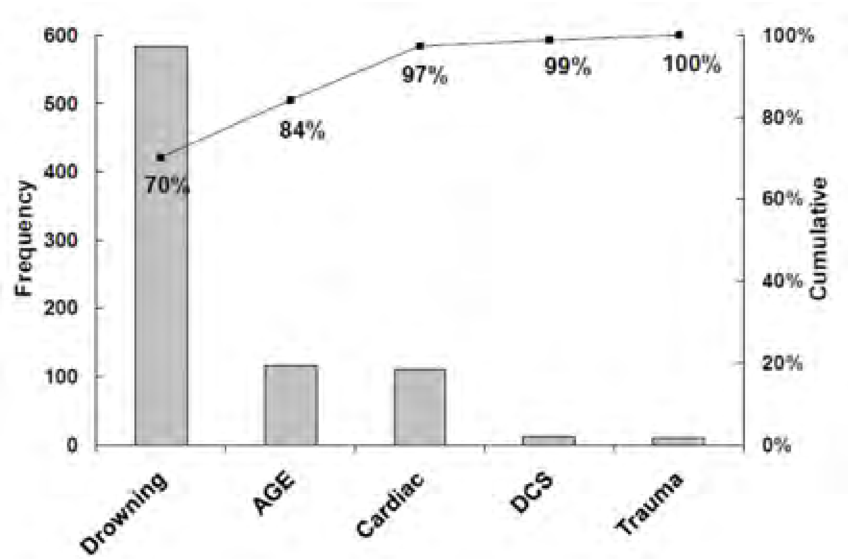


"According to DAN, 'Assessing associations and making causal inferences based on surveillance system data, such as that from diving fatalities, is uncertain because of inherent defects in data quality and completeness.'"

The study had a number of admitted limitations. According to DAN, "Assessing associations and making causal inferences based on surveillance system data, such as that from diving fatalities, is uncertain because of inherent defects in data quality and completeness." Indeed, the DAN study was notable for the way it collected data: DAN affirmatively sought data from a variety of sources. These are the methods used for data collection on which the DAN Annual Diving Reports are based (Vann et al. 2008). By contrast, international data sources such as those collected by BSAC and Project Stickybeak in Australia (with the cooperation of DAN Asia-Pacific) encourage individuals to submit information directly to the researchers, and they even go so far as to publish downloadable forms on the Internet to facilitate the collection of information (Cumming et al. 2011; Acott 1999, 2003). Consequently, the BSAC and Project Stickybeak studies seem to have more complete data of a higher quality, although for a smaller population of divers.

DAN identified the following additional limitations: (1) disabling injuries were identified for only 590 of the 947 decedents; (2) triggers and disabling agents were even more difficult to identify, and DAN was able to do so in only 346 and 342 cases respectively; (3) postmortem examination of divers has requirements beyond standard autopsy practice that was not always implemented by medical examiners; (4) the reference group for each disabling injury was all other disabling injuries; therefore, triggers and disabling agents associated with specific disabling injuries were not always identified completely, and their relative importance was necessarily conditional on death; and (5) surviving divers would be a better reference population (Denoble et al. 2008).

Figure 3: Causes of Death identified in 814 of 947 scuba fatalities, 1992-2003 (Denoble et al. 2011)



However, even studies incorporating data from surviving divers can have limitations. Acott (1999) identified in his study of equipment malfunction in 1,000 diving accidents a number of additional limitations associated with accident/fatality data: (1) often events are reconstructed from a jigsaw puzzle of information that lacks substantiation of events by the victim; (2) valuable information may be forgotten during the turmoil of the rescue and resuscitation so that the recorded events may be an oversimplification of what happened; (3) events are often changed to suit the perception of what happened and are seen in the light of "doing the right thing"; and (4) reports may be either subject to investigator bias and report "what must have happened" and not what did happen, or only legal issues may be addressed.

"Despite their admitted shortcomings, the available scientific studies of diving accidents and fatalities provide an excellent resource and a starting point for further research and awareness action."

Despite their admitted shortcomings, the available scientific studies of diving accidents and fatalities provide an excellent resource and a starting point for further research and awareness action. Denoble et al. (2008) found from DAN's 10-year study:

"[A]nalysis of diving fatality case data identified many triggers and disabling agents that are the focus of existing diving safety guidelines. What is new is recognition that a majority of fatalities were associated with a minority of triggers and disabling agents. This suggests that diving fatalities might be reduced by additional emphasis on the prevention of key triggers, disabling agents and intrinsic medical factors in accordance with the Pareto principle. The design and implementation of practical solutions for avoiding triggers and disabling agents is the province of training specialists…. Some diving fatalities are unavoidable, but the practically irreducible level appears yet to be achieved."

Although triggers were identified in only one-third of cases (346 of 947), the most common triggers were identified as insufficient gas (41 percent), entrapment (20 percent) and equipment problems (15 percent). Similarly, disabling agents were identified in only one-third of cases (332 of 947); however, emergency ascent (55 percent), insufficient gas (27 percent), and buoyancy trouble (13 percent) were the most common disabling agents and, together, accounted for 95 percent of the 332 deaths.

Disabling injuries were identified in 590 of 947 deaths. Of these, the three most common disabling injuries, asphyxia (33 percent), arterial gas embolism (AGE) (29 percent) and cardiac incidents (26 percent) contributed to 88 percent of deaths. Other disabling injuries were ascribed to trauma (5 percent), decompression sickness (DCS) (2.5 percent), unexplained loss of consciousness (LOC) (2.5 percent) and inappropriate gas (2 percent).

DAN's experience collecting information to fulfill its mission of improving dive safety is similar to that which attorneys experience in solving legal issues associated with scuba diving fatalities. In the United States, medical examiners conducting improper autopsies on dive accident victims are the norm rather than the exception. This leads to misinformation about the cause of death. Emergency service personnel usually devote more investigative resources to routine automobile accidents than they do to investigating diving fatalities. To be fair, first responders usually are not trained in how to properly investigate a scuba diving fatality; indeed, most first responders are not even certified scuba divers. However, it is not uncommon to see that routine investigative techniques are not followed, witnesses are not interviewed, dive computers are not downloaded and equipment is not properly examined. Consequently, the triggers, disabling agents and disabling injuries that lead to scuba fatalities are left to lawyers to uncover.

Identifying the most common health issues, dive practices and behaviors that result in, or contribute to, a fatal dive mishap is fundamental to improving dive safety, accurately calculating insurance risks, improving dive training and solving legal issues related to diving fatalities. Without improving the collection of information and the identification of root causes of diving fatalities, none of these goals are likely to be met anytime soon.

"Drowning is a diagnosis of exclusion and, in many cases, no effort is made at the time of an accident or during the initial investigation to exclude other causes of death or to determine why a diver drowned."

Uncertainty Leads to Litigation

Very few cases are cut and dry, where fault and responsibility are clear. Consequently, the legal panel members universally expressed their belief that uncertainty about what causes divers to die, how events may have unfolded underwater and the inability to accept responsibility for making mistakes are the major factors that cause a dive accident to develop into a dive lawsuit. Simply put, uncertainty leads to litigation.

Furthermore, the greatest number of diving fatalities occurs in older divers; in other words, the primary bread-winners of the family (Denoble et al. 2008). These fatalities can be financially devastating to surviving family members. Consequently, families of injured divers often sue to recover lost income, loss of consortium and money for pain and suffering that the family members incur due to the loss of a loved one. When the cause of death is uncertain and families are financially devastated by the loss, litigation is a virtual certainty, regardless of who may be at fault.

Research shows that drowning is listed as the cause of death in 70 percent of scuba diving fatalities (Denoble, Caruso et al. 2008; Denoble, Pollock et al. 2008). However, drowning often means that a diver simply died while underwater. There are no standard diagnostic criteria for drowning. Drowning is a diagnosis of exclusion and, in many cases, no effort is made at the time of an accident or during the initial investigation to exclude other causes of death or to determine why a diver drowned. Caruso (2011) pointed out that drowning "is a very unrewarding finding if you just stop there."

Craig Jenni observed: "When we, or family members of a decedent, see drowning on an autopsy report, there is a presumption and misconception among the general population that a dive professional should have somehow intervened, much like a lifeguard would at a pool. That creates a burden of responsibility from a defense perspective to establish why exactly this person drowned as opposed to a simple drowning that could have been prevented such as at a pool with a lifeguard." Furthermore, a great deal of litigation that we have seen recently is simply because family members, loved ones, are angry. It is a normal emotional response to the loss of their loved one. They want to hold someone else accountable.

This desire to hold someone accountable causes prolonged litigation, particularly where scant information is available to show what happened to cause a diver's death. Lawsuits are fought over the events leading to a cause of death. Unfortunately, judges and juries — not doctors, divers, lawyers, researchers or family members — often decide what caused fatalities, and they do so with the assistance of lawyers and experts who are paid to advocate a particular side of a case.

Consequently, what Caruso described as "a very unrewarding finding" of drowning from a medical perspective can be a very rewarding finding from a financial perspective for law firms and experts involved in dive accident litigation but for virtually nobody else. Millions of dollars are spent each year to determine why divers die underwater. Just one lawsuit can involve the expenditure of hundreds of thousands of dollars to determine what caused one diver's death. This money could be better spent to conduct research, education and prevention to save the lives of many divers and, ultimately, to reduce the wide variety of costs associated with scuba fatalities.

Lack of Information is Problematic in Conducting Legal Proceedings

Stephen Hewitt described the failure to collect and safeguard evidence at the scene of an accident as one of the principal problems associated with scuba fatalities. Without evidence, a party bringing or facing allegations of fault will be unable to prove or defend their case. For example, a diver may have suffered from decompression sickness after a dive, but why? Was it due to a dive instructor's failure to supervise the diver, or because the diver panicked and made a rapid ascent to the surface? Data stored in a dive computer could hold the answer, but if the data is not retrieved and maintained the answer could be lost.

The legal consequences of failing to collect and safeguard information identifying the cause of a diving fatality can be dramatic. In the United States, failure to preserve, identify and produce critical information such as dive computer data can result in sanctions for spoliation of evidence, including monetary sanctions and termination of litigation in favor of the party requesting the lost information. In Europe the burden of proof rests on the diving professional to prove he or she was not at fault in causing a fatality; automatic liability is assumed on the part of the professional when selling package travel. In other words, the dive professional is guilty until proven innocent.

"In the United States, failure to preserve, identify and produce critical information such as dive computer data can result in sanctions for spoliation of evidence, including monetary sanctions and termination of litigation in favor of the party requesting the lost information."

Francois Jaeck (2011) provided a summary of a legal regime in Europe that affects more than 500 million people. In June 1990, the Council of Europe enacted a directive on package travel reversing the burden of proof between a professional and a consumer. Previously, the injured diver had the responsibility of proving that the dive professional was responsible for causing their injuries. Now, however, automatic liability of the professional is assumed when selling package travel. To date, more than 27 countries have amended their domestic legislation to comply with the directive. The European regulation has drastically changed the rules by stating that tourism actors can be declared responsible even if they have not committed any fault. If the professional cannot demonstrate the real cause of the accident and that this cause is attributable to the diver, the professional automatically will be held responsible. In Europe it is no longer a demonstration of fault or negligence that determines the outcome of the trial in a scuba case but the demonstration of the cause of the accident. Consequently, dive professionals have placed a much greater emphasis on the immediate collection of evidence to escape automatic liability in the event of a future legal proceeding.

David Concannon provided examples of cases in which dive computer data could have or did provide the definitive answer to what caused a scuba fatality. In one case, more than $1 million was spent in legal fees and costs to litigate a diving fatality lawsuit where the answer to what happened to a solo diver was stored in the dive computer, but the data was irretrievably lost by the victim's widow. The case lasted more than four years before the equipment manufacturer, a training agency, instructors and a dive boat owner were finally exonerated, but nobody knows what caused the diver to drown. However, in another incident involving similar equipment, dive computer data conclusively demonstrated that diver error caused a diver to drown, and no case was ever filed.

"The information stored in these computers has essential applications, including the ability to support research that promotes diver safety, prevents or helps us to understand the causative factors in dive accidents, and helps to prevent or resolve litigation."

The failure to obtain data stored in dive computers is especially problematic (Concannon 2007). Downloadable dive computers have been on the market for almost 15 years. The information stored in these computers has essential applications, including the ability to support research that promotes diver safety, prevents or helps us to understand the causative factors in dive accidents, and helps to prevent or resolve litigation. Yet, unbelievably, divers do not routinely review or preserve dive computer data after an accident or serious incident, even though their basic training teaches them to record and/or download dive data. Now, the failure to obtain and preserve dive computer data can have dramatic consequences in diving fatality litigation.

In December 2006, the federal court system throughout the United States adopted new rules governing the collection of electronically stored information and its admissibility at trial (Concannon 2007). The new rules, which also have been adopted in a majority of state court systems, apply to dive computer data. They require the preservation of electronically stored information, disclosure of its existence to opponents in litigation without a request, collection and production of this data during the litigation process, and they provide for the imposition of sanctions for the failure to do so. These sanctions can be severe, from the imposition of fines ranging from a few thousand to millions of dollars, a finding that the party failing to produce data has "spoiled" evidence, or an outright dismissal of a lawsuit in favor of the party deprived of the data and an award of damages. Despite these nearly four-year-old changes in the law, investigators, victims' families and dive professionals routinely fail to obtain and/or preserve data stored in dive computers. This perpetuates uncertainty, prolongs litigation and increases costs for everyone involved.

Lawsuits are fought over the identification of triggers, disabling agents and disabling injuries. Like bats that live in the darkness of caves, lawyers thrive in the gray areas. Uncertainty means prolonged litigation, which is expensive and distracting and ultimately can lead to unsatisfying results for all involved.

Methods for Enhancing Training and Diver Education to Reduce Future Fatalities

There was considerable discussion about methods for enhancing training and diver education to reduce future scuba diving fatalities. Who, exactly, is supposed to be doing the training, and what can be done about divers not following their training once they leave their instructors' supervision?

It is worth remembering that scuba diving is an inherently risky sport. The human body is not designed to function underwater, and the risk of injury is present in all physical activities. All divers are taught the risks of scuba diving in their initial and any advanced-level training they may take. All divers must understand and accept the risks of scuba diving before they ever enter the water and be prepared to overcome any adverse events that may befall them once they enter the water. All divers are taught to "plan your dive, and dive your plan," not to dive beyond their training and experience levels, and that overconfidence kills.

Scuba diving is also a relatively safe sport. As Denoble, Pollock et al.'s (2008) study pointed out:

"In a survey of 444 subjects, for example, scuba diving was ranked as more risky than snow skiing but less risky than bungee jumping, rock climbing, motorcycle racing, hang gliding, cliff jumping and sky diving. In fact, the actual likelihood of injury in open-water recreational diving seems to be 100 times less than the likelihood of injury in snow skiing (Pedersen 1997)."

Consequently, all of the panelists felt that there isn't really a "problem" of divers dying underwater, because some fatalities are inevitable in a sport involving some degree of risk and with millions of dives being performed every year. However, there is a very real problem of divers not following their training or diving within their experience levels, and this is the underlying cause of a majority of accidents. Additionally, medical issues such as cardiovascular events and obesity are an important part of the problem (Denoble et al. 2008), and divers bear primary responsibility for assessing their individual health and fitness to dive.

"There is a very real problem of divers not following their training or diving within their experience levels, and this is the underlying cause of a majority of accidents."

Mark Hruska and the other panelists observed that in 25 years of litigating hundreds of diving accident cases, 85-90 percent of these cases were simply the result of diver error. This range is consistent with the results of several scientific studies (O'Connor 2007; Acott 2001, 2005; Helmreich 2000; Alnutt 1987). For example, in a review of 1,000 recreational diving mishaps performed in Australasia, Acott (2005) determined that 87 percent were caused by human error; inexperience and insufficient training accounted for 14 percent and 8 percent respectively of the contributing factor to the mishap. Similarly, in studies of other high-reliability industries (e.g., aviation, nuclear-power generation, offshore oil production and medicine), the cause of approximately 80 percent of mishaps is generally regarded as human error (O'Connor 2007; Helmreich 2000).

As for experience levels, Vann et al. (2005) reported that "[th]e number of dives in the previous 12 months was related to the occurrence of death." There were more occasional than regular divers among fatalities. This study included various statistics for 89 of 109 recreational diving fatalities from 2003. A majority of the divers had only open-water or advanced open-water certifications. Furthermore, information about the number of dives performed by the diver in the 12 months prior to the incident was available in 54 cases. Of this number, nearly 45 percent of divers had no dives or had not dived in the previous 12 months; another 28 percent of divers had less than 20 dives in the past 12 months. Only 28 percent of divers could be classified as regular divers, or those having made more than 20 dives in the previous 12 months. There were at least 10 "novice divers," or those with 20 or fewer lifetime dives. From these figures, one can surmise that most divers have the training they need to safely perform most recreational scuba dives.

However, they may not have enough recent experience to fall back on when an otherwise routine recreational scuba dive escalates into a critical incident.

Unfortunately, DAN's data on experience levels can change dramatically from year to year given the small sample size and inconsistent reporting of data. For example, in DAN's 2006 data, only 56 divers out of 75 fatalities in the United States and Canada were known to be certified divers, but the certification level was known in only half of these cases (Vann et al. 2008). Similarly, the number of years since a diver's initial certification was known in only 38 cases (51 percent). Thirty-nine percent of those with known history had been certified 10 years or more, and 19 percent one year or less. Consequently, evaluation of experience level as a specific risk factor in diving is not possible based on sparse data that is not examined over a multiyear period.

A lack of solid information about diver-experience levels in fatalities from year to year is unfortunate, given that careful examination of this risk factor in other activities has yielded significant information about the cause of fatal accidents and solutions for reducing such accidents. For example, a thorough study of 2,501 general aviation accidents over a 17-year period (1983 to 2000) determined that the majority of all fatal accidents (57 percent) took place when the pilots had between 50 and 350 flight hours (Craig 2001). This period in which fatal accidents were most likely to occur — which begins immediately after a pilot obtains a private pilot's license and leaves an instructor's supervision, and continues through obtaining an instrument rating and experience flying in various conditions — was dubbed "the killing zone." This is the period in which a pilot is confident of his flying ability even though his actual flying experience is low.

"In planning for a dive, divers must consider their training and recent level of experience and then conduct their dives accordingly."

Craig (2001), noting that similar findings were reported in a 1974 National Transportation Safety Board (NTSB) report, pointed to "a pilot's inexperience mixed with a dose of overconfidence as a fatal mix." Interestingly, from a training perspective, the total number of fatalities inside "the killing zone" dropped by nearly 41 percent after the NTSB reduced the minimum flight-time requirement for a private pilot to obtain his or her instrument rating from 200 hours to 125 hours. The NTSB did so after it determined that the greatest cause of fatal accidents was pilots flying into bad weather while they were "building time" to qualify for their instrument rating at 200 flight hours after obtaining their private pilot's license at just 50 to 60 flight hours (Craig 2001).

There was some discussion of whether training agencies and resorts should require recertification or refresher courses before allowing a diver to make a particular dive. There was no consensus on this issue; in fact, there was sharp disagreement. Ultimately, every member of the panel agreed that it is the diver's responsibility to make sure they are capable of making a particular dive on any given day. It is the diver's responsibility to ensure that they plan their dive and dive their plan. In planning for a dive, divers must consider their training and recent level of experience and then conduct their dives accordingly. If these basic rules are not followed, we are likely to continue seeing 85 to 90 percent of fatalities that are simply the result of diver error.

Suggestions for Improvement

The panelists identified several areas where improvement could be made to reduce the number of diving fatalities and their related costs.

First, it is essential that more useful information is collected through more thorough data-collection methods and that this information is analyzed to determine the root cause of diver fatalities and near fatalities. Some examples of fairly thorough diving fatality studies include the British Sub-Aqua Club's paper (Cumming et al. 2011), DAN's series of Annual Diving Reports on diving accidents and fatalities, and the Diving Incident Monitoring Study (DIMS; Acott 2003). Any diver interested in learning more about the cause of scuba diving fatalities can obtain these studies on the Internet, as well as dozens of other scientific studies on diving, by visiting the DAN website (*www.DAN.org*) or the Rubicon Research Repository (*http://archive.rubicon-foundation.org*).

Second, stakeholders must increase cooperation with first responders and medical examiners to facilitate effective incident investigation, the collection and preservation of data, and accurate reporting. Similarly, first responders and medical examiners must seek out and/or accept this cooperation when offered.

Craig Jenni observed that one problem facing investigators is a lack of resources remarking that "because there is such a low incidence of diving fatalities and their investigations, from a primary investigation perspective, those who are statutorily authorized to do the investigation — medical examiner's office, law enforcement — do not have the resources to be able to do the type of investigations that we are talking about here for the most part." One way to correct this problem is for members of the diving community to reach out to federal, state and local authorities and offer their expertise when and where appropriate.

The following suggestions were made to overcome the problems associated with inadequate data collection and/or inadequate resources:

- Scuba equipment manufacturers could assist in accident investigations where equipment problems are thought to be a contributing factor.
- Stakeholders could develop and distribute protocols for effective accident investigations and medical examinations, which could be distributed by DAN or published on its website.
- DAN and workshop participants could educate those involved in accidents and accident investigations about the need to collect and preserve dive computer data and other relevant information.
- Stakeholders could disseminate appropriate data to interested parties (DAN, researchers, equipment manufacturers, training agencies, families and the public) so problems can be identified and addressed more effectively.

"Stakeholders must increase cooperation with first responders and medical examiners to facilitate effective incident investigation, the collection and preservation of data, and accurate reporting."

Discussion Summary

At the conclusion of the legal panel presentation, discussion questions ranged from how dive professionals and divers can protect themselves from lawsuits, to how to ensure that medical information is made available to researchers in light of strict privacy laws.

One of the most interesting questions involved an effort to quantify what percentage of diving fatalities each year turn into actual lawsuits. The panelists had a variety of answers, depending on their client base and geographic location. Mark Hruska commented that nearly every recreational scuba diving fatality in Florida becomes a lawsuit, an interesting remark given that Florida leads the United States in the number of scuba diving fatalities each year (Vann et al. 2008). Steve Hewitt remarked that lawsuits appeared to be more common in cases where there is a huge economic impact due to the diver's age and earning capacity, where the diver is between the age of 40 and 60, and where the cause of death is unclear. Given

DAN's recent statistics (Vann et al. 2008) that 82 percent of females and 72 percent of males were 40 years or older, with a median age of 43 and 50 respectively, there appears to be fertile ground for more lawsuits.

Another question involved how often a failure of the buddy system is the target of litigation. The collective answer was not much, although the trend of suing dive buddies is on the upswing (Coleman 2008). Most of these cases involve a failure to rescue the deceased diver or situations where the deceased diver's family is looking for an additional source of insurance to collect from. This question, however, illuminated another problem: A large number of fatalities occur in solo diving situations or in situations where buddy separation occurs, thereby complicating the investigative process (Caruso et al. 2003; Vann et al. 2008).

Finally, a remark was offered that some divers seem to think it is their constitutional right to go diving, regardless of their health and other limitations, and there was little that could be done to keep some people from becoming statistics. The panel members universally agreed that this was a problem, and Concannon remarked that "sometimes you can lead a horse to water, but you have to put the right end in the trough." Generally, the panel members emphasized adherence to industry standards, awareness of the risks associated with diving and acceptance of personal responsibility as the best way to avoid scuba diving fatalities.

Conclusion

Overall, the legal panel expressed its collective belief that more and better data are needed to identify the underlying causes of scuba diving fatalities before any progress can be made in significantly reducing such fatalities. It is difficult to solve a problem without knowing exactly what the problem is. However, significant progress was made on this front throughout this workshop, although there is clearly more work to be done.

"If divers made better decisions further back in the decision tree so that common triggers did not occur, a significant number of fatalities and their associated costs could be avoided each and every year."

Finally, divers must take more responsibility for their own safety. Some fatalities are inevitably caused by situations escalating out of control. However, the vast majority of diving fatalities can be attributed to human error. If divers made better decisions further back in the decision tree so that common triggers did not occur, a significant number of fatalities and their associated costs could be avoided each and every year.

References

Acott C. Equipment malfunction in 1,000 diving incidents. *SPUMS J* 29(3):122-126; 1999.

Acott C. 457 Equipment Incident Reports. *SPUMS J* 31(4):182-195; 2001.

Acott C. Recreational scuba diving equipment problems, morbidity and mortality: an overview of the Diving Incident Monitoring Study and Project Sticky Beak. *SPUMS J* 33:26-33; 2003.

Acott C. Human error and violations in 1,000 diving incidents: a review of data from the Diving Incident Monitoring Study (DIMS). *SPUMS J* 35:11-17; 2005.

Alnutt M. Human factors in accidents. *Brit J Anaesth* 59:856-864; 1987.

Caruso J. The forensic investigation of recreational diving fatalities. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Caruso J, Uguccioni D, Ellis J, Dovenbarger J and Bennett P. Buddy versus solo diving in fatal recreational diving accidents. *Undersea Hyperb Med* 30:210; 2003.

Coleman P. Scuba diving buddies: rights, obligations, and liabilities. *University of San*

Francisco Maritime Law Journal 20(1):75; 2008.

Concannon D. Dive litigation in the electronic age: the importance of preserving dive computer data in the event of an accident. *Dive Center Business* 10(6):24-31; 2007.

Craig P. *The Killing Zone: How and Why Pilots Die.* New York: McGraw-Hill, 2001.

Cumming B, Peddie C, Watson J. A review of the nature of diving in the United Kingdom and of diving fatalities, Jan. 1, 1998-Dec. 31, 2009. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Denoble P, Marroni A, Vann R. Annual fatality rates and associated risk factors for recreational scuba diving. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

Denoble P, Caruso J, de L. Dear G, Pieper C, Vann R. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med* 35(6):393-406; 2008.

Denoble P, Pollock N, Vaithiyanathan P, Caruso J, Dovenbarger J, Vann R. Scuba injury death rate among insured DAN members. *Diving and Hyperbaric Medicine* 38(4):182-188; 2008.

Helmreich R. On error management: lessons from aviation. *Brit Med J* 320:781-785; 2000.

Jaeck F. Collecting data and investigating a diving accident: focus on the European law. In: Vann R, Lang M, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011.

O'Connor P. The nontechnical causes of diving accidents: Can U.S. Navy divers learn from other industries? *Undersea Hyperb Med* 34(1):51-59; 2007.

Pedersen D. Perceptions of high risk sports. *Perceptual Motor Skills* 85:756-758; 1997.

Vann R, Caruso J, Denoble P, Freiberger J, Pollock N, Dunford R, Uguccioni D, Dovenbarger J, Nord D, McCafferty M. *DAN's Annual Diving Report: 2008 Edition*. Durham, N.C.: Divers Alert Network, 139pp.; 2008.

Vann R, Denoble P, Pollock N. Rebreather Fatality Investigations. In: Pollock N and Godfrey J, eds. *Diving for Science 2007.* Proceedings of the AAUS 25th Symposium. Dauphin Island: American Academy of Underwater Sciences; 2007.

Vann R, Freiberger J, Caruso J, Denoble P, Pollock N, Uguccioni D and Dovenbarger J. *Report on Decompression Illness, Diving Fatalities and Project Dive Exploration: 2005 Edition.* Durham, N.C.: Divers Alert Network; 2005.

Discussion

DR. PETAR DENOBLE: Are there any legal tactics that divers or dive operators should consider to improve their position in case a diver dies so that his family is not denied insurance? Definitely we would like to improve investigations, but probably nothing else will change in the next five, 10 years, again, 80 percent of divers, diver errors out there, but how we can improve our position from your experience? What I can do as a diver or dive operator?

DAVID CONCANNON: I think I understand the question. What can we do — what can dive operators do to improve their position to protect themselves and things of that nature? This is just my personal opinion, not as a lawyer but as a diver. I really like it when I go someplace to dive and the dive operator checks out my skills and my abilities. I do not get offended by that. I would not be unhappy; I would be, but I understand, hey, you are too fat, you have been sitting around a desk too much in the last year, so maybe you ought to do an orientation dive first. That is just my feeling on it. It is not a hard and fast rule, but I think that if you have been in this industry long enough, you can spot a statistic a mile away, you know who the divers are who are going to probably make a mistake and lead to an accident. And I think you have a moral responsibility to maybe flag them if you can. That is just my opinion.

MARK HRUSKA: I would disagree a hundred percent with that. Right now we are facing an issue where we are being threatened with a lawsuit because an instructor did not want to train a child who had ADD. The instructor was worried about the safety of the child, which is obvious. And this guy just did not want to take on that responsibility. If you are going to stop and evaluate every obese diver who comes in your shop and then be responsible for determining whether or not they are good to go, I think that is a burden that no operator should ever assume or should even have to assume. So that is just my thought on that. I would have to respectfully disagree with you there.

CRAIG JENNI: Likewise. I want to add, the whole idea behind personal responsibility is ultimately it is the diver's responsibility as to whether he or she is qualified and in condition and has done the predive check of his equipment and the predive plan with his partner to determine whether he is capable of making that dive. Anything to take away from that is asking for trouble unless you are in an instructional setting. So, Doctor, to answer your question maybe more succinctly and correctly, how to protect the dive operator, follow the industry standards, follow safe dive practices, utilize liability releases and have a good insurance company. As far as the individual is concerned, I am not altogether sure I understood your question, but I think I understood it to be, how do you protect yourself as an individual if your dive partner experiences some kind of a problem and is injured or killed? Was that the nature of your question? Well, we are seeing more and more lawsuits arise as a result of dive partners of decedent divers. It is a very sticky question, very difficult thing. It is unique. It is individual to each case. Each one of those has a unique setting to it, and it depends on so many variables that it would be hard to identify those in this simple setting or this short setting. The simple plan would be to make sure that you are familiar with your dive plan that you have agreed to with your dive partner and that you are familiar with their dive equipment. Be able to respond in an event of an emergency, and do the best you can. As a dive buddy that is what we would all want from our dive buddy in the event that we had an emergency.

DR. JAKE FREIBERGER: I would like to try to find out how big the problem is of liability suits after fatalities. I would like to know what your estimate is of the percentage of fatalities that have liability cases generated by them. I would like to know whether or not those are commercial versus recreational. And then finally, if you can answer this, I would like to know what percent of the liability claims made by the plaintiff are attributable to equipment, training, either the charter operation, and then finally attributable to a fitness-to-dive recommendation. So you may need to answer this individually. I know you probably have not thought about this as a group, but just the five of your collective experience if you could discuss that.

JENNI: What a multifaceted question. I will narrow it to exactly what I want to answer, and that is what you will get.

FREIBERGER: How many cases have you had in the last five years?

JENNI: We probably have 40 to 60 active cases right now.

FREIBERGER: What percentage of the fatalities ended up as cases?

JENNI: I had the pleasure of working with these three gentlemen co-defending lawsuits. When you ask what percentage of those from fatalities and what percent were injuries, I really do not have any knowledge.

FREIBERGER: That was not the question. I was asking of the fatalities, what percentage ended up as lawsuits?

HRUSKA: I can tell you in Florida that almost every recreational fatality ends up in a lawsuit.

CONCANNON: I can answer. From my perspective in my practice I have far more incidents in the files. An incident is classified as a fatality. Whatever the statute of limitation is in that particular jurisdiction, might be two years, might be three years, it is an incident from that time period that might turn into a lawsuit before the expiration. Normally it happens at the end of that time period, and maybe 1 in 10 incidents turns into litigation and actual lawsuit. I am not talking about things that are settled before a lawsuit is filed, but in my experience it is roughly 1 in 10 cases actually goes and becomes a lawsuit.

FREIBERGER: Are any of you able to break it down into equipment, training, charter operation or fitness to dive?

CONCANNON: Some of us have a variety of clients that we represent. Some of us represent training agencies. Some of us represent equipment manufacturers. So ordinarily our files probably relate to our clients. But generally speaking, in these cases the plaintiffs' attorneys have a "sue them all" mentality and allege everything you can think of, everything-but-the-kitchen-sink mentality. So the vast majority of them are "this was a defective training case," "this was a defective equipment case," and then the other issues like fitness to dive come later.

FREIBERGER: So there is no area that you can attribute to increased legal risk?

CONCANNON: Where I see a hundred percent of my cases come from is the inability of somebody to accept that somebody did something wrong. That is an honest answer.

STEVEN HEWITT: I would like just to add to your question. Again, I am on the West Coast. I see different kinds of cases. I only see kinds of cases from the different clients that I work for, so there is a limitation there. But if you want to identify two or three common factors in the large cases that present the biggest exposure for the dive community and have a huge economic impact, and that is where you have someone between the ages of 40 and 60 who is dying. The cause of death is not clear; it is not well-explained. Usually there is a buddy separation somehow, buddy is not there to give information. There is usually some kind of an element to the whole picture where there is this suggestion that if something had been done differently, the decedent might have survived.

FREIBERGER: So that can apply to any of the categories I mentioned, it sounds like, it just depends on what the attorney chooses?

HEWITT: The way you posed your question, those are the common factors.

MARTY McCAFFERTY: One of the problems we run into at DAN on the medical information line is a number of divers who consider diving a constitutional right, and that is really problematic. We do expound on all the risks that we can or have knowledge of when it comes to medical conditions and diving. And we do find that divers operater shop. They know if they go to one dive operator, they are going to require a medical release, somebody else does not. If they know their medical condition is likely to raise red flags, they simply go to an alternate dive operator who does not require it. So part of it is the dive industry itself. Two is that we need to stop being politically correct and hit divers over the head with the information that they need to know, and we are failing to do that, all of us, industry included. The other issue is how are we going to get, because of the small number of fatalities every year — yes, West Coast, Southeast — where we have a large number of divers, they are going to take the time to invest because they see more dive fatalities. You take a sheriff's department in Lake Woebegone, Minn., he sees one diving death every three years, they are not going to spend the time or the money to make some kind of protocol. So how are we going to address this across the board? Also, how do we get with health information problems? Our neighbors north of the border are militant about confidentiality laws, and this makes for a real problem. Working at DAN trying to get information from foreign governments is extremely impossible. So legally how do we try to get more cooperation with agencies that see very few numbers? And how do we get those confidentiality laws circumvented when necessary?

CONCANNON: One suggestion I would have is that I looked on the DAN Asia-Pacific website, and there is a questionnaire that divers can fill out and provide information about critical incidents on the DAN Asia-Pacific website. There is not currently one on the DAN America website that I could find. That is one way to gather information that would get around the confidentiality laws because the people who own the information are submitting it. That is a very difficult question to answer. As you indicated and Mark said, you can lead a horse to water, but you have to put it right into the trough. And we see a lot of accidents that are people who feel like it is their constitutional right to dive, and they go out and they make a mistake and it is fatal. I do not honestly think that is a question we can answer in the time we have left, but we can discuss over the next two days if anybody wants to take a quick crack at it.

HEWITT: I know in the racing context, some of the organizations use presigned medical release authorizations, but it is very complicated and very sticky, takes a lot of sophisticated legal maneuvering to put something together like that that is valid.

DR. FRANS CRONJE: A fair number of the fatalities or drownings are unwitnessed; that would suggest failure of the buddy system. And my question to you is how often, if at all, is the buddy system really the target of the liability lawsuit, and would that ultimately possibly change the dedication toward a better buddy system if it were the case?

HRUSKA: I can answer the first part of your question. There have been several, not a lot, suits where the buddy has been sued for failing to act as a proper buddy. That usually comes about when there is no other source of insurance and the buddy has a homeowners insurance policy that will cover that particular incident. So that has not been a big area of litigation. But it is, for every one of us who dives regularly and crawls on a dive boat and ends up with a partner that you have never met before, something to think about because it can and does happen.

CRONJE: Then this is more about pockets than principle?

CONCANNON: There was a great law review article published last year on buddy liability. I've seen it in some of my cases where clearly it appears that the buddies — it is not a situation where there was a failure to rescue. It is very difficult, first of all, to sue a buddy. Second, there is an extreme reluctance oftentimes on the part of the family member to sue a buddy because it might have been the dead diver's best friend, wife, husband, brother. So you do not see it very often, but we are seeing it more regularly. We also see a lot of incidents that occur from solo diving, unfortunately. And that makes life a lot more difficult.

JENNI: We as divers are in a three-dimensional environment, frequently with limited visibility. There is a reason why we teach buddy procedures at the entry level. This is a common occurrence. So it is not altogether out of expectation to find that buddy separation is a component or an element of some fatalities. It is the nature of the environment that we are in. You cannot eliminate that type of risk.

FRANCOIS JAECK: You have to know that in France the highest rules that exist an implied contract of assistance between two divers. That makes it easier to sue your partner.

DR. PETER BENNETT: I raised an equipment issue earlier. I am not sure this is necessarily the right panel to bring this up. But it struck me again while I was sitting here, was that death due to drowning? And what is drowning? It is water going in the mouth. And why does it go in the mouth? Because you have a mouthpiece which we drop out and we breathe in water. If you put a full face mask on, it is not going to be drowning. I just wonder if we should be thinking of one piece of equipment, having a full-face-mask diving. And I wonder if you have cases with full face masks or is there a predominance of just the mouthpiece?

CONCANNON: I personally have never had a case involving the full face mask.

JENNI: I have done investigations of commercial-diving fatalities and public-safety-diving fatalities utilizing full face masks. It complicates the equipment issue to a certain degree. Certainly from your perspective and what you are addressing as far as an incapacitated diver having a regulator, a conventional mouthpiece style, set in stage regulator, falling out of their mouth, a full face mask would be great, but that is not what the standard in the industry is, and I don't see it going that direction.

KARL HUGGINS: One of the things that has been brought up is the dive computer and interrogating the dive computer. One of the things that I have found is that people who just pull the information off and look at it without knowing what the computer does or how it stores the information or what it is looking at can sometimes make erroneous conclusions based on that information. So in an investigation if you are getting information from the computer, you want to know how it is recording the information. It's like the ascent-rate warnings. If you just look at the screen and it shows a vast ascent rate, that means it occurred sometime during the dive, not necessarily during the final ascent. Then what does that ascent-rate warning indicate? I may mean they went faster than 60 feet per minute, and that is all you can say. Just know what the limitations are of that witness that you have so you do not just draw conclusions without knowing the underlying data gathering of that piece of equipment.

CONCANNON: I appreciate that. Three years ago I wrote an article for *Dive Center Business* on the importance of preserving dive computer data. That was then picked up by Willis Insurance, and they sent that out to all their insurers. I believe they might require downloads to be submitted in addition to reports. But there are two problems associated with the collection of dive computer data. One is if you do not know what you are doing, you can overwrite the data and lose it. Number two is the interpretation you picked up on. As Steve Barsky said this morning, if you are doing an accident investigation or some type of equipment exam, just state the facts. Do not state your conclusions; state the facts. It is the collection of all the facts from many different sources that will come to a well-reasoned conclusion. Oftentimes in my experience the first conclusion that is reached at the time is maybe the most obvious, and then it is erroneous because later on you get other information. You can spend years chasing a rabbit down a hole and going in the wrong direction because somebody said something at the time or thought they saw something and go off in a completely different direction. It is the facts and the data that are important.

GENE HOBBS: I fully accept the fact that if I die while I am diving it is probably going to be because of something stupid I did. My family and all my dive buddies are aware that they are supposed to make this information available. The investigations themselves are a reactionary kind of thing. Thinking about being more proactive, just a few minutes ago we talked about the question of medical releases and getting all of my personal medical history out there is a little difficult. What about a power of attorney? What if I were to set this up now, where my attorney could guide the investigation immediately upon my death? They would find out and start making the phone calls to the coroners' offices, making sure they do get in contact with Dr. Caruso, making sure that my dive gear does go to the appropriate testing facility. My preference would be, obviously, the USN Experimental Diving Unit. Is there a way to set that up so that divers can actually take the responsibility themselves, and do you have any suggestions on how that might be able to go into practice?

CONCANNON: My suggestion is to put your wishes on a card, laminate it, and put it with your dive gear. In the event of an accident, call Steve Smith, and get that done. You would be one of the few people who do. I am not trying to be facetious, but it is one of those things where chances are, depending on where you do your diving, you have a more likely than not chance that the investigation is not going to be handled appropriately. Any mechanism you can use to assist is a good one.

HOBBS: There does seem to be quite a bit of interest between the technical side of things and making sure the information does get out there. That comes back to an educational issue. Is there a way to educate the general diving public to make them want to do that, and would you as legal professionals be willing to help guide that process proactively?

CONCANNON: The answer to the second question is yes, on my behalf.

HRUSKA: Never really thought about that.

CONCANNON: The answer to the first question is I personally read *Alert Diver* cover to cover every time I get it in the mail. Some of the diving press is a good place to start. Those of you who are instructors cannot hurt. There is a lot of different ways to skin a cat, different ways to disseminate information, but that could be one of them. Anybody else want to comment on that?

JENNI: Gene, I think it would be an outstanding idea to have a system set up where divers could acknowledge that they want so and so made aware of their death in the event of a death and that they want a pre-prescribed investigation. I am not altogether sure that is viable in today's legal world. Although I think it is very admirable of you to publicly announce that your diving death would likely be as a result of your own — and that you would want this follow-up investigation. Presumably the purpose of that follow-up investigation would be so that the rest of us could educate ourselves to avoid making the same mistakes that you made and, therefore, save other lives. That would be an ideal, utopian setup, but I just do not think that the legal climate is going to allow something like that.

DR. RICHARD VANN: Steve, you had mentioned how important getting a good investigation immediately was. Is there a role perhaps for the diving professionals? If they were trained to do some basic investigation, would that be at all useful?

HRUSKA: You are talking about the divemasters and so forth? I think they have a hard enough time being divemasters let alone investigators. I think other than taking basic steps to preserve equipment and getting the names of the witnesses to an event and filling out their incident reports per the requirements of their insurance companies, I think they have enough on their plate. Beyond that, I would not want to task these folks with any more than they have to do.

Collecting Data and Investigating a Diving Accident: Focus on the European Law

Maître François Jaeck
Avocat à la Cour[1]
Executive Director of DAN Europe Legal Network
4 Place Guerry - BP 30217
41006 Blois Cedex, France

Recreational diving accident litigation and the tightening of case law has contributed to a major liability exposure change in Europe, resulting in the need for all parties to collect evidence and make genuine investigations into the causes of an accident if they want to be suitably compensated or not be held liable through lack of evidence. Force majeure and the admissibility criteria have also changed. Not only is irresistibility of an event a factor, but the demand that proof of unforeseeability must now also be brought. A review of the new European liability regime is discussed and its effect on dive professionals and package travel considerations. A complete reversal of the burden of proof is now the norm, since henceforth tourism professionals are ipso jure responsible for any injurious event occurring during a consumer's holiday.

"A complete reversal of the burden of proof is now the norm, since henceforth tourism professionals are ipso jure responsible for any injurious event occurring during a consumer's holiday."

Introduction

Recreational diving, as we understand it today — i.e., using self-contained underwater breathing apparatus (scuba) — while presented in Capt. Cousteau's works[2] in the most enchanting light, is still widely regarded in Europe as a risky activity to the extent that it has been decreed as such under certain states' legislation.[3]

This notion is supported by the legal regulations issued under the Civil Code, generally recognized in Europe, under the terms of which responsibility falls to dive accident victims (who are deemed to have accepted the risks of this activity) to establish the fault or negligence[4] of a third party to attempt to get compensation from said party.[5] Consequently, recreational diving activity organisers have also traditionally rarely been concerned with establishing the real cause of a death that occurred during diving activity, considering — rightly, under law — that it was up to the victim to establish any possible fault or negligence. These principles are still legally valid in the possible event of action on the part of the victim or victim's beneficiaries against the professionals supposedly responsible.

We have, however, seen a tightening of case law[6] with regard to the conditions of admission of cases of force majeure, or those in which fault or liability on the part of the victim are liable to exempt the professional. This compels the professional to engage in actual investigations if he or she justifiably foresees the possibility of one of these two causes of exoneration of their own responsibility being validly raised.

Moreover, since the 1990s, the situation in Europe has undergone a complete reversal because the victim has acquired this recreational diving provision as part of a "package travel" deal. In fact, the drive to protect consumers and make it easier for them to claim compensation led the Council of Europe to adopt Directive 90/314/EEC[7], which completely reverses the burden of proof in existing relationships between tourism professionals and European consumers. This about-face fundamentally changes the attitude that the organizer of deep-sea diving holidays must take when a recreational diving accident occurs.

Force Majeure: The Tightening of Admissibility Criteria

The traditional legal definition of force majeure was simple: an external, unforeseeable, irresistible event that exempts the (legally) liable party of all responsibility. This cause exempting responsibility is generally admitted under all legal systems, whether they be based on common law or civil law. However, in Europe we have seen, born of a concern to provide greater protection for the victim against the professional, a tightening of the conditions of admission under law of this responsibility-exempting circumstance.

In the past, it only required that an event be "irresistible" for force majeure[8] to be invoked. (In 2002, for example, the French Cour de Cassation[9] — final court of appeal — decided that the death of a renowned lecturer constituted a case of force majeure solely on the basis of the irresistibility of such an event.) Now, however, the courts demand that proof of unforeseeability must also be brought.[10] In such a case, a large wave caused a sudden movement of the dive boat, causing a diver to fall. The court of appeals[11] decided that despite the wave being irresistible, it was nevertheless not unforeseeable.

Similarly, although not directly connected with a dive accident, the Jolo hostage case is indicative of the European courts' concept of force majeure. During a diving holiday purchased from a travel agency in Sipadan, Malaysia, a group of tourists were attacked at their hotel on April 23, 2000, by a gang of armed men who took them at gunpoint to the island of Jolo in the Philippines. They were held with some 20 other hostages for several months by the rebel Islamist group Abu Sayyaf. Some of these tourists were French, who, once freed, took out legal action in France on the basis of the French law of July 13, 1992. (The EC Directive below describes the text that transposes into French law.[7]) The travel agency had argued, quite logically, for the existence of a case of force majeure. The French courts, both initially (2006) and on appeal (2009), found against them on the basis that a hostage-taking situation was not unforeseeable,[12] when, of course, there was no doubt as to the irresistible nature of the situation.

"Professionals become liable and remain so as long as they cannot demonstrate fault or negligence on the part of the victim or a genuine case of force majeure."

Such a concept could be easily applied to a recreational diving accident, which is not in principle in any way unforeseeable.

This strengthening of the conditions of admission of force majeure, however restrictive it may be for professionals, is only a small breach in their line of legal defense under the law, as they still remain, legally speaking, "on the defense," which therefore presupposes that the plaintiff has already demonstrated fault or negligence to attempt to establish their liability. However, in 1990 the European authorities decided purely and simply in certain conjectural instances to reverse the roles. Professionals become liable and remain so as long as they cannot demonstrate fault or negligence on the part of the victim or a genuine case of force majeure. Professionals are therefore in the firing line and are liable to get hit.

The New Liability Regime

On June 13, 1990, the Council of Europe adopted a directive that fundamentally altered the rule of law with regard to consumer action against tourism professionals, within the scope of the sale of "package travel." A directive is a legislative act passed by the institutions of the European Union that stipulates the rules that member states must transpose into (i.e., include in) domestic law.

A "package" means the prearranged combination of not fewer than two of the following when sold or offered for sale at an inclusive price and when the service covers a period of more than 24 hours or includes overnight accommodation:

1. Transport

2. Accommodation

3. Other tourist services not ancillary to transport or accommodation and accounting for a significant proportion of the package (in this case, deep-sea diving provision)[13]

The sale of such tourist package deals, particularly for recreational diving, is very common in Europe.

Thus, to date, more than 27 European countries have amended their domestic legislation to comply with this directive.[14] This new legal regime therefore affects more than 500 million consumers. However, throughout Europe tourism professionals very often remain unaware of this, continuing to believe that they are only held accountable for their own faults or negligence and believing that being able to demonstrate that an absence of fault or negligence on their part will be enough to protect them from possible prosecution.

Whereas, as per the Council Directive of June 13, 1990:[15]

1. *Member States shall take the necessary steps to ensure that the organizer and/or retailer party to the contract is liable to the consumer for the proper performance of the obligations arising from the contract, irrespective of whether such obligations are to be performed by that organizer and/or retailer or by other suppliers of services without prejudice to the right of the organizer and/or retailer to pursue those other suppliers of services.*

2. *With regard to the damage resulting for the consumer from the failure to perform or the improper performance of the contract, Member States shall take the necessary steps to ensure that the organizer and/or retailer is/are liable unless such failure to perform or improper performance is attributable neither to any fault of theirs nor to that of another supplier of services, because:*

   — *the failures which occur in the performance of the contract are attributable to the consumer,*

   — *such failures are attributable to a third party unconnected with the provision of the services contracted for, and are unforeseeable or unavoidable,*

   — *such failures are due to a case of force majeure such as that defined in Article 4 (6), second subparagraph (ii), or to an event which the organizer and/or retailer or the supplier of services, even with all due care, could not foresee or forestall.*

"In Europe we are now seeing a complete reversal of the burden of proof, since henceforth tourism professionals are now, ipso jure, *responsible for any injurious event occurring during a consumer's holiday."*

In other words, in Europe we are now seeing a complete reversal of the burden of proof, since henceforth tourism professionals are now, *ipso jure*, responsible for any injurious event occurring during a consumer's holiday. Clearly, a recreational diving accident could constitute such an injurious event.

This reversal of the burden of proof henceforth requires tourism professionals or their insurers to meticulously gather all available details in the event of a recreational diving accident and to seek to thereby establish the causes of it. In effect, the latter are no longer liable because they may have committed a fault or been negligent, but because the law says so.

Each state's law, as derived from this Council of Europe directive, allows for only three possible escape clauses under this directive:[16]

- Demonstrating that "the failures which occur in the performance of the contract are attributable to the consumer," in other words, that the cause is attributable to the victim
- Establishing that the cause of the accident constitutes a case of force majeure
- Establishing that the cause of the accident is a result of the intervention of a third party to the contract

Thus, while this Council directive was "simply" aimed at making it easier for consumers to take action against tourism professionals in the event of an injurious event during a holiday, one of the unexpected effects, in terms of recreational diving, is that the debate has been moved from the "comfort zone" of "fault" and "negligence," or the absence thereof, to that of the cause of a diving accident, which is much more tricky to determine.

All of which now means that it is incumbent upon tourism professionals (package travel organizers or vendors of such travel packages) to make a genuine commitment to gathering information relating to diving accidents and as far as is possible establish their causes.

For, by default and *ipso jure*, they will be held fully and automatically liable in accordance with the Community directive. A third-party act being an unlikely possible scenario in terms of recreational diving accidents, in practice for tourism professionals it comes down to "act of the victim" and "force majeure."

The issue is narrowed still further given that case law in certain states considers that professionals may not be exempted from their obligations except by proving that the fault of the victim can be largely categorized as force majeure.[17] And so it comes full circle. Professionals are held liable — by law — regardless of whether they have committed a fault or been negligent, except where they can demonstrate that a death is attributable to force majeure, which presupposes genuine investigations.

Although in the past diving accidents were defined as those that occurred during recreational diving activity, and although divers were held to have accepted the risks of such activity, European law is now far more severe. At the same time as research has progressed and there is better understanding of how to reduce the risks of decompression-related accidents, the law has become more nuanced. A diving accident is not a decompression accident. A decompression accident is not necessarily accidental.

"Although in the past diving accidents were defined as those that occurred during deep-sea diving activity, and although divers were held to have accepted the risks of such activity, European law is now far more severe."

In a recent ruling on July 3, 2008, France's highest appeal court, the Cour de Cassation, made it clear that an "accident" was defined as the sole and sudden act of an external cause.[18] Since the inquiry had allowed it to be established that no alarming event had occurred during the dive itself or the return to the surface, that the technical and safety regulations had been complied with, that the death could not have resulted from faulty decompression, it was not possible to maintain the use of the term "accident." This effectively deprived the victim's spouse of an insurance payout, as she was only entitled to it in the event of an "accidental" death. This time, the victim's beneficiaries have been "penalized" for not having actually tried to determine the causes of an accident.

Conclusion

It is clear that the courts will assess the cause of a diving accident that will allow liabilities incurred to be defined and the victims' right to compensation to be determined rather than make a straightforward search for fault or negligence. The courts now require a genuine search for the cause of a diving accident before determining a victim's right to compensation, to declare a professional liable, or to *ipso jure* exempt them of all liability.

Whether they be professional organizers of travel that includes recreational diving, whether they be diving instructors or organizers, whether they simply be divers or their beneficiaries, all parties now need to collect evidence and to make genuine investigations into the causes of an accident if they want to be suitably compensated or not be held liable through lack of evidence.

"All parties now need to collect evidence and to make genuine investigations into the causes of an accident if they want to be suitably compensated or not be held liable through lack of evidence."

Endnotes

1. French term. The American equivalent would be "attorney-at-law."

2. http://fr.cousteau.org/technology/scaphandre — © Cousteau Society

3. i.e. France, Code du Sport, Articles L.231-2 et A.231-1/6°

4. In the original text "Faute," which covers both intentional action and negligence.

5. i.e. France, Cour de Cassation, 1st Civil Division, 09 March 1983, unpublished

6. Under Article 5 of the Civil Code, judges in France may not give "arrêts de règlement" (judgments that set a binding precedent). This means that courts cannot be bound by previous rulings. A court can rule on the basis of prior holdings, however, where there is a strong link between the principle and the resolution of the case.

7. Council Directive 30/314/EEC of 13 June 1990 on package travel, package holidays and package tours

8. France, Cour de Cassation, 1st Civil Division, 06 November 2002, Appeal 99-21203

9. Cour de Cassation — The French Cour de Cassation is France's highest appeal court, responsible for ensuring the law is properly applied. As such it does not rehear cases, but it has the power to quash decisions made by the lower courts on points of law. It is split into six divisions: three civil, one criminal, one social and one commercial.

10. France, Cour d'Appel Angers, 07 March 2006, unpublished.

11. Court of appeal (British English) / Court of appeals (American English)

12. France, Tribunal de Grande Instance, Paris, 07 June 2006

13. Council Directive 30/314/EEC of 13 June 1990 on package travel, package holidays and package tour, Art. 2

14. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:71990L0314:EN:NOT#FIELD_FR

15. Council Directive 30/314/EEC of 13 June 1990 on package travel, package holidays and package tour, Art. 5

16. Council Directive 30/314/EEC of 13 June 1990 on package travel, package holidays and package tour, Art. 5.

17. France, Cour d'Appel Angers, Formal Sitting, 07 March 2006, www.legifrance.gouv.fr

18. France, Cour de Cassation, 2nd Civil Division, 03 July 2008, Appeal 07-17150

Developing and Evaluating Interventions Using Surveillance Data

Kristen L. Kucera
Division of Occupational and Environmental Medicine
Duke University Medical Center
Durham, NC 27705 USA

Stephen W. Marshall
Department of Epidemiology
The University of North Carolina at Chapel Hill
Chapel Hill, NC 27599 USA

Epidemiological studies and surveillance systems are described, their temporal scales defined and the impact of randomization factors discussed. A nonexhaustive listing of examples of surveillance systems data sources for fatal and nonfatal injuries are provided, such as the National Collegiate Athletic Association's (NCAA) Injury Surveillance System (ISS). The case-crossover design has been used to study the transient effects of intermittent exposures on rare acute events and defines case times (the period immediately before the onset of event) and control times (the previous dives of the subjects) within the same individual. In the context of scuba diving, the cases and controls are dives, not divers. Advantages of the case-crossover design are that subjects serve as their own controls and are self-matched on individual-level confounders, and there is no need to recruit control subjects because subjects provide both case times and control times. High-quality surveillance data is important for monitoring trends and informing interventions. Analytic epidemiological studies such as pre/postdesign or case-crossover design can be "spun off" surveillance systems.

Epidemiology and Surveillance

What is epidemiology?
Epidemiology is the study of the distribution and determinants of health-related states or events in a population and the application of this study to control of health problems. Epidemiology is interested in quantifying associations between exposures or risk factors (gender, BMI, Q-angle, sport) and outcomes (ACL injury). In many cases, health outcomes — such as injuries — have multifactorial causes. Typically, however, epidemiologists focus on a subset, or even a single factor, in the long chain of events leading to an injury.

"Typically, epidemiologists focus on a subset, or even a single factor, in the long chain of events leading to an injury."

Observational studies quantify relationships and associations between factors in a "real world" — or nonrandomized — setting. Because it is hard (often impossible) to randomize the factors studied in epidemiology, control of covariates that might distort relationships ("confounders") is very important. This is in contrast to clinical trials or studies in which subjects can be randomized, and randomization protects against confounding.

Surveillance
Public health surveillance is defined as the "ongoing systematic collection, analysis and interpretation of data essential to the planning, implementation and evaluation of public health practice, closely integrated with the timely dissemination of these data to those who need to know" (Thacker, Berkelman 1988). The key words

in this definition are "ongoing," "systematic" and "timely." Surveillance systems are different from research studies. Research studies have defined start and end dates; surveillance is typically a continuous function. Research studies can take many years to produce results; surveillance systems emphasize speedy dissemination and communication. In both research and surveillance, the methods are systematic, meaning that they are standardized to yield consistent results over time.

The purpose of surveillance is to identify trends in time, place or person using mortality and morbidity data. Historically, surveillance was primarily used for disease-outbreak notification. In more recent decades, surveillance of chronic disease and predisease states (diabetes, obesity) has become prominent. Surveillance of health-risk behaviors is also important. A large federal system known as the Health Risk Behavior Survey monitors behavioral activities such as smoking and physical inactivity. There are many surveillance systems for injury currently operating in the United States. For fatal injuries, these systems typically log every death (a complete census). For nonfatal injuries, however, the numbers of events are so large that some sampling is required. A partial listing of data sources for fatal and nonfatal injury surveillance is shown in Table 1. Note that this is a listing for purposes of providing some example of these systems and is not intended to be an exhaustive list. For example, the major systems for surveillance of fatal occupational injury, the Fatality Assessment and Control Evaluation (FACE) and Census of Fatal Occupational Injury (CFOI), are not included. Also not included are data from trauma registries, poisoning centers, the Department of Justice or managed care.

"The purpose of surveillance is to identify trends in time, place or person using mortality and morbidity data."

Evaluating Interventions: Standard Pre/Postdesign

Example of a surveillance system: the NCAA ISS

A good example of a well-established surveillance system is the National Collegiate Athletic Association's (NCAA) Injury Surveillance System (ISS). The NCAA ISS was developed by the NCAA in 1982 and is a national injury data-collection tool for collegiate athletics (Dick et al. 2007). It represents the largest continuous collection of collegiate athletic injury data. The data is collected by certified athletic trainers (ATs) working in universities and colleges across the United States. The system used to involve pen and paper data collection but was converted to web-based data collection in 2004.

Currently, the system is operated by Datalys Center for Sports Injury Research and Prevention. Individual schools volunteer to provide data, and then athletic trainers in each school collect data. A recent validation study of men's and women's soccer in 15 schools found that reporting is 88 percent for injuries with more than one day of time loss.

Dissemination of information is an important component of surveillance systems. In the case of the NCAA ISS, the data are analyzed by Datalys Center for Sports Injury Research and Prevention, and reports are provided to the NCAA's Competitive Safeguards and Medical Aspects of Sports committee (an advisory committee) and from there to the relevant sport rules committees (legislative committees). In addition to informing rule changes in this manner, the surveillance system can also be used to evaluate the effect of rule changes.

Men's football: heat injury in the NCAA

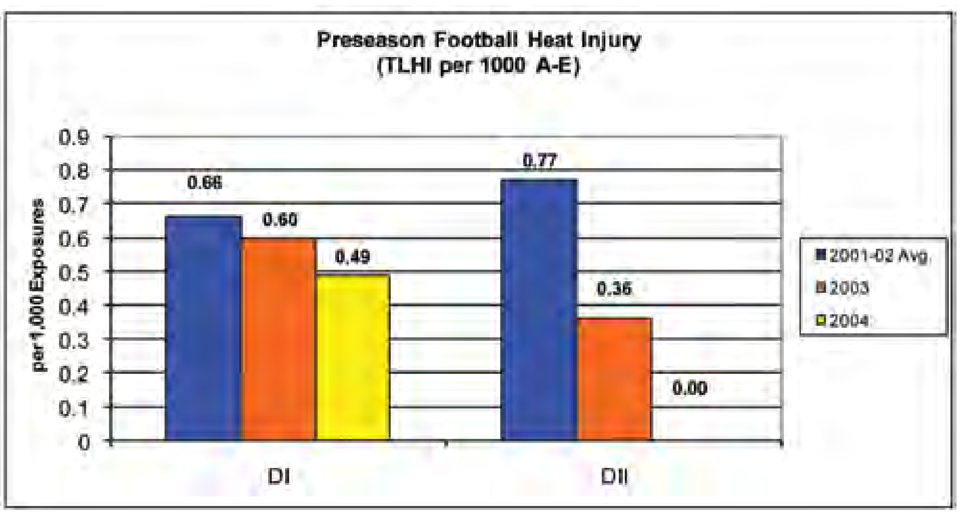
Based on analysis of the NCAA ISS data on heat injuries, the NCAA found that 95 percent of heat injury in football occurred in preseason. Furthermore, 85 percent of these events occurred wearing full pads or helmets, and 87 percent occurred on days with multiple practices. Note that only heat injuries resulting in time loss were captured by the ISS.

As a result, a Preseason Practice Policy Development Team was formed. It comprised football coaches, American Football Coaches Association (AFCA) representatives, physicians, certified athletic trainers, student-athletes, athletic directors and NCAA staff. It resulted in series of NCAA Football Preseason Practice Modifications. Beginning in 2004-05 academic year, it was required that programs have a five-day acclimatization period. During the period, there could be only one practice per day, for a maximum three hours. On Days 1 and 2, only helmets could be worn; on Days 3 and 4, helmets and shoulder pads could be worn; and on Day 5, full equipment could be worn. There were to be no consecutive multiple-session days; there had to be three hours recovery between practices, and days with multiple practices were limited to five hours per day in total.

The intervention was evaluated using the NCAA ISS data, and it had a dramatic decrease in the incidence of heat injury (Figure 1). This type of evaluation is known as a simple pre/postdesign. Injury rates following the implementation of an intervention are compared to injury rates prior to the intervention. Ideally, a control group that did not get the intervention would also be included in the analysis to control for other changes that occurred over the same period that were unrelated to the intervention. In the case of the NCAA, there is no other relevant population that could be used as control group, so the evaluation was limited to comparing postintervention rates to preintervention rates. The danger with this design is the lack of control of other temporal effects and the resulting potential bias due to temporal confounding.

"Injury rates following the implementation of an intervention are compared to injury rates prior to the intervention."

Figure 1: Rates of heat injury among collegiate football players from the NCAA's Injury Surveillance System (NCAA ISS)



Evaluating Interventions: Case-Crossover Study Design

Case-crossover design

When researchers are interested in specific study questions or targeting specific risk factors, an epidemiologic study design is chosen (prospective cohort, case control, etc.). The case-crossover design has been used to study the transient effects of intermittent exposures on rare acute events. The classic and first application of this design examined factors that trigger myocardial infarctions (Maclure 1991). A traditional case-control study compares the exposure status between

Table 1: Some Sources of Injury Surveillance Data in the United States

Target Universe	Data Source	Agency	Injury Coding	Fatal or Nonfatal?	Data Access	Design	Focus
All physician visits (ED, ambulatory, and private office)	National Ambulatory Care Surveys (NHAMCS-ED, NHAMCS-OPD, NAMCS)	CDC/NCHS	ICD-9-CM	Nonfatal	Free download: www.cdc.gov/nchs	Sample	General
ED visits	NEISS All Injury Program (NEISS-AIP)	CDC/NCIPC	ICD-9-CM	Nonfatal	User-driven table generator: www.cdc.gov/ncipc/wisqars/ Free download: www.icpsr.umich.edu	Sample	Injury
Inpatient discharges	National Hospital Discharge Survey	CDC/NCHS	ICD-9-CM	Nonfatal	Free download: www.cdc.gov/nchs/	Sample	General
Inpatient stays	National Inpatient Survey (NIS)	AHRQ HCUP	ICD-9-CM	Nonfatal	Purchase via www.ahrq.gov/data/ User-driven table generator: http://hcupnet.ahrq.gov/	Sample	General
Ambulatory visits	State Ambulatory Surgery Databases (SASD)	AHRQ HCUP	ICD-9-CM	Nonfatal	Purchase via www.ahrq.gov/data/ Currently has 23 states	Census	General
ED visits	State Emergency Department Databases (SEDD)	AHRQ HCUP	ICD-9-CM	Nonfatal	Purchase via www.ahrq.gov/data/ User-driven table generator: http://hcupnet.ahrq.gov/ Currently has 20 states	Census	General
Households	Medical Expenditure Panel Survey (MEPS)	AHRQ MEPS	ICD-9-CM	Nonfatal	Download from www.ahrq.gov/data/ User-driven table generator: www.meps.ahrq.gov/mepsweb/	Sample	General
Households	National Health Interview Survey (NHIS) Injury Supplement	CDC/NCHS	In-house (basic)	Nonfatal	Free download: www.cdc.gov/nchs/nhis.htm	Sample	Injury
Death certificates	Vital Statistics – Mortality data	CDC/NCHS	ICD-10	Fatal	Free download: www.cdc.gov/nchs/deaths.htm	Census	General
Death certificates	Vital Statistics – Mortality data	CDC/NCIPC	ICD-10	Fatal	User-driven table generator: www.cdc.gov/ncipc/wisqars/	Census	Injury
Collegiate sports injuries	Injury Surveillance System (ISS)	NCAA	In-house (detailed)	Nonfatal	www1.ncaa.org/membership/ ed_outreach/health-safety/iss/index.html Request data (no charge)	Registry	Sports injury

Table 1: Some Sources of Injury Surveillance Data in the United States (continued)

Target Universe	Data Source	Agency	Injury Coding	Fatal or Nonfatal?	Data Access	Design	Focus
Physician visits & ambulatory care in DOD personnel	Defense Medical Surveillance System (DMSS)	Army Medical Surveillance Activity (AMSA)	ICD-9-CM	Nonfatal	User-driven table generator: http://amsa.army.mil/AMSA/amsa_home.htm Table generator provides data on active duty personnel only. Can request other data.	Census (non-combat)	General military
All fatal motor vehicle crashes	Fatal Analysis Reporting System (FARS)	NHTSA	KABCO (basic)	Fatal	www.nhtsa.gov/ (click on NCSA) Free download: ftp://ftp.nhtsa.dot.gov/fars/ User-driven table generator: www-fars.nhtsa.dot.gov/	Census	Motor vehicle injury
Nonfatal motor vehicle crashes in U.S. resulting in injury	National Accident Sampling System (NASS) Crashworthiness Data Sys. (CDS)	NHTSA	In-house (detailed) Also AIS & ISS	Nonfatal	Free download: ftp://ftp.nhtsa.dot.gov/NASS/ NASS is more detailed than GES, i.e., more variables. Crashes resulting in property loss without injury are excluded.	Sample	Motor vehicle injury
Non-fatal motor vehicle crashes in U.S. resulting in injury and/or property loss	National Accident Sampling System (NASS) General Estimates System (GES)	NHTSA	KABCO (basic)	Nonfatal	Free download: ftp://ftp.nhtsa.dot.gov/GES/ GES is much less detailed than NASS, i.e. fewer variables. Crashes resulting in property loss without injury are included (this is about 50% of GES crashes).	Sample	Motor vehicle injury
Homicide, suicide and unintentional firearm	National Violent Death Reporting System (NVDRS)	CDC/NCIPC	ICD-10	Fatal	Free download: www.icpsr.umich.edu/NACJD/ More details at www.cdc.gov/ncipc/profiles/nvdrs/default.htm Currently has 16 states, plus a region in CA	Census	Injury from violence

Key:

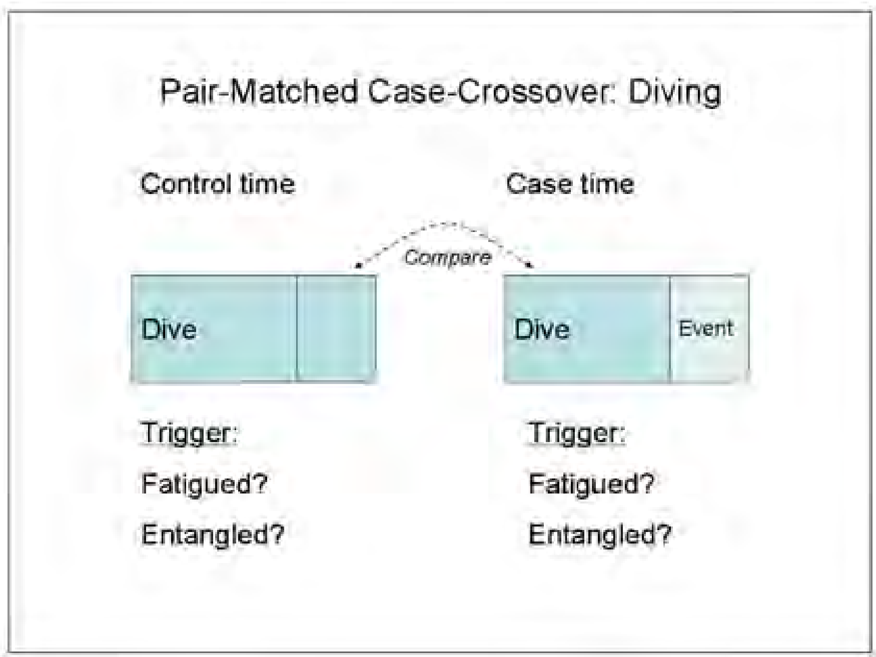
AHRQ – Agency for Healthcare Research and Quality
AIP – All Injury Program
DoD – Department of Defense
HCUP – Healthcare Cost and Utilization Project
NCAA – National Collegiate Athletic Association
NCHS – National Center for Health Statistics
NCIPC – National Center for Injury Prevent. and Control
NEISS – National Electronic Injury Surveillance System
NHAMCS – National Hospital Ambulatory Medical Care Survey
NHTSA – National Highway Traffic Safety Administration
OPD – Outpatient Dept; ED – Emergency Department

cases or individuals with the outcome of interest (heart attack patients) and controls or individuals without the outcome of interest (other patients). Case-crossover studies define case times and control times within the same individual (time when individual had a heart attack compared to a time when they did not have a heart attack). The key analytic question for case-crossover study is: How unusual is it to have the transient exposure or trigger right before the onset of event? In the heart attack example, the trigger might be physical exertion. In the current context of scuba diving, the cases and controls are dives, not divers.

In case-crossover designs the outcome or event of interest for cases may include diving deaths, "near-misses" or decompression illness (DCI). "Case times" are defined as the period immediately before the onset of the event. The potential triggers for the event may include hazardous diving conditions, diver fatigue or entanglement. Case times are compared to control times, or times when the event of interest did not occur. "Control times" may be defined as the previous dives of the subjects. For controls, we are interested in "Were conditions hazardous, or were they fatigued on previous dives?" Figure 2 provides an example of a pair-matched case-crossover design applied to diving.

"Subjects serve as their own controls and are self-matched on individual-level confounders or fixed factors like age, gender and years of experience."

Figure 2: Example of pair-matched case-crossover design applied to diving (based on Figure 1 in Muller et al. JAMA 1996, Muller et al. 1996)



Advantages of the case-crossover design

This design is widely used for injury research including cell-phone use and car crashes (Redelmeier, Tibshirani 1997) and occupational injuries (Mittleman et al. 1997; Sorock et al. 2004). There are advantages to the case-crossover design for injury research. First, subjects serve as their own controls and are self-matched on individual-level confounders or fixed factors like age, gender and years of experience. For case-crossover designs, it is often easy to find case subjects (emergency calls, DCI, diver deaths), but cases should represent a defined time/geographic population. For example, using emergency calls, cases should represent the catchment population for the emergency-call service area. The second advantage is there is no need to recruit control subjects because subjects provide both case times and control times. This design compares exposure frequency in case times to exposure frequency in control times.

Another unique advantage to this design is that self-matching automatically adjusts for all individual-level confounders — including those that are not measured. This is an appropriate study design when there are no temporal trends in exposure prevalence over time and when confounders are NOT transient exposures. It does not control for confounders that are transient exposures (time trends in diving).

Case-crossover example: hand injuries in small-scale commercial fishing
The case-crossover study design has been used to identify potential triggers for hand injuries among small-scale, independent commercial fishermen working in North Carolina (Kucera et al. 2007) . Given that 22 percent to 52 percent of all fishing-related injuries are hand injuries (Marshall et al. 2004; Norrish, Cryer 1990), a case-crossover study was conducted. The research question of interest was: Do transient risk factors influence the risk of work-related commercial-fishing hand injuries?

During weekly phone interviews, fishermen were asked about fishing work, exposures and whether they were injured. Hand injuries were defined as "accidents or events that damaged your hand, wrist, finger or thumb and required first aid at the time of injury, or medical care at some later time or time away from work." Eligible case times included interview periods in which a hand/wrist/finger injury was reported. These case times were self-matched to control times or interview periods in which a hand/wrist/finger injury was *not* reported. Potential triggers included maintenance work, glove use, using more than one gear type during the week, joint pain and location fished.

During the two-year follow up, 46 of 217 fishermen reported 65 hand injury events (cases). Injury events were not severe: 60 percent had no time off work or no external care, 22 percent had no time off but some external care, and 18 percent took time off work. Triggers for hand injury among these fishermen included performing maintenance work (OR=2.2, 95 percent CI: 0.9-5.3) and using more than one gear type (OR=2.0, 95 percent CI: 0.6-6.5). Protective factors for hand injury included glove use (OR=0.8, 95 percent CI: 0.3-2.0), joint pain (OR=0.7, 95 percent CI: 0.1-3.7) and working on the ocean (OR=0.8, 95 percent CI: 0.1-4.5).

"Defining the population at risk enables researchers to quantify risks and associations by calculating incidence proportions and rates."

Applications to Diving

Improving and utilizing diving data
One of the purposes of convening this conference was to review and improve diving data. Focus areas included the data-collection process (consistent and accurate definitions and missing data), defining the population at risk (or denominator) and quantifying diving frequency and duration. After the data has been collected, information dissemination and evaluating diving interventions are areas for further development.

Defining the population at risk enables researchers to quantify risks and associations by calculating incidence proportions and rates. This is a challenge for all epidemiology researchers, particularly in sports research. Diving is especially challenging due to the lack of a means to enumerate the population at risk. Some of the ways the population at risk has been defined in the diving literature include the number of divers via insured members (Denoble et al. 2008), population-based estimates from census surveys such as the National Sporting Goods

Association (Smith 1995) and number of dives via number of cylinder fills from dive shops (Ladd et al. 2002).

With access to a population at risk, the pre/postdesign is very useful in evaluating the effects of current practices and the implementation of new interventions. The case-crossover design would be ideal for diving research in which finding control subjects and defining the population at risk can be a challenge. Diving outcomes of interest for this design would include fatalities, "near-misses" and DCI. Case times could be obtained from a variety of sources including registries, insurance claims, surveys, emergency services call-outs (ambulance or police) and medical records. Depending on whether the event of interest resulted in a fatal or nonfatal incident, control times could be abstracted from individual dive logs or records for fatalities, obtained from records of case "near-misses" and from next of kin or the dive buddy. A particularly useful control would be the "usual frequency" of the trigger during a certain reference point (dives in the past year, past 10 dives).

Diving safety issues

When planning, implementing and evaluating interventions, diving issues could fall into four main areas: 1) training and education, 2) screening for medical conditions and other age- and sex-related risk factors, 3) supervision and equipment such as point of sale, equipment checks and maintenance, and 4) regulation such as proof of certification prior to cylinder rental. Regardless of which area researchers investigate and hope to intervene on, evaluating the intervention can be achieved through several means. Researchers may be interested in whether current practices and/or interventions work. This can be determined by analyses of existing data and looking at trends or by conducting interviews with divers, safety experts and other key informants. This information may help formulate and implement new practices and interventions. The study designs discussed above such as the pre/postevaluation and the case-crossover may help evaluate the effectiveness of these new interventions.

"The case-crossover design would be ideal for diving research in which finding control subjects and defining the population at risk can be a challenge."

Challenges to intervention success

Interventions are delivered in different countries, among different groups in different ways, and it is important to be aware of potential challenges and barriers to intervention success. In other words, intervention work is challenging for all those involved. These are just a few barriers that have been mentioned by experts within the diving industry: oversight and jurisdiction, fear of lawsuits, higher insurance rates, increased time to train divers, and recognizing risks will scare away new divers. The success of any intervention depends upon the recognition and consideration of these issues before, during and after the intervention.

Summary

In summary, high-quality surveillance data is important for monitoring trends and informing interventions. Analytic epidemiologic studies such as pre/postdesign or case-crossover design can be spun off surveillance systems. The NCAA's approach in successfully addressing heat illness in preseason football demonstrates the value of involving multiple stakeholders throughout the process. Note that the case-crossover study may be particularly useful for diving research when the population at risk is not available.

Acknowledgements
Thanks to Randy Dick for background information on many aspects on the NCAA ISS, including the details of the heat-injury intervention program and permission to reproduce Figure 1.

References
Denoble P, Pollock N, Vaithiyanathan P, Caruso J, Dovenbarger J, Vann R. Scuba injury death rate among insured DAN members. *Diving Hyperb Med* 38: 182-188; 2008.

Dick R, Agel J, Marshall S. National Collegiate Athletic Association Injury Surveillance System Commentaries: Introduction and Methods. *J Athletic Trg* 42: 173-182; 2007.

Kucera K, Loomis D, Marshall S. Case-crossover study of triggers for hand injuries in commercial fishing. *Occup Environm Med* 65: 336-341; 2007.

Ladd G, Stepan V, Stevens L. The Abacus Project: establishing the risk of recreational scuba death and decompression illness. *SPUMS J* 32: 124-128; 2002.

Maclure M. The case-crossover design: a method for studying transient effects on the risk of acute events. *Am J Epidem* 133: 144-153; 1991.

Marshall S, Kucera K, Loomis D, McDonald M, Lipscomb H. Work-related injuries in small scale commercial fishing. *Injury Prev* 10: 217-221; 2004.

Mittleman M, Maldonado G, Gerberich S, Smith G, Sorock G. Alternative approaches to analytical designs in occupational injury epidemiology. *Am J Ind Med* 32: 129-141; 1997.

Muller J, Mittleman M, Maclure M, Sherwood J, Tofler G. Determinants of Myocardial Infarction Onset Study I. 1996. Triggering myocardial infarction by sexual activity: low absolute risk and prevention by regular physical exertion. *JAMA* 275: 1405-1409; 1996.

Norrish A, Cryer P. Work-related injury in New Zealand commercial fishermen. *Br J Ind Med* 47: 726-732; 1990.

Redelmeier D, Tibshirani R. Association between cellular-telephone calls and motor vehicle collisions. [comment]. *NE J Med* 336: 453-458; 1997.

Smith N. Scuba diving: how high the risk? *J Insur Med* 27: 15-24; 1995.

Sorock G, Lombardi D, Peng D, Hauser R, Eisen E, Herrick R, Mittleman M. Glove use and the relative risk of acute hand injury: a case-crossover study. *J Occup Environ Hyg* 1: 182-190; 2004.

Thacker S, Berkelman R. Public health surveillance in the United States. *Epid Rev* 10: 164-190; 1988.

Discussion

KEN KURTIS: I'll be the shill for this one, too. Given the paucity of information in the dive industry, the relatively low numbers that we deal with statistically, the fact we generally do not know the denominators, we may or may not know the numerators, how do we get anything that is even remotely reliably accurate?

DR. KRISTEN KUCERA: Yes, that is the question. If I knew the answer to that, I think I could write a book. That is a good question. Steve, do you have any thoughts?

DR. STEPHEN MARSHALL: Variable data quality exists everywhere. Now you guys might feel you are challenged, but everyone pretty much feels that way. You usually look for the gold. If we are underground, go for the gold. I usually try to audit data quality, try to find the best quality data. That is not your finishing point. That is your starting point. Then you can start to build something off of the people or the region that has more quality data. Now sometimes there is good quality data in insurance claims, but in my experience usually not. Usually the best quality data comes from medical or some sort of clinical service profession. They are also the people most interested in prevention and data sharing. So a good group of clinicians is usually where you can start. With your industry, with diving it is so diverse and so geographically spread out, it is a challenge. You can get groups of a lot of people reporting things consistently, that starts to establish your piece of gold. Then you can kind of create data standards and build from that. But constantly monitoring and auditing data quality is something that we do. It is really important to keep. You cannot ever stop doing that.

KUCERA: Nothing is going to ever be perfect. It is going to have some weaknesses and limitations. Recognizing those, can we still act? Can we still move forward with something? I think that is always something to think about.

DR. JAKE FREIBERGER: It is really very informative, especially for someone like me who is interested in putting together studies like this. Are you able to use retrospective data that goes back for a number of years? What are the limitations on using a study like this? The second question is what level of evidence does this correspond to? Is it similar to case-control study?

KUCERA: It is considered to be observational, so it definitely would go along the lines of a case control. If it is nested within a cohort study, that's better — that is how we are supposed to do case control and case crossover. That moves it up a little bit. But the first question was about retrospective data.

FREIBERGER: How far back can you go?

KUCERA: I think if you are looking at existing records and the records are pretty detailed, I would imagine you can go back pretty far. If you are going to use next of kin or buddies or individuals, then you are going to have that memory decay.

MARSHALL: Seems to me the world changes every 10 years completely. I do not usually go any further than 10 years.

STEVE BARSKY: We have a lot of incidents that occur in diving that are never reported, a lot of near misses. The divemaster goes in, throws somebody back in the boat. The diver did not need to be resuscitated but needed to be rescued. Somebody gets trapped underwater, and somebody cuts them out. Would it be possible or feasible for Divers Alert Network to have a self-reporting system on their website for people to report these near misses and collect data that way?

MARSHALL: I think the near misses are really important to get. Traditionally, in occupational injury surveillance, they have always tried to get near misses. The idea of analysis of near misses is they are very close to bad, fatal events, except for somebody got lucky; they were close to the boat, someone else was there with a knife. The trick is usually to get complete data on them. I think diving is one of those things where if it is bad, it is very bad, and if it is not very bad, then it does not get reported.

DR. NEAL POLLOCK: This is in response to Steve. We have been planning to do the near-miss reporting. We actually have a capture system set up for freediving incidents. It is true in fatal incidents we can never get complete case data. So we want to get the near misses so we can get a more complete story. We have that ready to go. It probably should be up for freediving within the next few months. Then we plan to expand to compressed-gas diving, technical diving, etc.

Annual Fatality Rates and Associated Risk Factors for Recreational Scuba Diving

Petar J. Denoble
Alessandro Marroni
Richard D. Vann
Divers Alert Network
6 West Colony Place
Durham, NC 27705

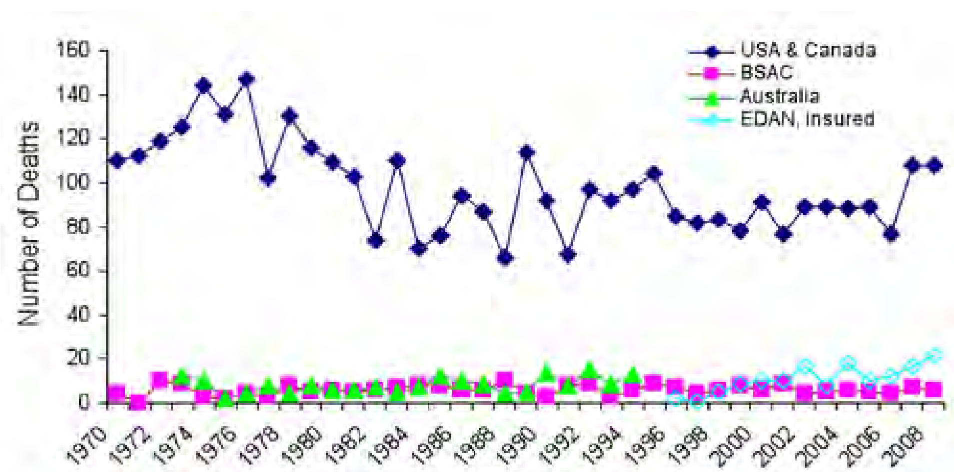
This paper assesses factors that affect the risks of dying while diving, discusses possible preventive interventions, reviews measures of recreational diving fatality rates, and explores fatality rates and safety criteria from other fields. Fatality rates vary according to estimation methods, demographics, and diving practices. The annual fatality rate (AFR) of 16.4 per 100,000 insured Divers Alert Network (DAN) members was similar to the rate recorded by the British Sub-Aqua Club (BSAC) but may be higher than the rate in the general scuba population. The most common causes of scuba fatalities were gas supply problems, emergency ascent, and cardiac events. The effects of age and gender were particularly striking.

Introduction

Scuba diving is a recreational activity with known inherent hazards that sometimes cause injuries and death. The number of deaths among recreational scuba divers has been monitored systematically by active surveillance systems for the last 40 years in several subpopulations around the world. The most complete data are available from Divers Alert Network (DAN) for the United States and Canada (Pollock 2008), the British Sub Aquatic Club (BSAC) for a subset of British divers (Cumming 2006), DAN Asia-Pacific (Lippmann 2008) and DAN Europe. Combined data are shown in Figure 1.

"The most common causes of scuba fatalities were gas supply problems, emergency ascent, and cardiac events."

Figure 1: Annual number of scuba deaths by four scuba organizations



The number of dive-related fatalities in these subpopulations varies with their size. The largest numbers have been reported for the United States/Canada (10-year average of 80 deaths per year), which has the largest estimated population of recreational divers (Monaghan 1988).

"Safety usually means that the risks are judged acceptable in the context of the expected benefits."

Scuba fatalities in the U.S. are estimated at 0.02 percent of all U.S. annual injury deaths and less than 2 percent of U.S. deaths due to drowning (Injury Facts 2004). The participation in scuba diving was estimated at about 0.5-1.0 percent of the U.S. population (National Sporting Goods Association; U.S. Census 2000). Using these estimates and DAN fatality records, the death rate among U.S. divers may be estimated at 3-6 per 100,000, with an unknown error of estimation.

The purpose of this paper is to assess factors that affect the risks of dying while diving, discuss possible preventive interventions, review measures of recreational diving fatality rates and explore fatality rates and safety criteria from other fields. The paper is based on a review of the dive safety literature, fatality data from DAN Europe and DAN America, and the general safety literature. DAN data include:

- DAN America insured member claims for 2000, involving 187 dive-related deaths (Denoble, Pollock et al. 2008)
- DAN Europe insured member claims for 1996-2008, involving 144 dive-related deaths
- DAN America fatality and injury databases for 1992-2003, including:
  - — Most common risk factors in 947 cases resulting from open-circuit (OC) diving (Denoble, Caruso et al. 2008)
  - — A case-control study of 165 fatal and 135 nonfatal arterial gas embolism (AGE) incidents (Denoble, Vann et al. 2005)
  - — A study of fatalities involving diabetes mellitus (DM), including 37 DM cases and 938 non-DM cases (Denoble, Pollock et al. 2006)

Safety Performance in Scuba Diving

Safety has been defined as a "freedom from those conditions that can cause death, injury, occupational illness or damage to, or loss of, equipment or property, or damage to environment (Military Standard 1993). Absolute safety, however, does not exist in any activity of life. Indeed, individual and societal progress is based on a willingness to take risk. Thus, safety usually means that the risks are judged acceptable in the context of the expected benefits.

Safety in engineering and public policy is measured by the annual number of deaths per million (DPM) in a specified group. The measure used in injury epidemiology is the annual fatality rate (AFR) or the number of deaths per 100,000 people exposed per year. The individual risk index (Individual Risk per Annum, or IRPA) is used by the UK Health and Safety Executive (HSE). The IRPA is the probability that an average person dies in one year as a result of that hazard and is calculated by dividing observed number of fatalities by the total number of subjects-years exposed (HSE 2001). All three measures assume the populations in question are permanently exposed to the hazards of interest.

For hazards to which people are exposed only part time (e.g., occupational, traffic, sport, recreation), risk calculation must use a denominator that includes both the number of participants and the time they have been exposed. For discrete exposures such as diving, the denominator may be the number of dives or the hours diving. However, these measures are difficult to come by and may need adjustment for the effects of depth or equipment.

A Survey of Recreational Scuba Diving Related Fatalities

BSAC, DAN Europe and DAN America are membership organizations that can provide denominators for calculating fatality rates. DAN America has about 200,000 members in the United States and Canada, and the number of fatalities among these members represents 20-40 percent of the total number of annual fatalities over the past 10 years. Because an unknown number of DAN members may not be divers and the DAN surveillance system may miss some deaths, fatality rates were based on members with dive accident insurance (who are more likely to be active divers) and the number of death claims submitted for this group (Denoble, Pollock et al. 2008).

During 2000-2006, there were 187 death claims among 1,131,367 insured member years for which the mean AFR was 16.4 deaths per 100,000 divers with a range of 14.2-19.0 over the period (Denoble, Caruso et al. 2008). Table 1 lists similar rates per diver as ordered by AFR.

Table 1: Scuba injury death rates

Group	Denominator	Time period	Rate (95%CI)	
			AFR (Per 100,000 divers)	Per 100,000 dives
USA, DEMA study (Monaghan 1989)	Estimated	1986	3.4 to 4.2	
Finland (Sipinen 1990)	Measured	1986, 1987	62 (7 – 117) (1 in 1,600)	
USA (National Safety Council 2004)	Estimated	1989	16.7	0.8 to 1.6
Australia (Lippmann 2008)	Estimated	1989	34 (1 in 3000)	1.7 to 3.4
Ontario, Canada (Heinicke 2008)	Survey	1986-1995	12.7	
Victoria, Australia (Lippmann 2008)	Tank fill count	1992-1996		2.5
Orkney, Scotland (Trevett et al. 2001)	Measured	1999-2000		3 - 6
BC, Canada (Ladd et al. 2002)	Tank fill count	1999-2000		2.04
Australia (Lippmann et al. 2008)	Survey	2000-2006	3.57 (1 in 28,000)	0.57
Japan (Ikeda and Ashida 2000)	Tank fill count		(8.8-33.8)	1.0 to 2.4
BSAC (Cumming 2006)	Measured	2000-2006	14.4 (10.5-19.7)	0.45*
DAN America Insured (Denoble, Caruso et al. 2008)	Measured	2000-2006	16.4 (14.2-19.0) (1 in 6000)	0.7**
DAN Europe Insured (unpublished)	Measured	1995-2008	71(59-82) (1 in 1400)	

* Average number of dives per member estimated by survey: 32 (Cumming 2006)
** Average number of dives per member estimated by survey: 25 (Dear 2000)

"There is no obvious explanation for why insured DAN and BSAC members would have several times higher AFRs than non-DAN and non-BSAC members."

AFRs based on estimated denominators (3.4-34 deaths per 100,000 divers) vary widely, while those of BSAC and DAN, which are based on known denominators, are much closer (14.4 and 16.4, respectively) and have overlapping 95 percent confidence limits (10.5-19.7). These discrepancies may result from errors in the estimated number of divers in the population as well as from differences in subpopulation risk regarding age, training, frequency of participation, type of activities and local dive conditions. However, there is no obvious explanation for why insured DAN and BSAC members would have several times higher AFRs than non-DAN and non-BSAC members. DAN Europe members, with 200,000 insured years and 141 fatalities in 13 years, had the highest mean rate, 71, and a wide range, 25-103. A high average rate (62.5) was also recorded in Finland for

1986-1987 among 8,000 divers. In the following years, however, the rates were less than 30 per 100,000 dives (Sipinen 1990).

Both DAN Europe and DAN America insurance may be more attractive to people who dive more frequently or aggressively than the rest of the recreational diver population. DAN Europe membership represents a smaller fraction of European scuba divers than DAN America membership and thus may deviate more from the population of divers in their area.

Fatality rates calculated per exposure vary from 0.57 per 100,000 dives in Australia to 4 (range 3-6) per 100,000 dives in Orkney, Scotland (Trevett 2001). While local diving conditions may be suspected for these differences, one must keep in mind that denominators for these two studies have been estimated using different methods and thus may not be equally reliable.

Benchmark Comparison with Recreational and Professional Activities

Table 2 shows AFRs and IRPAs for various recreational and professional activities. Comparisons of fatality rates between such activities are useful as indicators of gross safety but must be made with careful recognition that the exposures differ.

Overall death rates during recreational diving, motor vehicle accidents and jogging were similar. Deaths during occupational exposures were often an order of magnitude lower.

"Overall death rates during recreational diving, motor vehicle accidents and jogging were similar."

Table 2: Individual risk per annum
Data from "Reducing risks, protecting people" (HSE 2001)

Sector	IRPA	Annual risk per 1,000,000 participants
Recreational diving (Denoble et al. 2008a)	1 in 6,000	163
Motor vehicle (National Safety Council 2004)	1 in 6,493	154
Jogging	1 in 7,700	130
Mining and quarrying	1 in 9,200	109
Construction	1 in 17,000	59
Agriculture, hunting	1 in 17,200	58
Manufacturing industry	1 in 77,000	13
Unintended drowning (National Safety Council 2004)	1 in 83,000	12
Fatalities to employees	1 in 125,000	8
Service industry	1 in 333,000	3
High school football (24-year average) (Mueller and Cantu 2008)	1 in 345,000	3

Are the Current Scuba Death Rates Acceptable?

There is no absolute or objective definition of acceptable death rate. Acceptability is hazard-specific and depends on the type of activity and mode of participation (voluntary/recreational, for wage, involuntary). Risks are perceived in multi-attribute terms, and a single measure such as a low AFR may not necessarily be acceptable (Bottelberghs 2000).

High-risk activities have mortality rates comparable to mortality rates of natural diseases of 10^{-2} deaths/person-year or 1 percent, while low-risk activities are comparable to natural hazards (e.g., earthquakes or tornadoes) with a mortality rate of 10^{-6} deaths/person-year (0.0001 percent). Activities with a fatality risk greater than 10^{-3} deaths/person-year (0.1 percent) are generally not acceptable to the public. Risks less than 10^{-6} (0.0001 percent) may be considered negligible (HSE 2001; Trbojevic 2010; Vrijlinga).

HSE has proposed a more flexible, if subjective, definition of acceptable fatality rate: "as low as reasonably practicable" (ALARP; HSE 2001). ALARP takes into account estimated risk, assessment of sacrifice to avoid risk (i.e., cost, time, trouble) and benefits derived from those sacrifices (i.e., fatalities avoided). By European standards in scuba injury death rates of 163 per 1,000,000 persons (0.0163 percent) are not negligible, and most divers would probably agree that continuous effort to achieve lower rates would be desirable.

Most Common Causes

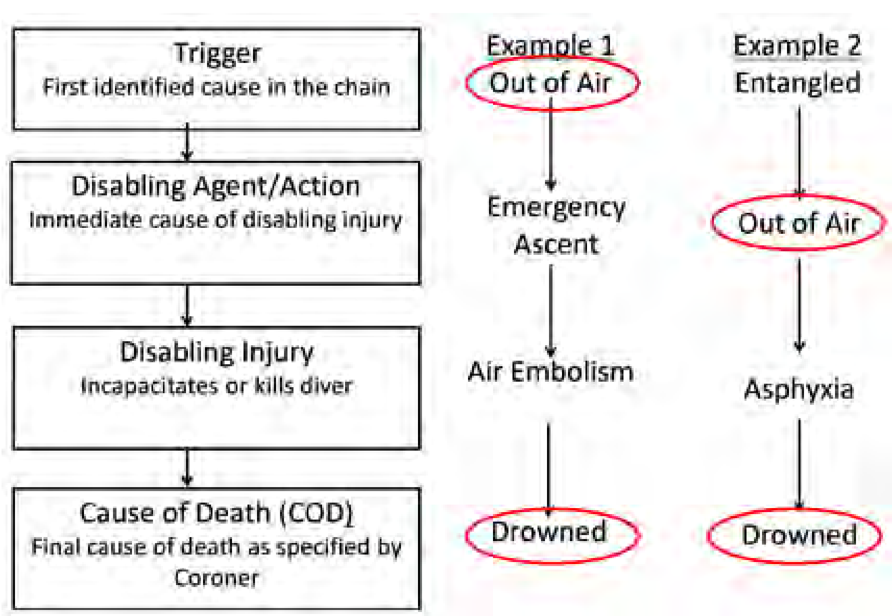
Each diving accident is worth investigating as it may provide lessons on how to avoid future accidents. Investigation should begin as soon as possible and be as thorough as possible. Nonetheless, some investigations will be incomplete as in the case of an individual who disappears while diving alone and is never recovered.

To assist the diving community in judging actions that might be reasonable and practical for reducing diving deaths, we reviewed factors most often associated with deaths in the multiyear fatality databases of DAN Europe and DAN America (Denoble, Pollock et al. 2008).

"Each diving accident is worth investigating as it may provide lessons on how to avoid future accidents."

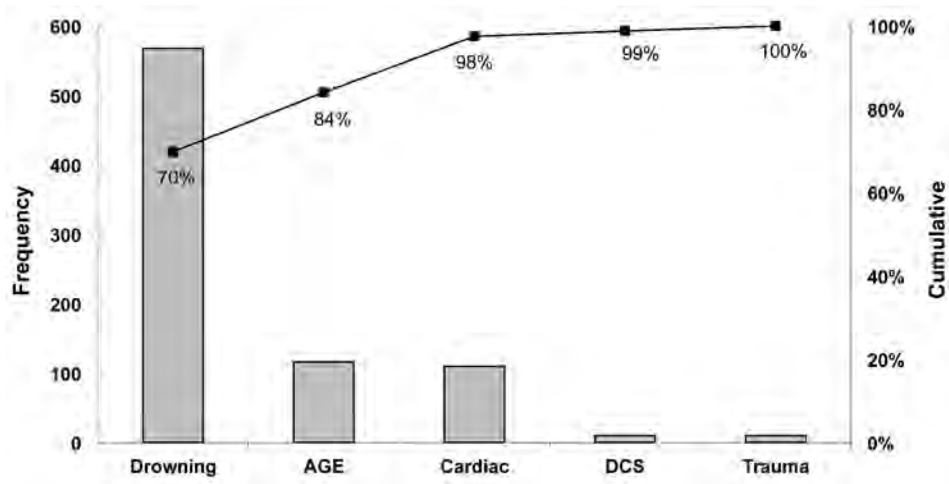
Accidents generally occur as a chain of events having multiple root causes, where a root cause is a specific underlying event that can be reasonably identified and for which guidelines may be proposed to prevent recurrences (Rooney et al. 2004). Removing just one root cause may break the chain and prevent a death. To assist the investigation of root causes, we defined four key events in the sequence of root causes (Figure 2). Two examples in Figure 2 indicate how a given root cause can appear in a different location in the sequence.

Figure 2: Modified root cause analysis (Denoble, Caruso et al. 2008)



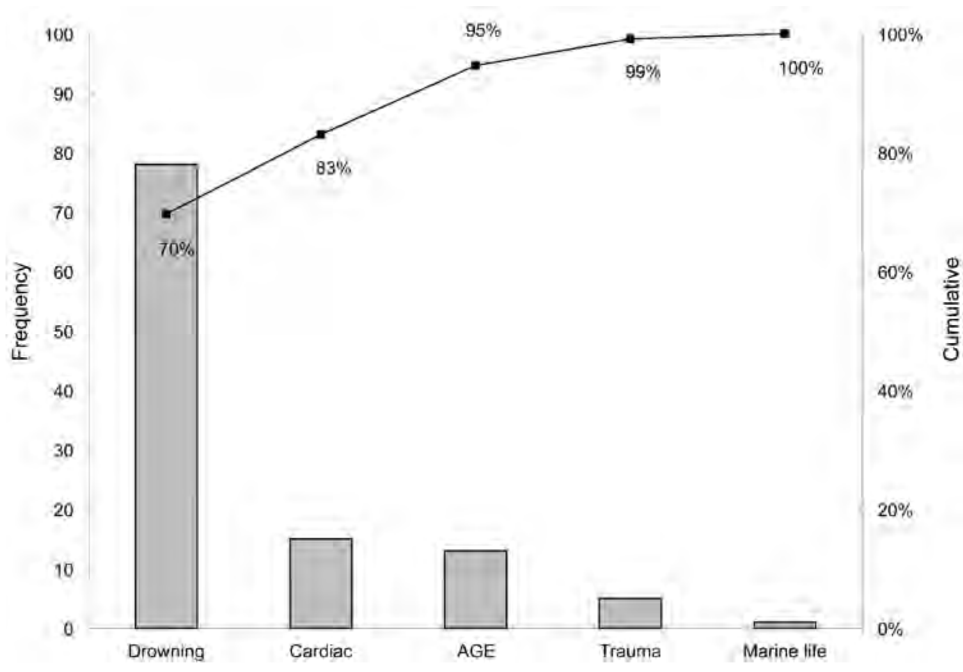
A retrospective analysis of 965 cases in the DAN fatality database for 1992-2003 found the distribution of causes of death (COD) shown in Figure 3 as reported by medical examiners (Denoble, Pollock et al. 2008). Figure 4 shows the COD distribution for DAN Europe data. The distributions were similar, although the populations were independent. As with many diving accidents, drowning was the most common COD, but COD rarely reveals factors that might be targeted for risk mitigation.

Figure 3: Cause of death in 814 DAN America scuba fatalities (not previously published)



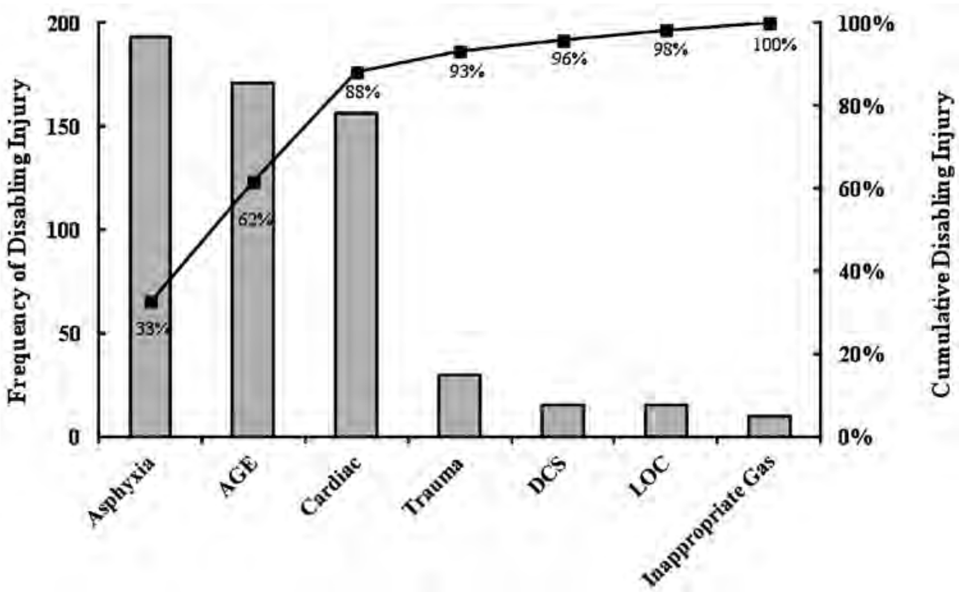
"AGE was often reported by medical examiners as a contributing factor in cases classified as drowning, but when disabling injuries rather than COD were examined, AGE was found to be involved in many fatalities with drowning as the COD."

Figure 4: Cause of death in 112 DAN Europe scuba fatalities (not previously published)



AGE was often reported by medical examiners as a contributing factor in cases classified as drowning, but when disabling injuries (Figure 5) rather than COD (Figure 3) were examined, AGE was found to be involved in many fatalities with drowning as the COD. Not unexpectedly, most AGE cases were associated with emergency ascent (odds ratio (OR)>30).

Figure 5: Disabling injuries in 590 DAN America scuba fatalities (Denoble, Caruso et al. 2008)



Cardiac events were also more common than indicated by COD (Figure 4). Most cardiac cases were associated with a pre-existing cardiac condition (OR>30) and age greater than 40 (OR=6). In 60 percent of cardiac cases, the divers noted dyspnea, fatigue, distress, chest pain or felt ill before diving but decided to dive anyway.

The Pareto principle holds that most undesirable events are associated with only a few causes (Busino 1987), which we observed to be true for diving fatalities. For example, gas-supply problems (41 percent), entrapment/entanglement (19 percent) and equipment troubles (16 percent) made up 76 percent of the triggers. Emergency ascent (60 percent), insufficient breathing gas (20 percent) and buoyancy problems (14 percent) made up 94 percent of all disabling agents (Denoble, Pollock et al. 2008).

"The Pareto principle holds that most undesirable events are associated with only a few causes, which we observed to be true for diving fatalities."

In a review of the most frequently identified root causes, there were 389 cases with complications of pre-existing diseases, 293 cases with buoyancy problems, 289 with emergency ascent, 217 with rough water, 199 with gas-supply problems, 109 with equipment problems and 75 with entrapment/entanglement. The number of root causes for a particular case varied from none to many, but some may have been missed due to insufficient information.

Gas-supply problems resulted mainly from inappropriate gas management. Most of the time, the trigger appeared at depth, and the diver drowned or suffered an AGE during emergency ascent. However, in some cases a diver surfaced with an exhausted gas supply and drowned due to inability to maintain buoyancy or breathe from a protected source of gas in rough seas.

Age, Sex and Cardiac Events in Diving Fatalities

The association of age, sex and cardiac events with diving fatalities was investigated among DAN members who had purchased dive accident insurance during 2000-2006 (Denoble, Caruso et al. 2008). There were 187 deaths in 1,141,367 member years.

Figure 6 indicates that the percentage of cardiac-related fatalities was 5 percent or less until age group 35-39 and increased until reaching a plateau of 30 percent in age group 50-54 and above. Divers older than 49 had a relative risk (RR) of a disabling cardiac injury 12.9-times greater than younger divers. Increased relative risks between older and younger divers were also found for AGE (RR=3.9) and asphyxia (RR=2.5).

Figure 6: Percentage of cardiac-related disabling injury among fatalities of various age groups (unpublished DAN fatality data)

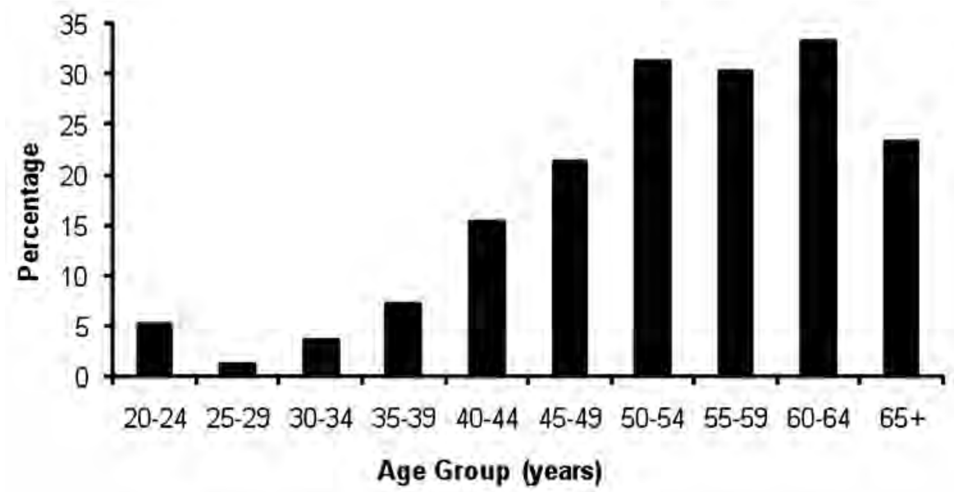
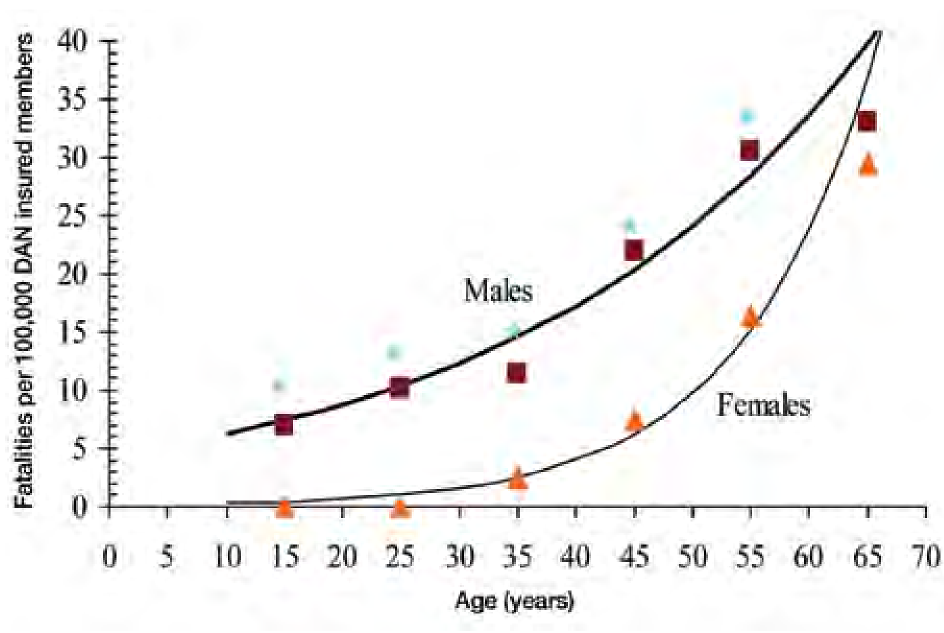


Figure 7 shows that the annual fatality rates were 10 per 100,000 divers for divers up to age 25 and nearly 35 per 100,000 divers at age 65. The rate for males was greater than for females by 10 per 100,000 divers up to age 65, after which the rates were essentially the same for both sexes. Relative risk between males and females decreased from 6 at age 25 to 1 at age 65.

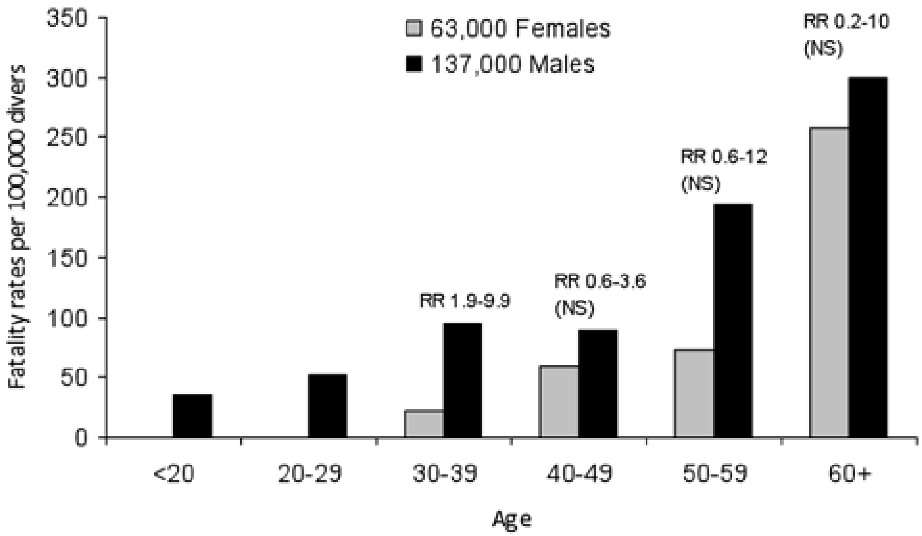
"The annual fatality rates were 10 per 100,000 divers for divers up to age 25 and nearly 35 per 100,000 divers at age 65."

Figure 7: Gender- and age-specific fatality accident rates (Denoble, Pollock et al. 2008, with permission)



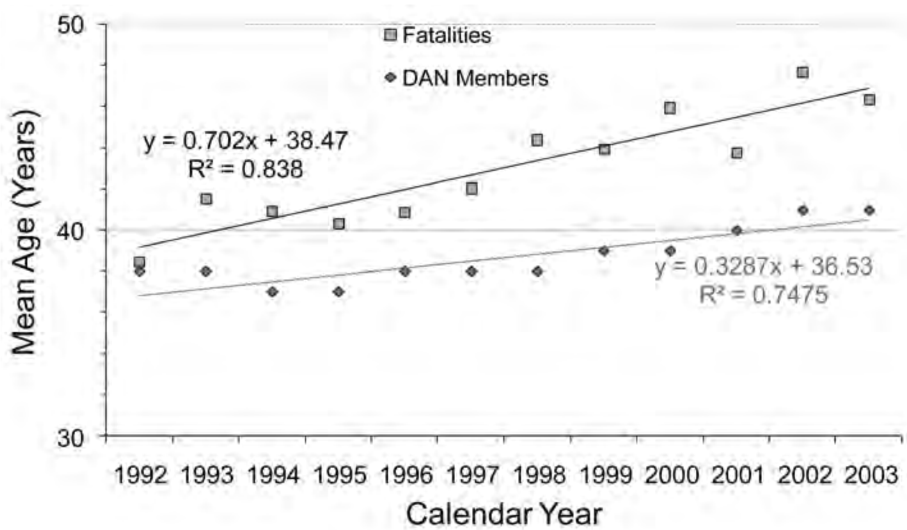
Similar trends with age and sex were observed for cases with cardiac events in the DAN Europe data but with higher rates (Figure 8). Up to age group 30-39, relative risks of fatalities were greater for males. For older age groups, risks were similar for both sexes.

Figure 8: Fatality rates and relative risk of death for males and females in DAN Europe insured members, by age group, for 1996-2008



The mean ages of DAN America members and all fatalities from 1992-2003 are shown in Figure 9. The mean age of members increased by one year in every four years, while the mean age of fatalities increased by two years in every four years. Fatalities were about two years older than members in 1992 and five years older in 2003 as a result of greater fatality rates for older divers.

Figure 9: Mean ages of DAN members and DAN member fatalities



"Fatal AGE was associated with divers in their first year of certification, and greatest risk occurred on the first dive of the day."

Risk Factors for Fatal AGE Compared with Nonfatal AGE

A case-control study based on DAN injury and fatality data used fatal AGE as cases and nonfatal AGE as controls (Denoble, Vann et al. 2005). Fatal AGE was associated with divers in their first year of certification, and greatest risk occurred on the first dive of the day. AGE risk appeared to decrease with experience. Other risk factors for fatal AGE included rapid ascent, running out of gas, buoyancy problems, obesity, age, use of helium and maximum dive depth. The odds of surviving AGE were greater for divers with a normal BMI.

A study in Belgium found 100–400 times increased risk of pulmonary barotrauma (PBT) during training dives, while emergency free-ascent training was associated with 500–1,500 times greater risk. These findings prompted Belgian sport diver federations to ban free-ascent training in 2006, after which there have been no further PBT cases related to training (Lafére et al. 2009).

Diabetes and Scuba Fatalities

A case-control study compared fatal accidents involving 37 divers with diabetes mellitus (DM) (cases) with 938 fatalities (controls) who were DM-free (Denoble et al. 2006). Cardiac events were associated with 40.5 percent of the DM cases and 15.9 percent of non-DM controls ($p<0.001$). Unexplained loss of consciousness occurred in 10.8 percent of DM cases and 1.3 percent of non-DM controls ($p<0.001$). These observations suggest the hypotheses that divers with DM may be at greater risk of (a) death due to chronic cardiac disease and (b) unexplained loss of consciousness. Further investigation is required to test these hypotheses as the number of fatalities with DM was small.

Conclusions

For insured DAN members, the individual risk of dying while diving was 1 in 6,000 per annum, which is equivalent to an annual fatality rate of 16.7 per 100,000 divers. Compared with published recommendations, these rates are not negligible and argue for measures that might reduce their incidence to "as low as reasonably practicable." An active surveillance system is essential to monitor success.

"The most common root causes were gas-supply problems, emergency ascent, cardiac health issues, entrapment/entanglement and buoyancy trouble."

The most common disabling injuries associated with death were asphyxia, AGE and acute cardiac-related events. The most common root causes were gas-supply problems, emergency ascent, cardiac health issues, entrapment/entanglement and buoyancy trouble.

The risk of death while diving increased with age, starting in the early 30s. This is likely due to the naturally increased prevalence of cardiac disease with age, but an increased association of AGE and asphyxia were also associated with aging.

Possible interventions to reduce fatality rates include:

1. Providing opportunities to maintain diving skills after initial training;
2. Raising awareness of the need to maintain a healthy lifestyle and control cardiovascular risk factors; and
3. Adopting dive practices appropriate for age, health and physical fitness.

References

Bottelberghs PH. Risk analysis and safety policy developments in the Netherlands. *J Hazard Mat* 71: 59-84; 2000.

Busino G and Pareto V. *The New Palgrave: A Dictionary of Economics*, Vol. 3. New York: Macmillan, pp. 799-804; 1987.

Cumming B. BSAC NDC diving incidents report. [serial on the Internet]. Date: Available from: http://www.bsac.org/page/805/incident-report-2006.htm; 2006.

Dear G deL, Uguccioni DM, Dovenbarger JA, Thalmann ED, Hanson E and Cudahy EA. Estimated DCI incidence in a select group of recreational divers. UHMS Annual Meeting abstract: http://archive.rubicon-foundation.org/782; 2000.

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

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

Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA and Vann RD. Scuba injury death rate among insured DAN members. *Diving Hyperb Med* 38: 122-128; 2008.

Denoble PJ, Vann RD, Pollock NW, Uguccioni DM, Freiberger JJ and Pieper CF. A case-control study of decompression sickness (DCS) and arterial gas embolism (AGE). *Undersea Hyperb Med* 32(4): 302-303; 2005.

Heinicke S. Scuba Diving. In: Tator CH, ed. *Catastrophic injuries in sports and recreation. Causes and prevention – A Canadian study.* Toronto: University of Toronto Press, pp. 180-191; 2008.

HSE. Reducing risk, protecting people: HSE's decision-making process. HSE Books, 2001. ISBN 0 7176 2151 0.

HSE. Policy and guidance on reducing risks as low as reasonably practicable in design. 2003. http://www.hse.gov.uk/risk/theory/alarp3.htm

Ikeda T and Ashida H. Is recreational diving safe? *Undersea Hyperb Med* 27 (suppl): 138; 2000.

National Safety Council. Injury Facts. Itasca, Il: National Safety Council, 2004.

Ladd G, Stepan V and Stevens L. The Abacus Project: establishing the risk of recreational scuba death and decompression illness. *SPUMS J* 32(3): 124-128; 2002.

Lafère P, Germonpré P and Balestra C. Pulmonary barotrauma in divers during emergency free ascent training: Review of 124 Cases. *Aviat Space Environ Med* 80: 371-375; 2009.

Lippmann J. Review of scuba diving fatalities and decompression illness in Australia. *Diving Hyperb Med* 38: 71-78; 2008.

Monaghan R. The risks of sport diving: just how many divers are there? *SPUMS J* 18(2): 53-60; 1988.

Monaghan R. Australian diving death rates comparisons with USA and Japan. *SPUMS J* 19(1): 25; 1989.

Mueller FO and Cantu RC. Catastrophic sports injury research: Twenty-sixth annual report, Fall 1982–Spring 2008.

National Sporting Goods Association, Mt. Prospect, Ill., Sports Participation in (year), annual: Series I and Series II (copyright); http://www.nsga.org/

Pollock NW, ed. *Annual Diving Report 2008 Edition*. Durham, NC: Divers Alert Network.

Rooney J and Van den Heuvel L. Root cause analysis for beginners. *Quality Progress*, July 2004, pp.45-53.

Sipinen SA. Analysis of fatal diving accidents in Finland 1987–1988. *Undersea Biomed Res* 16(1): Supplement; 1990.

Trbojevic VM. Risk criteria in EU. www.risk-support.co.uk/B26P2-Trbojevic-final.pdf. Accessed August 2010.

Trevett AJ, Forbes R, Rae CK, Sheehan C, Ross J, Watt SJ and Stephenson R. Diving Accidents in Sports Divers in Orkney waters. *Scot Med J* 46:176-177; 2001.

U.S. Census 2000. Participation in selected sports activities statistics. http://www.allcountries.org/uscensus/435_participation_in_selected_sports_activities.html

U.S. Department of Defense. Military standard. System safety program requirements. MIL-STD-882C, 19 January 1993. Downloaded from http://www.everyspec.com on 2010-04-20 T15:04:50.

Vrijlinga JK, van Geldera P and Ouwerkerke SJ. Criteria for acceptable risk in the Netherlands. Netherlands: Delft University of Technology, http://www.safedriver.gr/studies/KINDYNOS/Criteria%20for%20acceptable%20risk%20in%20the%20Netherlands.pdf

Discussion

CAROL CHRISTINI: I am with Insurance Management Service. I do insurance for the diving industry. I have a question about the statistics. I know that as an industry we need to focus on if we can prevent one death, we should be doing something, and I am all for that. And I know we have to start somewhere with the data. But my concern is that the data may be a little bit skewed because it only reflects DAN members. There may be a lot of divers out there who are not DAN members. I wonder if that factor has been taken into consideration in these statistics. And if not, do you think that without that consideration that the statistics are skewed?

DR. PETAR DENOBLE: That is a very valid question. One way to answer that was to assemble these professionals here and bring data from various sources. That was our main reason to get people together here and present four different sources of data and then discuss what you just said, definitely why these dive groups have different fatality rates. You cannot expect that — we know, for example, that for decompression illness that it is only 1 in 10,000 dives if you dive in Caribbean from a very nice liveaboard. If you go somewhere in the cold water and do wreck diving, your incidence rate might be 20 in 10,000 dives. Probably that's the same for mortality rates, but DAN data are similar to BSAC data. There may be some differences with Australia or some other regions, and I hope we will discuss it more extensively today here.

STEVEN HEWITT: Could I ask you to go back to the last slide? Under the conclusion that the risk of death while diving increases with age, have you looked at other recreational activities involving physical exertion to see if there is a corresponding risk of death while participating in them?

DENOBLE: Yes, indeed, but, you know, I did not want bring here excuses for us to stop thinking about this. If we compare our curve of fatality rates by age with rate of myocardial infarction by age in the United States population, they pretty much coincide. But this may be deceiving. I am not saying that age is a factor in fatalities. Age is just associated, and factors are something that comes with age. Age is sort of a marker here for potential diseases and things like that.

KEN KURTIS: But I have a preface to a question and a follow-up. The preface is, as you said earlier, for me personally, it is impossible to get good data out of the dive industry. When you compare data from year and data from year, there is no way the two things can be correct. Early on you had an estimate when you were converting from accidents per diver to accidents per dive. You had an asterisk at the bottom, which was estimated at 25 dives per year. I am just wondering where the 25 came from, and I probably have a follow-up question from that.

DENOBLE: The 25 came from a survey conducted years before, and it was presented by Dr. Guy Dear at UHMS. That is the best we could get to, and other things were well matched. So this is here. This was estimated based on 25 dives. They had like 50, 55 dives per year, and he will talk about that. Also there are some other rates that are not there, like you would see from PADI. I put this number in red because it is just an estimate, unlike this 16.4 fatality per 100,000 divers, which was based on a real denominator, not an estimate.

KURTIS: The follow-up actually sort of answers Carol's suggestions. I would say I would rather have accurate slightly skewed data than what we do with them. But would it be practical — 200,000 members who every year have to renew — would it be practical to make as part of renewal process, a required field of how many dives did you make last year, and if you wanted certification and level? All of a sudden this data we cannot get you would at least have within this group some reliable data.

DENOBLE: May I first tell you that maybe we do not need 200,000 members to answer that question. We can do smaller survey. One has just been launched to about 2,000 members inquiring not only about number of dives, number of injuries, about health status, current health conditions, health practices, access group to health providers and all the diving practices.

UNIDENTIFIED SPEAKER: One of the problems with that is the validity of the data, and not that divers would lie or somehow skew the truth, but the problem would be that we were not sure we would be able to verify the data.

KURTIS: I agree with that. The more questions you ask, the less likely you would get answers. But I would also suggest that even self-reported, maybe inaccurate, data is better than the wild guesses that we do right now, which is essentially what we do as an industry.

UNIDENTIFIED SPEAKER: One of our partners in DAN Europe does ask some of those questions, so they do have some of the data.

GORDON BOIVIN: I am a field guy. I have no idea what you are talking about. What can I do to help? I have heard the phrase “root cause pathway” mentioned by you, lawyers, Mr. Barsky. So obviously somewhere along the line when I am interviewing, when I am collecting data in the field, I should be looking at things that relate to triggers, disabling factors, harmful agents. While I am not making an opinion about what those are, but should I be making an effort to identify them?

DENOBLE: Triggers, disabling agent were judgments. While you are first responder there, you should get all the facts about an accident as you can. Maybe Steve Barsky can answer better than me. But if you ask why, why, why, at the end you will practically capture all important data. You will capture all root causes. And, no, if you can put that, have a time scale and kind of diagram, that is fine but not necessary. If you provide just all related factors that you have discovered, later it can be judged how it can be classified.

STEVEN BARSKY: I am looking around the room, and I am noticing lots of gray hair and balding going on here. Maybe I missed something here. But we have this nice, neat chart that shows the number of accidents going down. But I think we also — maybe I did not see it, maybe you said it in a different way that I did not understand — did you ever really compare it to what the population estimates are of divers, let’s say populations estimates from NSGA, which is about the only one that we really have?

DENOBLE: We did not extrapolate this to general diving population. We presented only data pertaining to insured DAN members.

BARSKY: I am just curious whether we are seeing fewer accidents because we are seeing fewer divers and less diving activity?

DENOBLE: Not necessarily. Most divers are ages 30 to 50, and you will get kind of a medium center of around 45. So it is not that most of the divers out there are 70 or 80 years old, but they appear to be definitely more affected; their fatality rate is higher than in 20 years old.

KARL SHREEVES: More of a comment for you, Ken, and also for Dr. Denoble some questions. I think it should be on the record that the term “wild guesses” in our lack of data probably overstates the position. I have been watching these presentations all day, and I haven’t seen a wild guess yet. I’ve seen your reasonable speculations and models and estimates based on the need to fill where we do not have information. Dr. Denoble’s information is not skewed. I think it is the least skewed we’ve seen so far. He has presented very hard numbers. Where we have to be cautious is if we take these and try to apply it to all diving populations, then it may be skewed. So just for some clarity, we need more information absolutely, but let’s not go so far the other way and pretend we are groping in the dark. It is more like we have a smaller flashlight than we would like.

KURTIS: I was referring to when we talk outside this room, not in here.

DENOBLE: This is a very valid comment, and thank you for bringing it up. We did not assume that this represents the entire diving community. This is strictly insured DAN members.

Diving Deaths Down Under

John Lippmann
Divers Alert Network (DAN) Asia-Pacific
PO Box 384 (49A Karnak Rd)
Ashburton VIC 3147 Australia

Combined diving fatality data starting in 1972 (N=351) are reviewed from Project Stickybeak and DAN Asia-Pacific. Equipment problems, breathing-gas management, rough water, anxiety and exertion were common triggers to fatal dive accidents in this series. The predominant (44 percent) disabling injury was asphyxia from the inhalation of water. The high incidence of cerebral air gas embolism (CAGE) and pulmonary barotrauma (PBT) as disabling injuries could be reduced by better monitoring of breathing gas, careful selection of the suitability of dive sites to reduce diver stress and careful attention to training and practice in ascent technique. The increasing incidence of cardiac-related disabling injuries could be reduced by better education of divers and doctors about the inherent, and potentially substantial, cardiac stressors associated with diving.

Introduction

The publication of diving fatality reporting began in Australia in 1972 with the introduction of Project Stickybeak by Dr. Douglas Walker, a general practitioner with an interest in dive medicine. Since then, Project Stickybeak reports have been regularly published in the *Journal of the South Pacific Underwater Medicine Society* (SPUMS), now as *Diving and Hyperbaric Medicine*, a joint journal of SPUMS and the European Underwater and Baromedical Society.

"It is difficult to collect good data for a variety of reasons, including remoteness, poor communication and, in some places, certain cultural issues."

In 2005, DAN Asia-Pacific (DAN AP) began incorporating all of the Project Stickybeak data into a DAN dive fatality database, along with the relatively scant data on dive-related deaths throughout other parts of the Asia-Pacific region. DAN Asia-Pacific has since launched its Dive Fatality Data Collection and Reporting Project, which incorporates Project Stickybeak. The first detailed joint reports were based on diving accidents in Australia in 2003 (Walker et al. 2009) and 2004 (Walker and Lippmann 2009). In addition, DAN Asia-Pacific regularly publishes summaries of regional diving fatalities in its Asia-Pacific editions of *Alert Diver*.

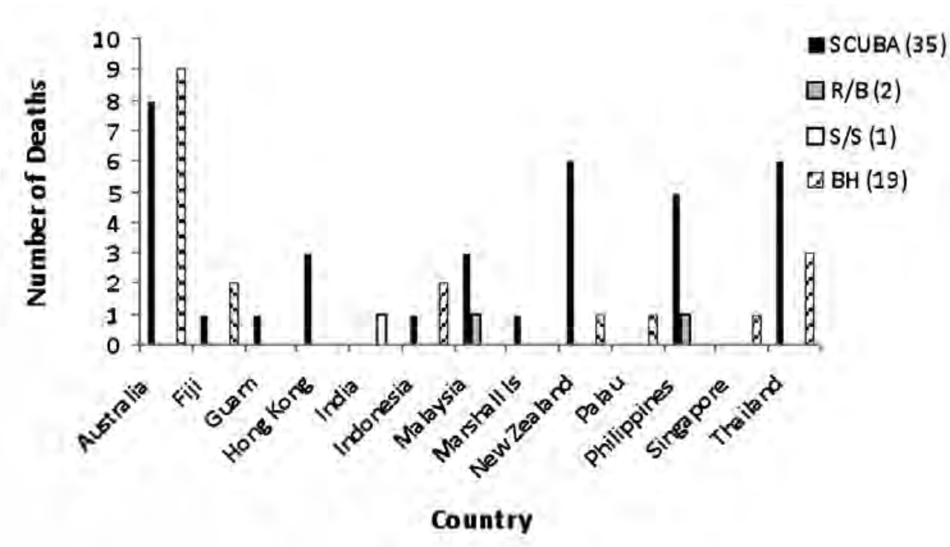
DAN Asia-Pacific has also published a series of combined reports on Australian diving deaths from 1972-1993, 1994-1998 and 1999-2002, which were previously published as individual annual reports in the SPUMS journal (Walker 1998, 2002, 2009). These combined reports include basic analyses of the data for the relevant periods.

Diving Fatality Data

Figure 1 shows a comparison of the provisional 2009 fatality numbers for the Asia-Pacific region. We believe that the numbers for Australia, New Zealand and Singapore are reasonably accurate. However, we have little confidence in the accuracy of the data from other countries and suspect that there would have been substantially more deaths in some of these places. It is difficult to collect good data for a variety of reasons, including remoteness, poor communication and, in some places, certain cultural issues. In addition, in some places there is a real reluctance to provide information due to the perception that news of a diving death(s) there could affect dive tourism to those areas. We have tried to gain the support of the international diver training agencies in our data-gathering efforts by notifying us when they hear of a death, but unfortunately this has been largely in vain.

In Australia, DAN Asia-Pacific has gained access to information on diving-related deaths recorded in the National Coronial Information System (NCIS) and was required to obtain various ethics approvals to do so. We also sought and obtained ethics approval to access information from various state coronial offices, something that is becoming increasingly difficult in this age of privacy protection. Not surprisingly, these approvals come with certain restrictions on how the data is used.

Figure 1: 2009 (provisional) Asia-Pacific dive-related deaths



Our first stage of data collection occurs as soon as we hear about a dive accident. At this time we try to obtain at least some basic information about what occurred so we can open a file. Sometimes we are able to speak to witnesses and at times are required to provide some counseling to rescuers, buddies or family. Once the investigation has progressed to completion through the coronial system, we seek access to coroners' report, police reports, witness statements, medical records and autopsy reports, where available. The existence and depth of these reports can vary greatly, depending on a variety of factors.

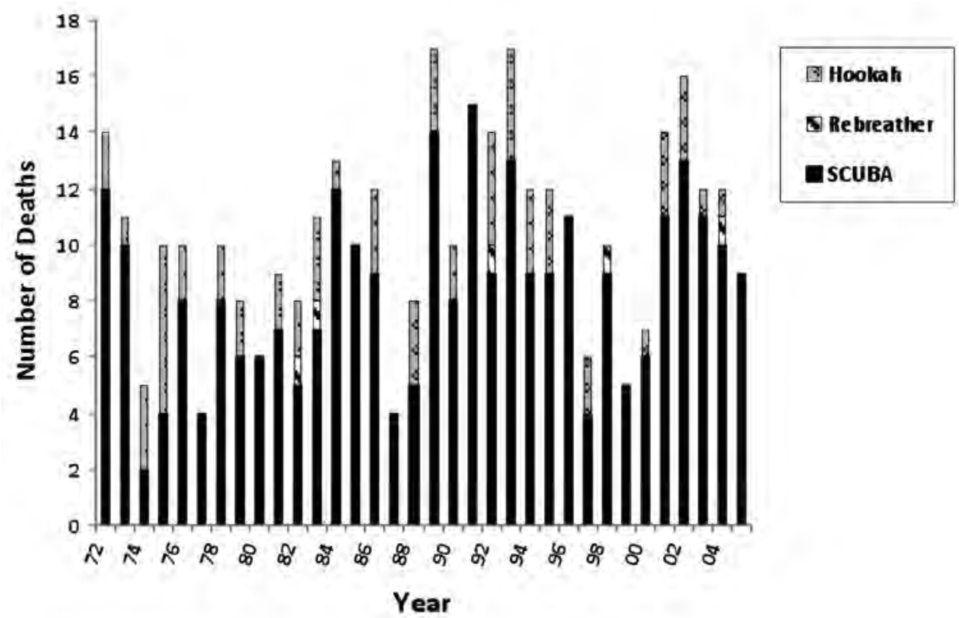
"In many other countries in the Asia-Pacific region, pathologists are generally unaware of the special autopsy requirements, and death is routinely given as drowning, with the occasional cardiac cause and, rarely, arterial gas embolism."

In Australia, the knowledge of the various pathologists of the special requirements for autopsies of diving accident victims is improving, largely as a result of the better dissemination of relevant information (Anon. 2008). However, CT scans, if conducted, are often delayed by more than eight hours and are therefore less useful in trying to differentiate gas from an embolism versus that from postmortem decompression and decomposition. In many other countries in the Asia-Pacific region, pathologists are generally unaware of the special autopsy requirements, and death is routinely given as drowning, with the occasional cardiac cause and, rarely, arterial gas embolism.

From 1972 to 2005, we have records of 351 deaths in divers who were breathing compressed gas underwater. These cases included 288 scuba divers (including five using rebreathers), 62 divers using surface supply and one with unknown breathing apparatus.

Figure 2 shows the distribution of these deaths over the years. One can see from Figure 2 that there appears to have been an increase in these fatalities since the earlier years of reporting, although the pattern is rather erratic.

Figure 2: Compressed gas deaths, 1972-2005



“Data from Australian government sport participation surveys from 2005 and 2006 indicate that at that time an estimated 80,000 Australian residents went scuba diving regularly and participated in almost 1 million annual dives.”

Table 1 (Lippmann 2008) shows the average annual fatality rate for various decades, or parts thereof, from which we have data. Although there has been an increase in the annual average of compressed-gas deaths over the decades, this was not significant (p = 0.12).

Diving Activity in Australia

There are approximately 50,000 new scuba divers trained in Australia annually, a number that appears to have remained relatively stable for the past 20 years (Esguerra et al. 1989; Wilks 1993).

Table 1: Average fatalities per year per period, 1972-2006

Years	All Modes	Scuba
1972-79	12.6	6.8
1980-89	12.8	7.9
1990-99	18.4	9.2
2000-6	23	9.1

Data from Australian government sport participation surveys from 2005 and 2006 indicate that at that time an estimated 80,000 Australian residents went scuba diving regularly and participated in almost 1 million annual dives (Australian Sports Commission 2005, 2006). In addition to this, in 2006-2007 an estimated 200,000 foreign visitors went scuba diving in Queensland (mostly on the Great Barrier Reef), conducting an estimated 1.2 million dives (Queensland Government 2007). Although the participation data needs to be interpreted with caution due to the small sample sizes, some are consistent with earlier surveys and provide the best available denominators to date.

Using the above data and the Australian fatality statistics from the DAN Asia-Pacific database, various estimates of the fatality rate for scuba diving can be calculated, as shown in Table 2.

Table 2: Scuba fatality rate in Australia, 2002-2006 (Lippmann 2008, 2009)

Australian residents	Overseas visitors
0.7 / 100,000 dives (95% CI = 0.3, 1.5)	0.4 /100,000 dives (95% CI = 0.1, 1.2)
8.5 /100,000 divers (95% CI = 4.2, 17.5)	1.5 /100,000 divers (95% CI = 0.5, 4.3)

Sequential Analysis

A sequential analysis was conducted of all compressed-gas diving fatalities that occurred between 1972 and 2005 as recorded in the DAN Asia-Pacific database. The 351 cases involved 283 on scuba, 62 on surface-supplied breathing apparatus (SSBA), five on rebreather and one unknown. Each incident was examined to determine the trigger, disabling agent, disabling injury and cause of death, as described previously (Denoble et al. 2008).

Triggers

The triggers identified were classified as related to equipment, gas supply, rough water, anxiety/stress, exertion, other and unknown. A breakdown within some of these categories is shown in Table 3. The incidence of the various groups of triggers is shown in Table 4. There was a fairly even distribution of accidents thought to be triggered by equipment, gas supply and rough water, while anxiety and exertion were thought to play an important role in a substantial number of events. It is not surprising that the mean age was higher with exertion-related triggers. It is interesting to note the increased representation of females with the anxiety-related triggers.

"There was a fairly even distribution of accidents thought to be triggered by equipment, gas supply and rough water, while anxiety and exertion were thought to play an important role in a substantial number of events."

Table 3: Triggers

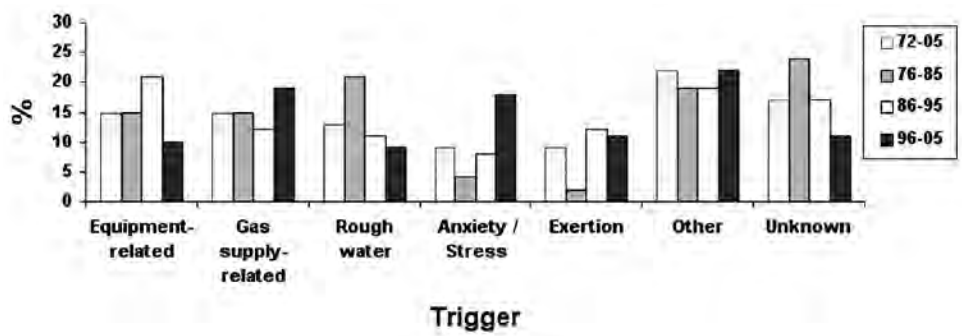
Equipment-related	Gas supply-related
BCD (e.g. sticky inflator) Hose entanglement Broken fin/mask strap Drysuit blowup Weight belt detachment Tank slippage	Out of gas Inappropriate gas Gas contamination Gas supply interruption
Rough water	**Other**
Surface conditions Current Surge Suction	Hit by boat Silting Spearfishing / fish collecting Vomiting Water in snorkel Suicidal intentions

Figure 3 shows the occurrence of the various trigger groups over the entire period and individually for three decades to try to highlight any apparent trends. Over the last decade there appears to have been a reduction in equipment-related triggers. If this is so, one could suggest that it may be due in part from improvements in equipment and/or better understanding and/or maintenance of equipment. There was an apparent rise in gas-supply-related and anxiety/stress-related triggers in the last decade shown.

Table 4: Relative occurrence (%) of triggers (n = 351)

Trigger	Occurrence %	Male	Female	Mean Age
Equipment-related	15	92	8	33
Gas supply-related	15	82	18	35
Rough water	13	80	20	36
Anxiety / stress	9	62	38	38
Exertion	9	91	9	47
Other	22	87	13	33
Unknown	17	90	10	36

Figure 3: Comparison (percent) of triggers over various periods



"Problems with gas supply were thought to have been the disabling agent in almost one-quarter of incidents and ascent issues in almost 20 percent."

Disabling Agents

The disabling agents identified were classified as gas-supply-related, cardiovascular disease, ascent-related, buoyancy-related and other, as shown in Table 5. The incidence of the various groups of disabling agents is shown in Table 6. Problems with gas supply were thought to have been the disabling agent in almost one-quarter of incidents and ascent issues in almost 20 percent. Of note, cardiovascular disease was believed to be the disabling agent in 14 percent of cases. Older divers and males were highly represented with cardiovascular disease (CVD) and other medical conditions.

Table 5: Disabling agents

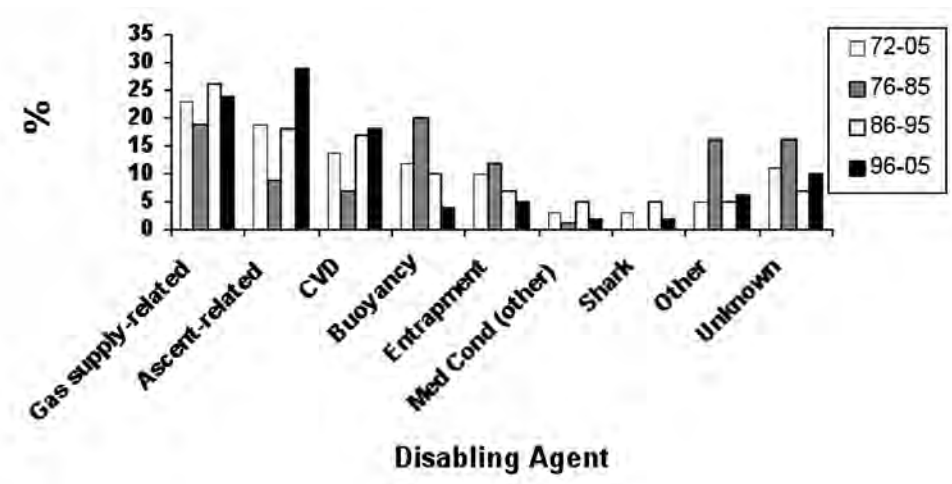
Gas supply-related Out of gas Inappropriate gas Gas contamination Gas supply interruption	**Cardiovascular disease** Older recruits to diving Aging divers Unfit divers	**Ascent-related** Rapid ascent Breath-holding on ascent Gas sharing on ascent
Buoyancy-related Lack/loss of buoyancy on surface Inadequate buoyancy control underwater (- or +)	**Other** Blow to head Propeller Vomiting underwater Hypothermia	**Other** (cont) Crocodile attack Inadequate decompression Laryngospasm Narcosis / CO_2

Table 6: Relative occurrence (percent) of disabling agents (n = 351)

Disabling Agent	Occurrence %	Male	Female	Mean Age
Gas supply-related	23	85	15	33
Ascent-related	19	80	20	36
CVD	14	92	8	50
Buoyancy	11	75	25	31
Entrapment	9	88	12	30
Other medical condition	3	100	0	44
Shark	3	90	10	30
Other	5	87	13	34
Unknown	11	84	16	36

Figure 4 shows the occurrence of the various groups of disabling agents over the entire period and individually for three decades. There was a consistent rise in ascent-related disabling agents over the decades reported and a consistent fall in buoyancy-related problems. It is interesting to note the apparent rise in cardio-vascular disease as a disabling agent from the initial decade of reporting. This apparent increase could be due to the participation of older divers and/or better reporting of the accidents.

Figure 4: Comparison (percent) of disabling agents over various periods



"There was a consistent rise in ascent-related disabling agents over the decades reported and a consistent fall in buoyancy-related problems."

Disabling Injuries

The disabling injuries identified were:

- Asphyxia
- Cerebral arterial gas embolism/pulmonary barotrauma (CAGE / PBT)
- Cardiac
- Trauma
- Decompression sickness (DCS)
- Other: stroke, gastrointestinal hemorrhage, head injury

The incidence of the various groups of disabling injuries is shown in Table 7. The predominant disabling injury (44 percent) was asphyxia from the inhalation of water while diving, which is unsurprising given the nature of the activity. CAGE/PBT was thought to have contributed to almost one-quarter of the deaths, and there was thought to be cardiac involvement in 16 percent of cases over the 33 years studied.

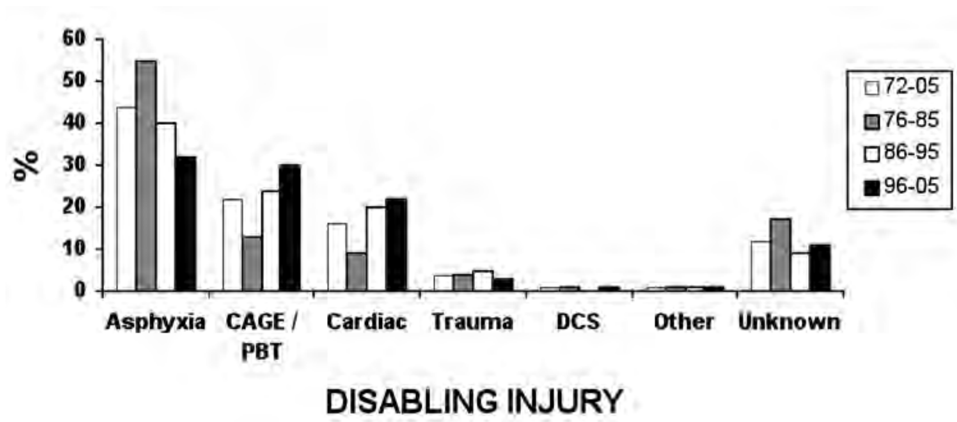
Table 7: Relative occurrence (percent) of disabling injuries (n = 351)

Disabling Injury	Occurrence %	Male	Female	Mean Age
Asphyxia	44	82	18	31
CAGE / PBT	22	84	16	36
Cardiac	16	91	9	48
Trauma	4	93	7	31
DCS	1	100	0	35
Other	2	100	0	47
Unknown	11	80	20	34

Figure 5 shows the occurrence of the various disabling injuries over the entire period and individually for three decades. There has been a steady decrease in asphyxia as a disabling injury. This has been accompanied by an increase in the number of divers who were thought to have suffered from CAGE/PBT or cardiac-related disabling injuries. The trends are unsurprising as, with the emerging greater awareness of the factors involved in diving deaths, pathologists and researchers are more inclined to look for factors other than drowning to explain the accident scenario.

"The trends are unsurprising as, with the emerging greater awareness of the factors involved in diving deaths, pathologists and researchers are more inclined to look for factors other than drowning to explain the accident scenario."

Figure 5: Comparison (percent) of disabling injuries over various periods



Cause of Death

The causes of deaths identified were:

- Drowning
- CAGE/PBT
- Cardiac
- DCS
- Trauma
- Other

The incidence of the various causes of deaths is shown in Table 8. The predominant cause of death was listed as drowning, which was reported to have occurred in half of the cases. This was followed by CAGE/PBT (19 percent) and cardiac-related causes (14 percent). Comparing Tables 7 and 8, it is apparent that there are differences in the relative frequency of certain disabling injuries and causes of death. It is thought that disabling injury is likely to be a better indicator for the assessment of diving accidents. Some of the deaths reported to have occurred from drowning are likely to have arisen from cardiac events or CAGE/PBT, which caused the divers to become unconscious and drown.

Table 8: Relative occurrence (percent) of various causes of death

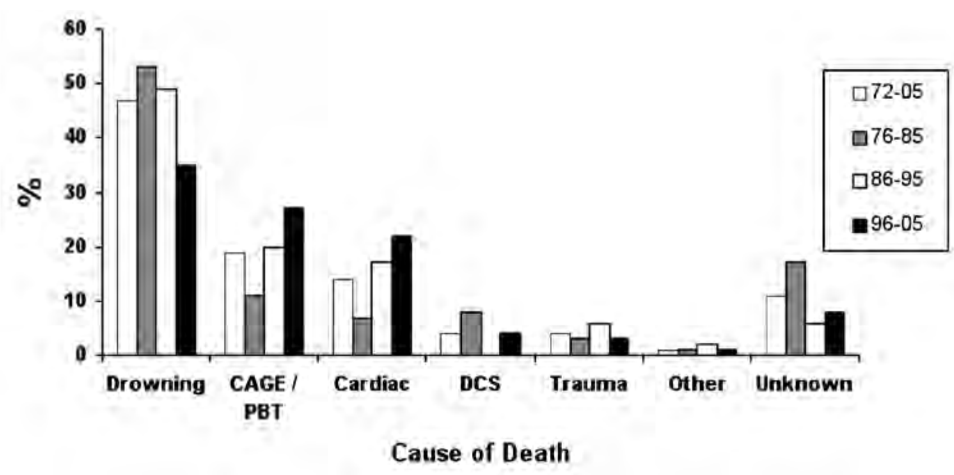
Cause of Death	Occurrence %
Drowning	50
CAGE / PBT	19
Cardiac	14
Trauma	4
DCS	1
Other	1
Unknown	11

Cardiac Causes of Diving Fatalities

As seen from Figure 6, there was been a steady increase in cardiac-related diving deaths over the three decades studied, from 7 percent in the first decade to 22 percent in the last. In 2003, 44 percent (4/9) of deaths were thought to have been cardiac-related; 31 percent (4/13) in 2004; and 20 percent (2/10) in 2005; giving an average of 34 percent over these final three years of the last decade reviewed.

"Some of the deaths reported to have occurred from drowning are likely to have arisen from cardiac events or CAGE/PBT, which caused the divers to become unconscious and drown."

Figure 6: Comparison (percent) of causes of death over various periods



Other Trends

A variety of other information was identified from the fatality reports, including the experience of the victims, weights management, BCD management, the remaining gas found in their supply, dive purpose, buddy situation, the depth at which the accident occurred, and the gender and age of the victim.

Experience

Unfortunately, the fatality reports from which these data were taken did not use an objective measure to record the experience of the victim. Instead, the statement of their level of experience was based on statements by the buddy or family (Walker, pers. comm.) This makes the determination of experience highly subjective and difficult to compare, except for those who had no experience. Seventeen percent of victims in this study died on their first dive, either under instruction, alone or with a friend (Table 9).

Table 9: Reported diving experience

Experience	Occurrence %
Experienced	44
Inexperienced	37
None	16
Unknown	3

Weights Management

Almost three-quarters of the victims were found with the weights in place as shown in Table 10. This highlights an ongoing problem of divers being reluctant, or unable, to ditch their weights when they get into trouble. It is likely that, on many occasions, by the time divers recognize the need to ditch their weights, they are too incapacitated to do so.

Table 10: Weights management (percent)

Weights	Occurrence %
On	73
Off	10
Buddy ditched	5
Tangled	1
None	1
Not applicable	1
Not stated	1

"Although ditching one's weights is not appropriate in certain circumstances, if a diver is in danger of losing consciousness underwater it is important that they gain positive buoyancy so that they rise to the surface and can be found more easily."

Although ditching one's weights is not appropriate in certain circumstances, if a diver is in danger of losing consciousness underwater it is important that they gain positive buoyancy so that they rise to the surface and can be found more easily. One way to achieve this is to ditch weights. Dive training courses should devote more training time to this important factor to imbed the skill, and divers need to remain cognizant of the importance of gaining positive buoyancy in an emergency.

BCD Management

As can be seen in Table 11, over the entire reporting period almost one-third of the divers who died were not wearing a BCD, although this figure dropped to 10 percent over the final decade as BCDs became standard fare. However, it is interesting to note that 36 percent of the victims failed to inflate their BCD. This figure rose over the last two decades and is probably a function of the increased wearing of BCDs.

Table 11: BCD management (percent)

BCD	Occurrence %
Not inflated	36
Not worn	32
Inflated	9
Part inflated	6
Faulty	4
Buddy inflated	3
Not applicable	1
Not stated	9

Inflating the BCD is an important first step for a diver in trouble to gain some positive buoyancy, although this is obviously impossible underwater if the gas supply is depleted.

Remaining Breathing Gas

Table 12 indicates that a third of the victims had sufficient remaining gas to make a safe ascent. Fifteen percent were low on gas, and one-quarter had depleted their gas supply. Some of these events were a result of entrapment, narcosis, equipment failure, poor planning and others from inattention and/or inexperience. Many of these situations could have been avoided by adequate equipment maintenance, better dive planning, especially with regard to gas management, and better attention to gas monitoring.

Table 12: Remaining gas (percent)

Remaining Gas	Occurrence %
Adequate	33
None	25
Low	15
Not stated	10
Not applicable	17

Purpose of Dive

Most of the divers (56 percent) were diving for recreation. A disturbing 8 percent of victims died during dive training (Table 13).

"Although diving with a buddy does not guarantee that assistance will be at hand, the presence of a buddy will usually increase the likelihood of help when required and reduce the time to rescue and first aid management."

Table 13: Purpose of the dive (percent)

Dive purpose	Occurrence %
Recreation	54
Collect seafood	16
Work	13
Training	8
Cave	4
Resort	2
Military	1
Other	2

Buddy Status

Although diving with a buddy does not guarantee that assistance will be at hand, the presence of a buddy will usually increase the likelihood of help when required and reduce the time to rescue and first aid management. This is important to reduce mortality and morbidity. Sixty-five percent of the victims were alone at the time of their accident, while an additional 17 percent separated from their buddy during the accident (Table 14).

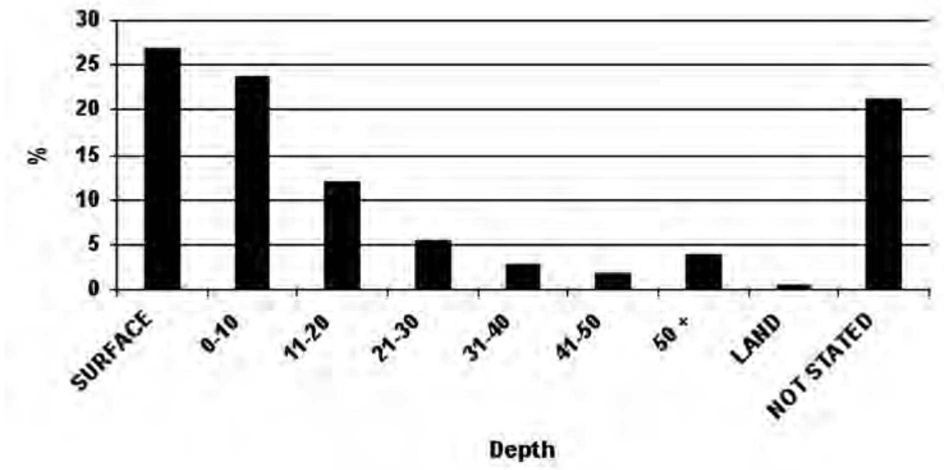
Table 14: Buddy status (percent)

Buddy Status	Occurrence %
Separated before	49
With buddy	18
Separated during	17
Solo	16

Depth

From Figure 7 one can see that more than half of the victims appear to have gotten into trouble within the first 10 meters, 27 percent of them at the surface.

Figure 7: Depth of accident (percent)



Gender

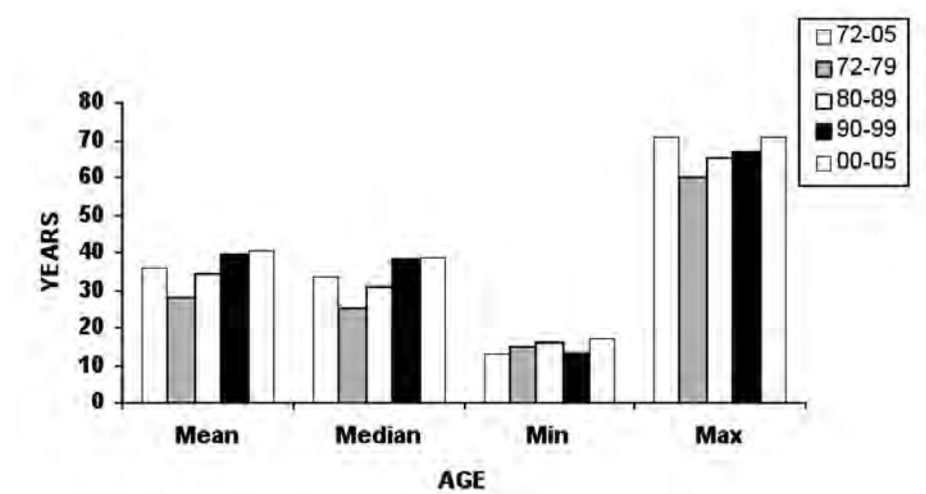
Over the entire reporting period 88 percent of the victims were males and 12 percent females. However, over the three decades studied, the percentage of female victims increased from 6 percent to 19 percent, reflecting a greater participation of females in the activity. PADI certification data for 2002-2008 indicate that females comprise an average of 33 percent of certifications during that period.

"Over the three decades studied, the percentage of female victims increased from 6 percent to 19 percent, reflecting a greater participation of females in the activity."

Age

The mean age of victims over the entire period was 35.8 years (median 34). The mean age for the decades, or parts thereof, steadily increased from 27.9 to 40.6 years (median 25-39) (Figure 8).

Figure 8: Age (percent)



Conclusion: Lessons Learned

Equipment problems, breathing-gas management, rough water, anxiety and exertion were common triggers to fatal dive accidents in this series. Adequate equipment maintenance, better breathing-gas planning and monitoring, thorough consideration of the suitability of the diving conditions and increased education, training and/or preparation of divers should help to reduce the frequency of these precipitants to serious diving accidents.

The predominant disabling injury was asphyxia from the inhalation of water, which appears to have occurred in 44 percent of cases. It is almost inevitable that most serious dive accidents will evolve to asphyxia due to the nature of the activity. However, the incidence can be reduced by ensuring that divers' aquatic skills are well-honed and increasing the appreciation of, training in and practice of attaining positive buoyancy by inflating one's BCD and/or ditching weights when appropriate.

The high incidence of CAGE/PBT as a disabling injury could be reduced by better monitoring of the breathing gas, careful selection of the suitability of dive sites to reduce diver stress and careful attention to training and practice in ascent technique.

Finally, the increasing incidence of cardiac-related disabling injuries could be reduced by better education of divers and doctors about the inherent, and potentially substantial, cardiac stressors associated with diving. This education, combined with appropriate diver health reporting and monitoring strategies, could reduce the incidence of diving fatalities from adverse health factors.

"It is almost inevitable that most serious dive accidents will evolve to asphyxia due to the nature of the activity."

References

Anonymous. *Fact File: Autopsy and the investigation of scuba diving deaths.* Surry Hills: The Royal College of Pathologists of Australasia, 2008.

Australian Sports Commission Standing Committee on Recreation and Sport. *Participation in exercise, recreation and sport, Annual Report 2005*. Canberra: Australian Sports Commission SCORS, 2006.

Australian Sports Commission Standing Committee on Recreation and Sport. *Participation in exercise, recreation and sport, Annual Report 2006*. Canberra: Australian Sports Commission SCORS, 2007.

Denoble PJ, Caruso JL, de L Dear G and Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med* 35(6):393-406; 2008.

Esguerra R, Ashbolt L and Callenbach P. *Report on a study of the Australian diving industry.* Lindfield: Diving Industry and Travel Association of Australia, 1989.

Lippmann J. Review of scuba diving fatalities and decompression illness in Australia. *Diving and Hyperb Med* 38(2):71-78; 2008.

Lippmann J. Australian scuba diving fatalities and decompression sickness. Erratum and further analysis. *Diving and Hyper Med* 39(1):48; 2009.

Queensland Government. *Queensland scuba diving and snorkeling report — visitor activities and characteristics.* Queensland Government (internal report only), 2007.

Walker D. *Report on Australian diving deaths 1972-1993.* Melbourne: JL Publications, 1998.

Walker D. *Report on Australian diving deaths 1994-1998.* Melbourne: Divers Alert Network Asia-Pacific, 2002.

Walker D. *Report on Australian diving deaths 1999-2002.* Melbourne: Divers Alert Network Asia-Pacific, 2009.

Walker D and Lippmann J. Provisional report on diving-related fatalities in Australian waters 2003. *Diving and Hyperbaric Medicine* 39:4-19; 2009.

Walker D, Lippmann J, Lawrence C, Houston J and Fock A. Provisional report on diving-related fatalities in Australian waters 2004. *Diving and Hyperbaric Medicine* 39(3):138-161; 2009.

Wilks J. Calculating diver numbers: Critical information for scuba safety and marketing programs. *SPUMS J.* 23:11-14; 1993.

Discussion

KEN KURTIS: I have a clarification request. On your depth slide, is that where they ended up or where they started?

JOHN LIPPMANN: That is the depth at which the accident was thought to occur. They got into trouble on the surface, they got into trouble within the first 10 meters.

DR. RICHARD SADLER: Regarding your talk and cardiac deaths or for all of the speakers for that matter, there is a lot of reasons for cardiac death, ischemic disease. Having reviewed some deaths, I have been disappointed with the quality of the autopsy reports because it does not specifically address these issues. How confident are you or is any of the presenters over the quality of our cardiac death categorization? Do we really know what is going on and why that occurs?

LIPPMANN: In Australia in the last few years we have gained confidence. There is a document that pathologists are using when they are performing the autopsies, and there is a better advisory system, and there is a better feedback system. And it is being queried. So they are getting better at autopsy and at writing the report. But then again, we have a fairly experienced pathologist, as DAN America does, reviewing all the autopsies and looking at the history of the dive, looking at the history of the person, the medical history, looking at the autopsy report and reviewing everything. In our reports in the last three years since we have taken it over we are making the determination of disabling injury, cause of death, not necessarily completely relying on what the coroner at the time said, using the tools that they provided. So it is getting better in Australia and certainly probably getting better here. So we are getting more confidence in that. Out of, for instance, Thailand we have no confidence. It is often just drowning or a heart attack.

SADLER: Just to answer that for the States, I would echo that. I have veto power on the database, so I will tweak some cases when they come in if they do not make sense. Unlike Australia, the United States has a much higher number and less control over the input of the data. While I am reasonably confident and know most of the medical examiners in places like San Diego and Los Angeles, cases that come in from smaller jurisdictions or certainly the cases from the Caribbean are abysmal. An autopsy sent in from a Caribbean country may mean that a general surgeon opened up the body, felt the organs for palpable coronary calcifications and said it was a cardiac death, and the heart was never weighed even or examined. So there is a lot of room for error. And in some cases, if there is not enough information there, I will have to just say that we cannot conclude the cause of death in a case.

A Review of the Nature of Diving in the United Kingdom and of Diving Fatalities (1998-2009)

Brian Cumming
Clare Peddie
Jim Watson
British Sub-Aqua Club
Telford's Quay, South Pier Road, Ellesmere Port
Cheshire CH65 4FL UNITED KINGDOM

The nature of United Kingdom diving is reviewed with descriptions of parameters such as dive site types, depths, water temperatures, underwater visibility, weather conditions and currents. Branch-based diving organisations are described with emphasis on the British Sub-Aqua Club. UK diver training systems rely heavily on the buddy system where skills and capability building of a buddy team emphasize buddy rescue skills, leadership skills and navigation. Dive management roles for different BSAC diver grades are summarized. Supervision, equipment, branch structure and decompression management, commercial training and the pace at which it takes place are all important attributes of UK diver training. The purpose, scope and data collection method of the BSAC Incident Report precedes the diver fatality analysis discussion of 140 of the197 incidents between 1998 and 2009.

THE NATURE OF DIVING IN THE UNITED KINGDOM

Types of Dive Sites

The 17,000-km coastline of the United Kingdom (UK) is highly diverse with more than 1,000 islands that provide a wide range of habitats for divers to explore including wrecks, caves, reefs, walls, piers, kelp forests and inland rivers and lakes.

The nautical history of the UK, the busy shipping lanes and many shipping casualties from two World Wars in which the UK was heavily involved has provided more than 44,000 shipwrecks distributed around the coastline, a significant proportion of which are visited by UK divers. The wrecks from World War I and World War II are deteriorating, and wave action has served to break up the shallower wrecks. However, a large proportion of the deeper wrecks remain intact and untouched. These wrecks provide a focus for the proliferation of marine life and a source of historical interest for divers.

"The nautical history of the UK, the busy shipping lanes and many shipping casualties from two World Wars in which the UK was heavily involved has provided more than 44,000 shipwrecks distributed around the coastline, a significant proportion of which are visited by UK divers."

The underwater topography in the UK is influenced by the highly varied geology and the effect of several ice ages. Therefore, the rock structures provide many reefs, walls and caves in which a very diverse and beautiful marine assemblage flourishes. Divers in the UK often become involved with voluntary organisations that record and survey marine sites and are active in the conservation of the sea.

Depths

Diving in the UK is available at all recreational depths (0-50 m), and there is a significant body of technical divers who explore wrecks in the mixed-gas range. Diving in the UK is sufficiently challenging that divers exploring deeper sites (>30 m) are encouraged to carry independent redundant gas supplies in the form of pony cylinders or twin sets.

Water Temperature

The water temperature in the UK is not as cold as expected from the latitude of the islands because of the influence of the Gulf Stream, which causes the temperatures on the west side of the UK to average 1°C to 2°C higher than on the east coast. In addition, temperatures seasonally range from 5°C (41°F) in winter to 18°C (64°F) in summer in the south of the islands and 4°C (39°F) in winter to 13°C (55°F) in summer in the north.

The majority of divers in the UK use a neoprene or membrane drysuit with an additional layer of thermal insulation underneath. Divers need to wear a neoprene hood and neoprene gloves that vary in thickness depending on the season. In the summer months in the south, divers can dive comfortably with a semidry neoprene suit, but most divers opt for a drysuit to give them year-round flexibility. The use of a drysuit adds additional bulk and the need to provide specific training in the use of the suit.

Underwater Visibility

The underwater visibility varies between 0 and 30 m depending on the seasonal growth of plankton that occurs during the spring and autumn seasons and the sediment load from estuaries and sediment churn during frequent windy periods. The underwater visibility and/or the loss of light due to surface plankton makes carrying a torch (dive light) necessary for almost all dives in the UK.

"The water temperature in the UK is not as cold as expected from the latitude of the islands because of the influence of the Gulf Stream…."

Weather Conditions

The prevalent weather conditions in the UK mean that the surface conditions are frequently unsuitable for diving in the open sea, especially in winter. Divers can be subject to seasickness and exposure, and good judgment is required to choose dive sites sheltered from the wind and to avoid uncomfortable sea crossings.

Consequently, diving in the UK is seasonal, with the majority of diving taking place in the sea from April to October because conditions in the summer are generally warmer and the sea conditions are more often favourable. Some divers make use of inland sites or sheltered sea lochs to maintain diving throughout the winter months.

Currents

Tidal ranges between 4 and 10 m and the nature of the topography mean that tidal streams between slack water periods often make dives on certain sites impossible. On the other hand, divers in the UK frequently enjoy the benefits of tidal streams to facilitate exciting drift dives that can carry divers over very long distances in the course of a dive.

DIVING ORGANISATIONS IN THE UK

British Sub-Aqua Club (BSAC)

BSAC is the national governing body for the sport in the UK and has a membership of 35,000 in the UK and abroad. The club was established in 1953 and has an internationally recognised training programme that prepares divers for the rigours of UK diving.

Structure of the Organisation (Branch Based)

About two-thirds of the BSAC membership are also members of smaller branches of the organisation. Each branch has an elected Diving Officer who is responsible for all diving and training matters in the branch and who controls the safety of the divers. The Diving Officer is provided with detailed training plans, training support materials and safety advice by BSAC.

The branch-based structure of BSAC creates a supportive, structured environment in which divers can receive training and experience diving in the UK safely. The branch structure means that new divers benefit from the leadership and knowledge of more experienced divers. The organisation consists almost entirely of volunteers supported by a headquarters of around 20 staff who service the administrative needs of the club. The instructors who provide training within their branches do so on a volunteer basis, and the instructors are qualified through a UK-based instructor training scheme that qualifies more than 300-400 instructors per year. The instructor trainers and the training of instructor trainers are controlled by a National Diving Committee.

In addition to a well-developed and structured training programme, BSAC offers additional courses in all aspects of the sport of diving, and in the last 10 years BSAC has extended the training programme to provide courses in mixed-gas and rebreather diving.

BSAC Schools

In the UK and abroad there are BSAC schools that offer BSAC dive training on a commercial basis to entry-level divers and to existing BSAC members who wish to further their training.

BSAC Overseas Franchises

In Japan, Korea and Thailand, BSAC has franchise organisations that offer BSAC training in those countries.

"The branch-based structure of BSAC creates a supportive, structured environment in which divers can receive training and experience diving in the UK safely."

Other Diving Organisations in the UK

There are other branch-based organisations in the UK: the Sub-Aqua Association (SAA), the Scottish Sub Aqua Club (ScotSAC) and the Comhairle Fó-Thuinn (CFT)/Irish Underwater Council that have a structure similar to BSAC but with a much smaller membership.

Other Training Agencies in the UK

There are several other training agencies active in the UK: PADI supplies a proportion of the entry-level training, as does SSI to a lesser extent. A number of different technical training agencies (IANTD, TDI, ANDI, ITDA, etc.) have serviced the divers who wish to extend their diving beyond the recreational range. These agencies offer training through dive schools and independent instructors but are not structured to provide support for continued diving experience.

UK DIVER TRAINING

The development and style of diving and diver training in the UK have been influenced and directed by the prevailing water conditions and the resources and facilities available.

Buddy System

Virtually all diver training systems rely on and promote the buddy system to provide some level of support between a pair of divers. A widely applied system in many parts of the world is for a number of buddy pairs to dive as part of a larger supervised group. This system requires buddy pairs to have basic skills, with in-water leadership (guiding, navigation, decompression management, etc.) and, if necessary, rescue assistance provided by a guide or divemaster. Such a system relies on the ability of the divemaster to see and maintain contact with the group, requiring good visibility.

Although in UK waters conditions can be encountered that would allow this system to be operated, the predominant conditions have resulted in UK training agencies (BSAC, SSAC, SAA and CFT) developing and evolving a different system.

The preferred UK system places the emphasis of diving procedure on a mutually supportive and appropriately skilled buddy pair. This means that within each buddy pair there needs to be shared skills and capability including:

- Buddy rescue skills
- Leadership skills
- Navigation

Buddy rescue skills
With the typical visibility conditions in the UK, a buddy pair should be able to reliably remain in sight of each other and be in a position to react to any problem that the buddy might encounter. It would be unlikely, however, that a supervising divemaster or rescue diver could maintain reliable contact. Consequently, the system in the UK has developed to teach full rescue skills from the start of diver training. The consequence of this has been to produce proficient buddy pairs in which either diver can provide rescue support to the other. The inclusion of rescue skills in initial training does increase the amount of time required to complete training but was initially consistent with the structure of club-based training.

"With the typical visibility conditions in the UK, a buddy pair should be able to reliably remain in sight of each other and be in a position to react to any problem that the buddy might encounter."

In response to changing attitudes to diving and diver training, in part due to establishment of professional agencies in the late 1990s, a more basic initial qualification structure began to be introduced but still retained important underwater rescue skills including the requirement for a controlled buoyant lift (CBL) of an unresponsive buddy. This allows divers with the entry-level qualification (BSAC Ocean Diver) to respond effectively should their buddy need assistance. It also means that due to initial training typically taking place in a swimming pool or similar sheltered water conditions that Ocean Diver students progressing to open-water training is capable of assisting their instructor should the instructor become incapacitated. The lack of resuscitation skills is then covered by the requirement for surface support.

Leadership skills
Although the skills requirement is for one member of a buddy pair to lead a dive, UK-based training provides leadership skills from entry-level qualifications so that both members of a buddy pair have some capability in this important role. This is to ensure, when two similarly qualified divers are diving together, that the conduct of the dive is by mutual understanding and agreement. In addition, it allows the handover or assumption of control from the designated dive leader during the dive if it becomes necessary to do so. There are prescribed "Dive Leader" level qualifications within the training programmes of UK-based organisations, but their specific role is orientated more toward leading less experienced divers or leading more challenging dives.

Navigation
With a reduced sphere of visibility the ability to navigate reliably is an important skill. In UK waters this ability becomes more important due to the prevailing types of diving. Wreck and offshore diving normally require the use of a shotline

as a reference to facilitate reliable location of the site and to control and manage a safe ascent. Shore diving usually has limited entry and exit points, and the seabed configuration is rarely as well defined as a typical coral reef.

Consequently, the ability to navigate underwater to locate and navigate around a dive site and to ensure that a shotline or appropriate exit point can be located is considered an essential skill. Basic skills of pilotage (navigation by natural features) and simple compass navigation are therefore taught at an early stage, with more advanced techniques such as distance line and wreck orientation being taught at second-level courses.

Supervision

Supervision of groups of divers, especially the less experienced, is still important. Because of the prevailing conditions, where it is not possible to supervise a group underwater, UK training has developed a system for surface supervision to manage diving and has incorporated this into the training for higher diver grades.

One of the key benefits of a branch-based training system is the level of supportive supervision that is provided by the group. An important benefit of this system is the opportunities it provides for cascading experience from senior divers to those with lower grades and experience. This cascading experience is also formalised within the training regime where each grade develops the role played in the management structure (Table 1).

"One of the key benefits of a branch-based training system is the level of supportive supervision that is provided by the group."

Table 1: Dive management roles for different BSAC diver grades

Diver Grade	Dive Management Role
Ocean Diver	Can dive with another Ocean Diver only under an on-site Dive Manager
Sport Diver	Trained to act as an Assistant Dive Manager
Dive Leader	Dive Manager dives to • Known locations • With a charter boat skipper
Advanced Diver	Dive Manager dives to unknown locations (exploration dives)
First Class Diver	Dive Manager for major Expeditions and/or projects

The requirement for Ocean Divers to dive under an on-site Dive Manager derives from the limitations of their rescue skills. The Ocean Diver has the capability to rescue a buddy to the surface, but by having on-site rescue support a full rescue including resuscitation can still be provided.

Support activities

Due to the fact that diver training in the UK developed from a largely branch-based system then, as well as supervisory support, a wide range of supporting services came to be provided by the branches as well. This includes the provision of boats, initially small inflatables and dorys, now including 5-9 m rigid-hull inflatables (RIBs) and even hardboats, compressors, oxygen equipment and more recently gas-blending equipment and portable defibrillators. UK branch-based organisations have also developed the relevant training programmes for these support activities.

Equipment

Because the typical temperature range of UK water is 4-18°C, some form of protective suit is considered essential. In the early stages of the development of diving in the UK neoprene wetsuits steadily became the main choice of divers, but this then required the use of significant amounts of weight to compensate for the buoyancy the suit provided, and there was a subsequent development of the need to compensate for buoyancy loss at depth. The introduction of buoyancy devices like the Fenzy adjustable buoyancy lifejacket and subsequent development of stab jackets, buoyancy compensators and more recently wings all introduced complexity and the need for training in their use. Initially dealt with by specialist courses, their use was quickly incorporated into core diver training programmes. The development of drysuits followed a similar pattern but has produced the added complication that there is the potential for a diver to use two means of buoyancy adjustment and the potential need, in an emergency, for a buddy to control four potential buoyancy sources. The growth of technical diving further compounds this.

One often unacknowledged consequence of improvements in suit technology is that divers in the UK are spending increasing amounts of time underwater because they are staying comfortable for longer. In the early days 20-30 minutes would have been considered a long dive, but in more recent times dives of at least an hour are becoming common and not just for technical divers. This has the impact of increasing bottom time and consequently increasing the amount of staged decompression time required. UK divers accept decompression penalties for the benefits of increased dive duration it provides. As a result of this acceptance, travelling UK divers frequently find it difficult to understand and accept the limitations employed by commercial operations in clear-water locations where dive time and depth limits are controlled to limit dives to well within no-stop decompression limits and short surface intervals for two-cylinder dives.

"One often unacknowledged consequence of improvements in suit technology is that divers in the UK are spending increasing amounts of time underwater because they are staying comfortable for longer."

Decompression

Two different features of UK diving contribute to the attitude toward decompression in UK diver training. With more than 44,000 wrecks in UK waters it is unsurprising that a large proportion of diving takes place on wrecks themselves or for the marine life that inhabits them. Wrecks in shallower waters are usually broken up or dispersed by wave action, thus deeper wrecks are often favoured by divers. Deeper depths together with a reasonable amount of time exploring such a wreck will require the acceptance of a decompression penalty. Scenic diving on the other hand may potentially take place at any depth, but unlike tropical reefs where the majority of life is in the top 5-10 m, temperate waters such as in the UK have variety throughout the depth range. In addition to that, on rocky shores kelp beds are predominant and difficult to swim through, and so diving normally takes place beyond the range of the kelp (12-30 m, depending on water clarity).

Before the advent of reliable dive computers in the 1980s, diving on tables would require an assumption of a square profile dive at the maximum depth regardless of the actual profile. UK diver training used tables (Royal Navy and then RNPL) that used multiple five-minute stops for simplicity and to add additional safety margins. This subsequently had a knock-on effect with divers accepting substantial penalties to maximise their enjoyment of diving. This has led to a wider acceptance and increasing use of nitrox to provide a safety margin rather than to reduce decompression time.

Branch Structure

Diver training in the UK developed on the basis of a branch structure in which groups of individuals joined together to provide training and support services as noted previously. Training is provided by experienced branch members. Instruction is most commonly done on a 1:1 basis. This allows the student more focused and personal attention and is consistent with the typical UK limitations of open-water teaching. Such a training strategy would have an implication for the cost of training if the instructors were not giving their time and effort free of charge.

The support of senior members of a branch who are not instructors provides an additional dimension to the development of divers. Little consideration or research has been completed to date on the benefits that accrue for all parties from having one or more people in this role-model position.

Commercial Training

The original training of divers in the UK took place at a very small number of commercial training establishments where the founder members of branches received their initial training. As the branch system developed, the training of divers and instructors was incorporated in their own programmes.

There always remained a level of commercial training available, and growth was slow until the 1980s, when a steady and significant growth in the range of commercial training organisations, usually U.S. based, began, and it has continued to increase since that time. Initially, the training programmes were not specifically oriented toward UK conditions. This did cause some problems, including fatalities, as a result of large dive group sizes, for example, but this has been addressed in conjunction with the UK Health and Safety Executive (HSE) and the training organisations themselves.

Speed of Training

Branch instruction is founded on a model of weekly meetings of the branch. This usually centers around a swimming pool where initial practical diver training takes place. Pool sessions are typically of one-hour duration. As a result of this, initial training can take some time, not least of which because each new pool session will spend time refreshing skills previously taught that may have deteriorated because of the intervening period. More intensive training consolidates existing skills quickly, requires less repetition and can be completed in fewer sessions. The potentially slower week-on-week training can help to ingrain the training deeper and reduce the loss of learned skills over time, and it is especially suited to those who prefer the less stressful pace, especially the nervous or less confident individual. Although slower in general terms, most branch training is organised to take place over the winter months when less open-water diving occurs. This allows progression to complete open-water training in the early part of the season, leaving the remainder of the season to enjoy diving.

"The potentially slower week-on-week training can help to ingrain the training deeper and reduce the loss of learned skills over time, and it is especially suited to those who prefer the less stressful pace, especially the nervous or less confident individual."

Commercial diver training is orientated toward a more compact and continuous delivery of training. The continuous delivery of skills encourages quicker consolidation of skills and knowledge and reduces the need to relearn or refresh skills. The growth in opportunities for commercial delivery of training coincided with a change in working life practice in the UK with people having a busier working life and much reduced available free time as a consequence. The attraction of a shorter and more predictable training programme therefore had identifiable benefits.

The demand to complete training quickly also ties in with the substantial growth of the holiday market for people in the UK. Foreign travel to tropical locations remains a major growth area. With diving as a major attraction, there is an increasing tendency for people to either learn to dive on holiday or gain their qualification in the UK with the objective of diving overseas.

THE BSAC INCIDENT REPORT

The Purpose and Ethos of the BSAC Incident Report

BSAC collates data on all UK sports diving incidents and publishes an annual report. This report is available to all, free of charge, and can be accessed through BSAC's website: *www.bsac.com/incidents*.

The aim of the report is to highlight issues of diving safety so that the lessons learned can be shared with as wide a diving audience as possible. BSAC uses the information derived from these reports to help with the development of its training programmes and to make recommendations on all issues relating to diving safety. All personal information is treated with the utmost confidentiality; no individuals or locations are identified, and no critique or comment is given against individual diving incidents.

The free BSAC "Safe Diving" booklet at *www.bsac.com/safediving* is a summary of the key factors a diver should consider to ensure a safe and uneventful dive. One important source of information for this booklet is the lessons derived from the annual incident analysis.

Scope of the BSAC Incident Report

The BSAC incident report includes any incident that involves sports diving; it does not deal with commercial diving (except where a commercial school or instructor is engaged in a sports diving activity). It includes information on all sports divers regardless of their affiliation, and it covers diving that takes place within England, Scotland, Wales and Northern Ireland and the territorial waters of the same. It covers diving in swimming pools, inland waters and the sea, and it encompasses any snorkel diving incidents as well as divers using breathing equipment.

"The aim of the report is to highlight issues of diving safety so that the lessons learned can be shared with as wide a diving audience as possible."

The incident report also covers incidents that have happened outside of the UK that involved BSAC members in some way. However, such incidents are not included within the scope of this paper.

Sources of Information

The BSAC incident report draws information from a number of different sources:

- Divers report incidents using the BSAC incident report form; see *www.bsac.com/incidentform*. This form has been adopted by a number of sports diving agencies in the UK, and such reports generally come from the individuals involved in a specific incident or from an operator-controlled dive site. This reporting mechanism is our preferred format as it presents information in a manner that is directly compatible with the incident database.
- The Maritime and Coastguard Agency (MCA) is the UK agency responsible for coordinating the response to marine incidents (and some inland sites). The MCA feeds information on diving incidents to BSAC.
- The Royal National Lifeboat Institute (RNLI) operates a lifeboat service around the UK in response to requests for assistance from the MCA. The RNLI supplies information on diving incidents to BSAC.
- Free-form reports are gleaned from a number of sources such as ad hoc statements sent to us directly or derived from credible Internet sources.
- BSAC uses a press-cutting agency to supply press reports on diving-related incidents that are published in UK newspapers.

Data Capture

Because of the serious nature of fatal incidents and the inevitable involvement of the emergency services, we are very confident that we capture information on all the diving fatalities that occur in the UK. Often we receive reports on such incidents from a number of different sources. We are equally certain that we do not capture information on all the nonfatal diving incidents. However, we are confident that we gather enough information on nonfatal incidents to be able to derive a good understanding of the nature of these incidents and the lessons that can be derived from them. The information gathered is fed into a database together with a synopsis of the incident. The synopsis is a factual (nonjudgmental) summary of the incident constructed from the information received; it contains no personal information, and it is published in the annual report.

Dive Survey

To be able to put diving incidents into perspective it is essential to have a background understanding of the type of diving that is taking place and of the demographics of the people involved. To this end, in the summer of 2007, BSAC undertook a countrywide survey at 35 representative dive sites. This survey investigated the demographics of those involved, their diving histories and the nature of the diving that they undertook. This survey involved almost 1,000 respondents, and it has enabled BSAC to develop a good picture of UK diving. Information from this survey has been used in this paper to put a number of factors into context.

Diving Incident Data — Scope of Analysis

The current incident database contains information that goes back to 1997, and this paper contains information from this database drawn from the period January 1, 1998, to December 31, 2009 — a period of 12 years.

BSAC uses a first-level categorisation for incidents as follows:

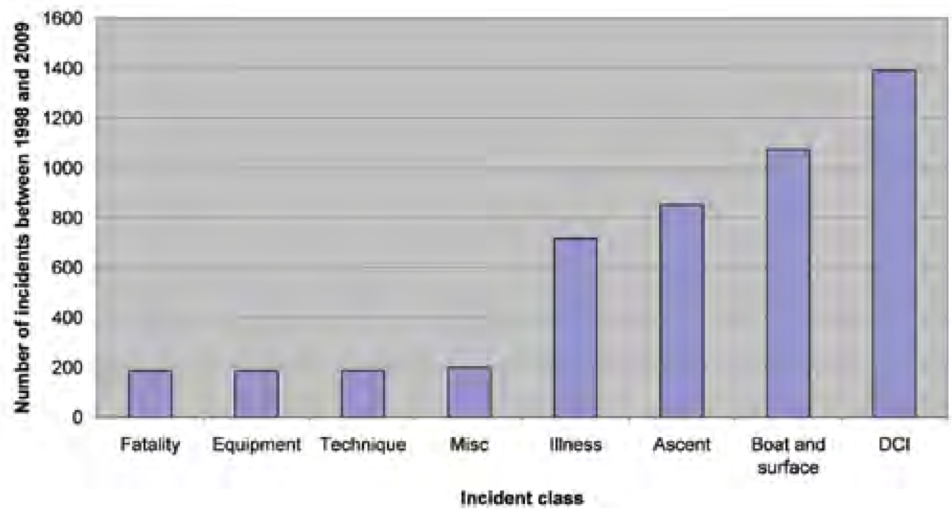
1. Fatalities
2. Decompression illness (DCI)
3. Surface or boating incidents
4. Ascent-related incidents
5. Technique-related incidents
6. Equipment-related incidents
7. Illness (non-DCI) or injury
8. Miscellaneous

Clearly, an incident could fall into more than one of these categories, but to avoid any double counting the more serious category (as indicated by the ranking above) is used. For example, poor technique that resulted in a rapid ascent, DCI and a fatality would be categorised as a "Fatality." However, if a fatality and DCI were avoided then it would be categorised as an "Ascent" incident.

In the 12-year period analysed in this paper there were a total of 4,799 incidents recorded in the database, and their distribution into these eight categories are shown in Figure 1. As can be seen, the smallest category is "Fatalities," and this chart shows 187 fatal incidents. Ten of these fatal incidents involved double fatalities, thus the total number of fatalities that occurred in this period is 197, analysed in more detail in the body of this paper.

"We are confident that we gather enough information on nonfatal incidents to be able to derive a good understanding of the nature of these incidents and the lessons that can be derived from them."

Figure 1: Distribution of incident classification for incident data, 1998-2009



"In some cases it was very clear exactly what happened, but in a number of cases there was insufficient evidence to be certain of the events, leading the authors to include an assessment of the most likely explanation."

ANALYSIS OF FATALITIES

Each fatal incident was reviewed to establish, as far as possible, the primary factor that led to the death; where relevant, secondary factors were also included. In some cases it was very clear exactly what happened, but in a number of cases there was insufficient evidence to be certain of the events, leading the authors to include an assessment of the most likely explanation. Finally, there are a number of cases where there is simply too little information to support any analysis of causal factors. The causal factors are reviewed in descending order with the most frequent first.

Insufficient information

This is the biggest category. In 57 of the 197 incidents (29 percent) there is simply too little known of the incident to be able to draw even tentative conclusions as to the causal factors. There are three main subdivisions of incidents in this category:

- Incidents where there are no surviving witnesses — This group includes solo divers, divers who became separated from their buddies before any apparent problem arose and divers involved in double fatalities.
- Incidents where insufficient detail is reported — These are less common since reports from coroners' court hearings are often, ultimately, obtained.
- More recent incidents where information has yet to be reported — As stated above, a valuable source of information is derived from coroner inquests. However, coroners' inquests can often happen years after an event, and there is no central source of coroners' reports nor is there a free right of access to such information in the UK.

The rest of this analysis looks at the remaining 140 incidents in which causal factors could be identified and their frequency (Table 2).

Table 2: Comparison of causal factors for 140 fatal incidents

Primary causal factor	Number	Frequency
Non-diving medical problem	38	27.1%
Rebreather	15	10.7%
Equipment problem	13	9.1%
Out of gas	12	8.6%
Inadequate pre-dive checks/brief	12	8.6%
Inexperience	10	7.1%
Buoyancy - light	10	7.1%
Buoyancy - heavy	8	5.7%
Narcosis	5	3.6%
Tangled (rope, debris)	5	3.6%
Trapped in wreck	5	3.6%
Other trauma	3	2.1%
Other rapid ascent	1	0.7%
DCI	1	0.7%
Unconsciousness	1	0.7%
Separation	1	0.7%
Total	140	100.0%

Nondiving-related medical problems

Thirty-eight cases (of the remaining 140) are ascribed to nondiving-related medical problems. In the great majority of cases these involved heart attacks, but there were a small number of strokes. Of these 38 cases, 27 are confirmed, and the remaining 11 are judged to be medical problems based upon the circumstantial evidence available. Two of these cases involved snorkel divers where it is not certain that any formal dive training had been received. It is arguable whether these incidents should be included in any analysis of diving incidents. However, they are recorded in the database for completeness.

Rebreathers

Twenty-seven cases (of the 197 fatalities) involved divers who were using rebreathers. However, seven of these fall within the "insufficient information" category, leaving 20 cases in the remaining group of 140 in which it is possible to draw conclusions. In five of these 20 cases the rebreather is not thought to be implicated in the fatality in any way (for example, a rebreather diver suffering a heart attack). This leaves 15 cases where it seems clear that the use of a rebreather was at the root of the incident. In 11 of these 15 cases it is believed that the diver made some error in the use of the equipment, the most common error being a diver entering the water without correctly switching on the equipment. In the remaining four of the 15 cases it is thought that some error occurred in the equipment itself. One of these cases involved what was described as a "homemade" rebreather, another involved a failed diaphragm, another involved "an oxygen surge," and the last was due to "an oxygen leakage" from the equipment.

It seems very likely that cases of diver misuse and equipment problems were also present in some of the seven cases where there is "insufficient information." However, there is no evidence available to prove this.

Overall, 27 of the 197 fatal incidents involved divers who were using rebreathers (14 percent). Our 2007 survey indicated that only 4 percent of divers were

"It seems very likely that cases of diver misuse and equipment problems were also present in some of the seven cases where there is 'insufficient information.'"

regularly using a rebreather. The disproportionate number of rebreather diver deaths strongly suggests a significant increase in risk when using such equipment. It is not suggested that rebreathers are inherently unsafe, but it would seem that there is a substantially increased opportunity to make errors.

Equipment problems (excluding rebreathers)

In 13 cases equipment problems are cited as the primary causal factor. These cases exclude technical problems with rebreathers. While such events could be said to be equipment problems, they are counted separately because they are felt to be a distinct and critical causal factor. In three cases the event was initiated by a regulator free flow. In three cases a regulator fault occurred that led to a loss of gas supply. Two cases involved weighting systems in which the diver was unable to drop weight (in one case the belt was tied on). Two cases involved buoyancy device (BCD) control failures. In one case the inlet valve jammed open and resulted in a rapid ascent, and in the second case the inlet valve jammed in the closed position and the diver was unable to gain buoyancy. One case involved a direct-feed hose failure. One case involved a cylinder pressure gauge that was over reading and resulted in the consequent and unexpected loss of gas supply. The final case involved a diver who was diving in a semidrysuit that was too big, became very cold and resulted in a chain of events that ultimately led to her death.

Out of gas

In 12 cases it is clear that a diver running out of breathing gas was the primary factor that caused the incident. Often these cases led to a failed attempt to use a secondary gas source, loss of buoyancy (sometimes due to a lack of gas to inflate a buoyancy device), separation and drowning. Two cases involved divers reentering the water to recover lost equipment and doing so with very low gas supplies. Overall, 36 of the 140 fatalities involved divers running out of breathing gas, although in many cases this was a secondary or tertiary factor brought on by other primary causes (such as being trapped underwater).

"Arguably inexperience is a root cause of the great majority of fatal incidents."

Inadequate predive briefing and/or equipment checks

Twelve cases fall into this category. Seven of these involved an incorrect equipment setup that was not discovered until the diver was underwater. The main issues here were a failure to connect drysuit or BCD direct-feed hose or a failure to turn breathing gas on prior to entry into the water. Three cases involved divers who unknowingly entered the water using their pony regulator instead of their main regulator and then ran out of gas unexpectedly early in the dive. One case involved a double fatality where the divers entered the water and encountered difficult and unexpected conditions that led to their deaths with one reported finding of the inquest being that the "dive brief was inadequate."

Inexperience

Arguably inexperience is a root cause of the great majority of fatal incidents. Had the divers been more experienced then they would not have run out of gas, not entered the water without proper equipment checks, etc. However, in some cases divers have undertaken dives (or been led on dives) that were clearly significantly beyond their current level of ability. One example of this is where a diver is diving to a depth way beyond the maximum defined by his qualification status. In 10 cases inexperience was considered to be the primary causal factor for the deaths, and all these cases involved divers who were under instruction at the time of the fatal incident. Three cases involved an instructor with two or more trainees; two of these involved students struggling with their air supplies, and one involved a student who became tangled in line and then became low on air. Generally, these incidents involved events that would have been trivial for more experienced divers. Typical examples include water in the face mask, water in the mouthpiece or difficulty clearing ears. However, an inability to control these events often led to panic and subsequent drowning. One case involved a diver's first UK dive, first drysuit dive and rough sea conditions.

In all cases had the training been conducted in more benign conditions (depth, visibility, water movement, etc.) it is very likely that a serious outcome could have been avoided.

Buoyancy — diver too light

Poor buoyancy control is responsible for a large number of diving incidents (particularly DCI), and in this analysis 10 fatalities are ascribed to divers being too buoyant. Four cases involved divers losing control of their drysuits and making rapid ascents (inverted in three of these cases). Two cases involved weights; one diver diving without any weights and another who accidentally lost his weights at depth. Two cases involved divers simply failing to maintain adequate buoyancy control. One case involved a diver having problems deploying a delayed surface marker buoy, and one case involved a diver carrying a bag containing a heavy weight clipped to his upper harness. When he adopted an upright posture the bag depressed his drysuit inflator, and he made a rapid ascent to the surface. Six of these cases resulted in a death through some pressure-related injury (pulmonary barotrauma or embolism). In one case an inverted diver drowned, in one case the casualty ended up sinking and drowning, and in two cases the actual cause of death is not known.

"Poor buoyancy control is responsible for a large number of diving incidents (particularly DCI), and in this analysis 10 fatalities are ascribed to divers being too buoyant."

Buoyancy — diver too heavy

Eight cases have diver overweighting as their primary causal factor. Four cases involved divers who sank rapidly at the beginning or during the course of a dive and became separated from their buddies (one of these experienced a burst eardrum). Two cases involved divers who had completed their dives but sank from the surface. One case involved a diver who surfaced rapidly, dived again to conduct his decompression but failed to stop at the required stop depth. One case involved a diver who was heavy and sinking and who was eventually lifted using his drysuit because his buddy could not inflate the casualty's BCD.

Although only eight cases have this problem as their primary causal factor, it is important to note that this issue is also present as a nonprimary factor in 25 of the 140 total analysed fatalities. In a significant number of cases a casualty reached the surface or very near to the surface during the course of an incident only to sink back down again. It is quite clear that if these casualties had managed to stay at the surface their chances of survival would have been greatly increased.

Nitrogen narcosis

Nitrogen narcosis is recorded as the primary causal factor in five cases. All cases relate to divers using air, and the depths were 60 m, 60 m, 57 m, 55 m and 51 m. All cases involved divers making poor decisions and becoming confused at depth. Three cases involved divers failing to follow depth and time constraints. One case involved a diver becoming confused and unable to deal with a tangled rope, and in one case the diver appears to have simply lost consciousness.

BSAC has always stated that the limit for air diving is 50 m (and then only for suitably qualified divers). BSAC also recommends the use of helium mixtures for depths deeper than 30 m (with a maximum limit of 80 m — again, only with suitable training).

Tangled
Five cases involved divers who became tangled in rope and lines. Two cases involved incidents in which divers became tangled in delayed surface marker buoy lines, two cases involved divers who became tangled in lines laid on the bottom (one of these was a solo cave diver), and one case involved a diver who became tangled in a shotline.

Trapped in shipwreck
Five fatalities resulted from divers becoming trapped inside a shipwreck and drowning when their gas supplies became exhausted. One case involved a double fatality. In another case a diver had removed his cylinder to get into the wreck. In another case the casualty was found apparently stuck in a narrow part of the wreck. In four of these cases it seems that the divers lost their way due to reduced visibility caused by their movements inside the wreckage. It is believed that none of these divers were using guide lines.

Other trauma
Three cases involved divers who received nonpressure-related physical traumas. One involved a diver who during a night dive struck his head against a rock in rough sea conditions, lost consciousness and drowned. Another involved a diver who was struck on the head by a boat's propeller, and the third involved a diver who fell under a trailer during the recovery of a dive boat. This last case is arguably nondiving, but it occurred during an action directly connected to diving activities and is therefore reported for completeness.

"Five fatalities resulted from divers becoming trapped inside a shipwreck and drowning when their gas supplies became exhausted."

Rapid ascent
One case involved a diver who for no known reason simply made a rapid ascent to the surface, signaled distress and then sank from sight. Other factors may have been at work, but they are not recorded.

Decompression illness
One case involved a diver who died from a pulmonary embolism. At the surface after an apparently normal dive, he made himself positively buoyant and signaled "OK" to his buddy, then without warning he lost consciousness and subsequently died.

Unconsciousness
One case involved a diver who was undergoing drysuit training in a swimming pool. Without warning she lost consciousness and died after two subsequent heart attacks. The cause of death was recorded as pulmonary edema due to immersion. It is not clear why she lost consciousness in the first place.

Separation
One case involved a diver who, with her buddy, became separated from their boat at the end of the dive. The dive pair was at the surface for 70 minutes after their dive in very rough sea conditions, and the casualty lost consciousness and drowned during this time despite efforts by her buddy to resuscitate her in the water.

Separation occurred in a total of 55 of the 140 analysed fatalities (39 percent), but in all cases, except the one recorded above, it was as a result of some prior perturbing event(s). Separations are caused by divers being too buoyant or too heavy, divers losing contact with each other in low visibility, divers distracted by problems with equipment and many other causes. While separation is not a key primary causal factor, it is clear that if separations could be avoided once an incident has started, the possibility for assistance from the casualty's buddy remains and a death might be avoided. Once separation has occurred, the potential for assistance from the buddy is gone. It is very plausible that actions to reduce the chances of divers becoming separated from their buddies will reduce the number of fatalities.

Exacerbating Factors

In addition to the major causal factors identified above, a number of exacerbating factors have also been identified. These factors are believed to have increased the opportunity for the initiating factor to occur and/or reduced the ability of those present to resolve the incident once it had started.

Nonpair diving

Nonpair diving includes solo divers and divers in groups of three or more. Twenty-six of the total of 197 fatalities involved solo divers who had deliberately chosen to dive alone, either entering the water alone or deliberately separating from other divers and continuing alone once underwater. This represents a fatality rate of 13 percent for solo divers. We currently do not have any data to put this number into perspective, but it is thought that the number of solo dives that take place in the UK is significantly less than this. Intuitively, solo diving is likely to be more hazardous since the absence of the possibility of buddy assistance must increase the chances of a negative outcome in the event of an incident.

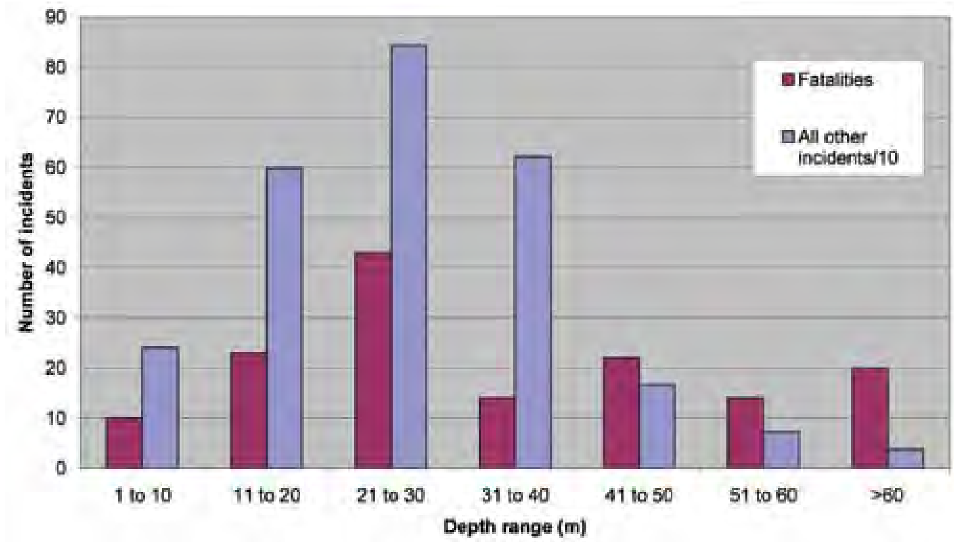
Thirty-eight cases of the 197 total involved divers diving in groups of three or more. Very often this was in a training situation in which a single instructor was with a group of two or more students. The drawback with this configuration comes when there is a problem. One diver (often the instructor) assists another diver who is experiencing a problem, and the other diver(s) are left unattended and then get into serious difficulties. Of these 38 cases, 28 resulted in a separation (74 percent), significantly more than the background level of cases of separation, which is about 40 percent. Clearly separation is much more likely when groups of divers are diving together and, as discussed above, separation is a factor that contributes to a negative outcome.

Depth

Figure 2 shows a comparison of the maximum depth (where known) of dives during which an incident occurred. The darker bars show the number of fatal incidents that occurred in the depth ranges defined, and the lighter bars show the number of the nonfatal incidents recorded in the database during the 12-year period of this study. The nonfatal incidents have been divided by 10 to enable a visual comparison to be made more readily. For clarity, if one looks at the 21-30 m depth range, the chart shows that the number of fatalities occurring in this range was 43, while the number of nonfatal incidents occurring in this range was 843.

"It is very plausible that actions to reduce the chances of divers becoming separated from their buddies will reduce the number of fatalities."

Figure 2: Maximum depths of dives in which incidents occurred



"Deep depths bring significant problems such as narcosis, greater gas consumption and long decompression, and when problems do occur the diver is much further away from safety and the support of his surface party."

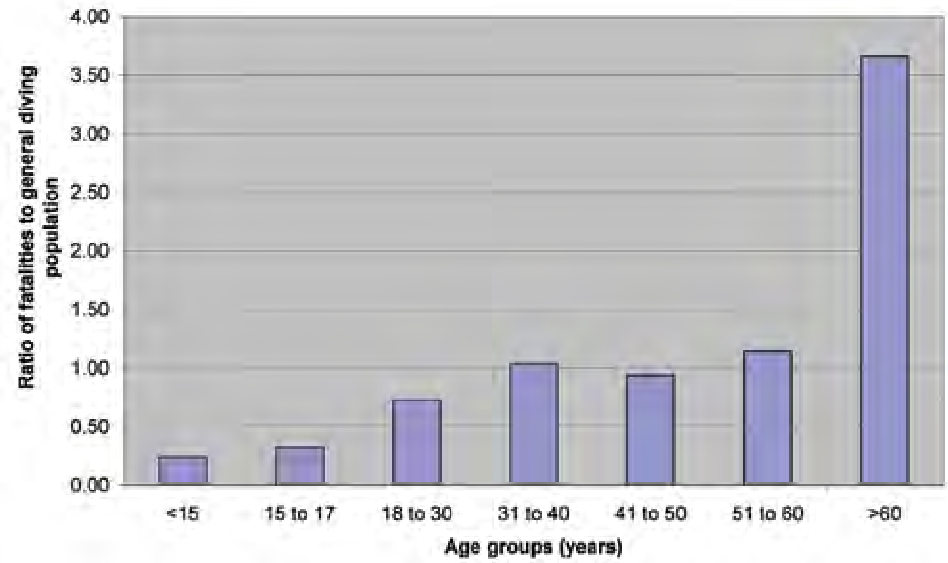
The nonfatal incidents are included to give an indicator of the "normal" distribution of diving depths, and the picture is, as might be expected, with the great majority (89 percent) of diving taking place in depths shallower than 41 m. This picture is probably somewhat biased toward the deeper depths since it includes 975 cases of DCI, and it is very likely that such incidents will involve deeper depths. Nevertheless, it is thought to give a good indication of the background of diving depths.

An examination of the depths of the fatalities, however, shows a clear bias toward the deeper depths. Among fatalities only 62 percent occurred in the "40 m or less" depth ranges, 38 percent occurred deeper than 40m, whereas only 11 percent of the diving takes place in this range. This finding is not unexpected. Deep depths bring significant problems such as narcosis, greater gas consumption and long decompression, and when problems do occur the diver is much further away from safety and the support of his surface party. The deepest depth recorded in this analysis involved a solo dive to 120 m. Note: This chart shows a total of 146 fatalities and 2,578 nonfatal incidents; in many cases the maximum depth is not known, and thus these incidents are not included in this chart.

Age

A recently identified trend is that the age of divers suffering fatal incidents seems to be higher than the age range of the general diving population, shown clearly in Figure 3. This chart compares the age grouping of divers who suffered fatal incidents compared to the age range of the general diving population derived from the 2007 diving survey. In each age range the percentage of fatalities in that group was divided by the percentage of divers in that group in the background survey. If the age range of fatalities exactly matched that of the background then each column would be unity, which, as can be seen, is not so. In the younger age groups it is less than 1, and in the over-60 group it is much higher than 1.

Figure 3: The effect of age on diving fatalities



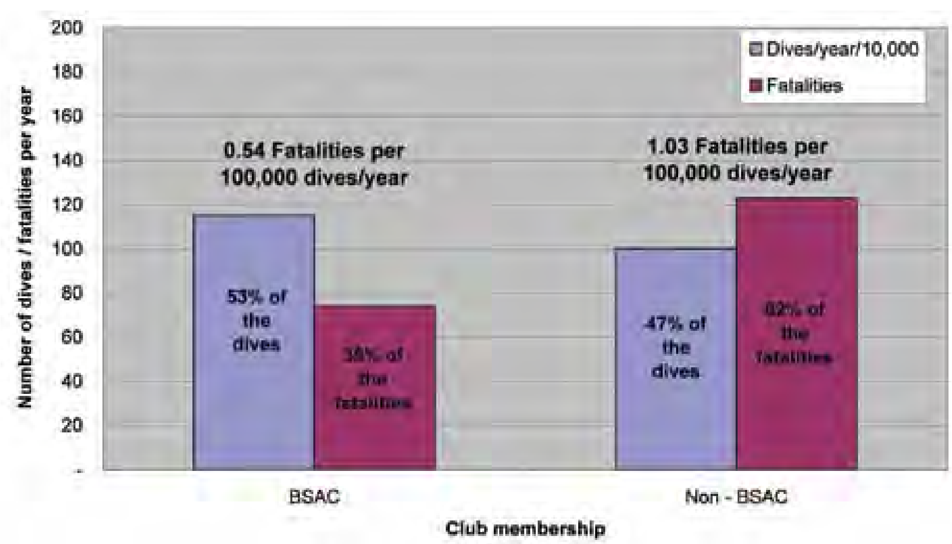
It is easy to speculate why this might be and very probable that much greater care is taken of young people in the <15 and the 15- to 17-year-old categories (depth limitations, pairing them with attentive elders and probably less susceptibility to nondiving medical problems). In the over-60 group the possibility for medical problems becomes more likely. The oldest fatality in the study involved a diver who was 78 years old.

"It is … very probable that much greater care is taken of young people in the <15 and the 15- to 17-year-old categories (depth limitations, pairing them with attentive elders and probably less susceptibility to nondiving medical problems)."

Club diving versus nonclub diving

One of the factors that was investigated as a result of the 2007 survey was the fatality rate of BSAC members versus non-BSAC members when compared to the amount of diving conducted by people in these groupings (Figure 4).

Figure 4: Fatality risk comparison



The 2007 survey indicated that slightly more than half the diving that takes place in the UK is conducted by BSAC members. A study of the fatal incidents in the 12-year period of this study shows that 38 percent were BSAC members (this includes individuals with multiple agency memberships), and 62 percent were not

BSAC members. A reduction of these two factors reveals that the fatality rate for BSAC members is 0.54 fatalities per 100,000 dives per year, whereas it is almost twice this at 1.03 fatalities per 100,000 dives per year for non-BSAC members.

While this may seem to be a strong advertisement for BSAC and its training programme (and it probably is), it is the authors' contention that more lies behind these numbers. It is our belief that any "good" club-based organisation improves diver safety for the following reasons:

- In a diving branch environment there are no commercial pressures to increase the speed at which training takes place. In fact, one criticism often leveled at the BSAC branch system is that it can be too slow. Typically branches hold weekly pool sessions and train new divers during the winter months, allowing for plenty of time for a sound basis of diving skills to be built.

- There are no commercial pressures to encourage instructors to take groups of trainees into the water. Usually diving clubs have a good ratio of experienced divers to trainees, and one-to-one training is normal, especially in open-water diving/training.

- Third, and perhaps most important, when trainees have finished their training and are ready to undertake "nontraining" diving, they are very likely to be accompanied by an experienced diver in a diving party that also has a lot of experience. This environment is able to avoid potential problems through the application of their knowledge and understanding and to nurture the ongoing development of the trainee diver. In nonbranch situations divers who have completed a training course usually lack this access to a supportive network and often take themselves diving with a similarly skilled buddy, sometimes with serious consequences. One of the reasons that a number of our inland sites have had significant numbers of fatalities is that relatively inexperienced divers can reach the site without any infrastructural support (they simply drive there) and have direct access to very deep water and challenging conditions. For this reason many of the better run sites insist on monitoring the skill level of their visitors.

"In a diving branch environment there are no commercial pressures to increase the speed at which training takes place."

SUMMARY AND CONCLUSIONS

Many of the conclusions from this study have already been highlighted in the paper, and there are no new "revelations." Earlier in the paper BSAC's "Safe Diving" booklet was mentioned, and in the great majority of fatal incidents it is possible to highlight a number of places where those involved diverged from the advice given in this booklet (also reflected in the advice given by other respected sports diving agencies). The only fatalities that are arguably unavoidable are those where some nondiving medical event takes place since it is very difficult to screen divers for potential serious medical conditions, and it would be unacceptable to place barriers to diving based simply on factors such as age or body mass index.

Key points to note for the "avoidable" incidents are as follows:

- Spend time in dive preparation. Time spent in this area could have prevented 29 percent of the analysable fatalities in this study.

  — Ensure that diving equipment is properly serviced.

  — Ensure that diving equipment is correctly prepared.

  — Ensure that diving equipment is properly fitted.

— Conduct rigorous buddy checks; don't let familiarity lead to cursory checks.

— Plan the dive, and follow the plan.

— Ensure that all divers understand the dive plan and actions to take if things start to go wrong.

— Buddy inexperienced divers with experienced divers.

— Avoid "nonpair" diving.

- Monitor the progress of a dive effectively. Care in this area could have prevented or arrested 18 percent of the analysable fatalities in this paper.

— Regularly check gas supplies and take action early to avoid running low.

— Don't progress the dive into unplanned directions, for example, going deeper than planned, or wreck penetration without appropriate equipment.

— Avoid becoming separated from your buddy, especially likely during ascent and descent. Use a datum (shotline, delayed surface marker buoy) to assist with this.

— Be alert to developing problems with yourself and your buddy, and be ready to act early and effectively, for example, avoiding and assisting with tangled ropes.

- Practice the key diving skills, and keep this practice up-to-date. Good diving skills could have prevented or arrested 16 percent of the analysable fatalities in this paper.

— Ensure that proper ascent rates can be achieved with ease.

— Ensure that divers are able to achieve surface buoyancy easily and quickly so they can secure themselves at the surface in an emergency situation.

— Practice out-of-gas procedures so they are second nature.

- Stay well within your personal comfort zone, and be ready to call off or abort a dive if necessary. Do not adopt a brave stance and assume that the dive must go ahead. Awareness of this point could have prevented 9 percent of the analysable fatalities in this paper.

— When diving with trainees or less experienced divers beware of this point from their perspective, and advise and guide them accordingly.

— Build up your experience gradually, progressing to more challenging environments at an acceptable pace and in the company of more experienced divers.

— Be prepared to rebuild this experience after a layoff from diving. Do not assume that you can start from where you left off.

As stated earlier in this paper, 57 of the total of 197 fatalities that occurred in the 12 years analysed relate to incidents where there is little or no evidence to glean information on any causal factors. However, there is no reason to believe that anything other than the factors identified in this paper applied to these 57 as well. On this basis it is probably fair to conclude that, if the guidelines presented in the above summary had been followed by those involved in these 197 fatal incidents, only those with a medical root cause would remain, and probably another 140 UK divers would be alive today.

"Stay well within your personal comfort zone, and be ready to call off or abort a dive if necessary."

Discussion

CRAIG JENNI: You just mentioned the 27-percent medical statistic, and so approximately a third of the divers had a nonmedical-related incident that led to their death. What does BSAC do in regard to medical screening and/or fitness to address that issue?

BRIAN CUMMING: Basically it is self-certification. You are asked to fill out a medical form and declare any preexisting conditions. That is what we do. One of the issues — and I am not a medical physician, so there are people in the room more qualified to answer this question than me — but my understanding is the ability to effectively screen for these conditions is quite full. You have to go through an extensive process to screen people out who are potentially going to suffer from these problems. It is something that we as an organization are starting to look at. There is a consultant cardiologist in the UK, one of our members, who has started to get very interested in this. One of the problems we have in the UK is that the coroner process is very much uncontrolled nationally. We do not have automatic right of access to coroner findings. We cannot demand that information. So a lot of the information that could come out of some of these fatal analysis is quite hard to come by, but it is something we feel we need to investigate a lot more.

DAN CALLAHAN: You seem to have a lot of information on deaths related to people who are diving solo. Do we have any information as to whether those people were actually trained in solo diving techniques or if they were untrained, and that is not necessarily a solo-diving death but something that leads back to a lack-of-training death?

CUMMING: I do not believe they were trained in solo diving. My guess would be these are people who have some diving certification of some type but then choose to go dive on their own. I don't think they have had specific training for solo diving, no.

GREG STANTON: You mentioned that many individuals might look at your database and make corrections, but did BSAC make any corrections in their training standards or activity standards based on this data?

CUMMING: The thing we have had a really big push on recently, perhaps not related to fatalities in a big way, but one of the major issues that has come out of the incident analysis is buoyancy control. A huge amount of other incidents were being caused by poor buoyancy control. That is something that we have worked on quite hard over the last two or three years, introducing new training processes for buoyancy control, and the data seem to be suggesting that it is having an impact on those sorts of incidents coming down. So, in general, yes, if there are major concerns that we can identify, yes, we do push toward it. The sad thing about this to me is I have been writing this incident report that we have produced for about the last 13, 14 years, and I found myself writing the same thing again and again. We continually reissue the same advice, do this, do not do this. It does not always happen. So other people were expressing it earlier today, what can you actually do? If someone is determined to say, I am not going to listen to any of that, I am going to do my own thing, majority rules. Does anybody want advice on computer maintenance?

DR. PETER BENNETT: You have many regional differences on Scapa Flow regarded as deep, technical diving, so on. Is it more there than anywhere else?

CUMMING: There are a lot of incidents at Scapa Flow, yes. I cannot give you numbers, but, yes, there are. It is a very popular site, dark, deep. We do get a fair share of incidents there.

UNIDENTIFIED SPEAKER: It is reasonably deep at Scapa Flow. It's quite good visibility most of the time.

Training Scuba Divers: A Fatality and Risk Analysis

Drew Richardson
PADI Worldwide
30151 Tomas Street
Rancho Santa Margarita, CA 92688 USA

Annual records of certifications issued, resultant training dives conducted and reports of diving fatality cases collected by the Professional Association of Diving Instructors (PADI) were examined and compared for two 10-year periods: 1989-1998 and 1999-2008, respectively. Three sets of data were grouped and analyzed for each of these 10-year periods:

1. *Fatalities occurring during PADI-sanctioned training programs or under supervision of a PADI member while enrolled in a non-PADI program — For this data set a total of 63,041,231 training dives were conducted in the 20-year period and 17,224,125 certifications issued with a total of 304 fatalities occurring. Rates were calculated by course and cumulatively. Cumulative fatality rates were calculated at 0.482 per 100,000 dives and 1.765 per 100,000 divers for the period. Comparison between the two 10-year periods showed improvement in rates within comparable range categories for training. The yearly fatality rate ranged from 0.3 to 0.683 per 100,000 dives and from 1.167 to 2.829 per 100,000 divers for the first 10-year period and ranged from 0.283 to 0.692 per 100,000 dives and from 1.001 to 2.698 per 100,000 divers for the second 10-year period. Cause of death and a variety of contributing factors were identified. Comparison between the two 10-year periods also showed consistent representation of gender, with females comprising 28.8 percent during the first 10-year period and 28.1 percent during the second 10-year period, and males comprising 71.2 percent during the first 10-year period and 71.9 percent during the second 10-year period.*

2. *Diving fatalities occurring outside of PADI-sanctioned training programs and involving a PADI-certified diver — A total of 808 fatalities for the 20-year period were researched. Because a reliable denominator was not able to be calculated, fatality rates were not calculated. However, a significant increase in the number of certifications issued in the second 10-year period was noted without a correspondingly proportional increase in fatality for this data set. Cause of death and a variety of contributing factors were identified. Of note, the median age for cardiac deaths increased in the second 10-year period (40 to 51.5 years of age), but the percentage contribution from this category was comparable (31.5 percent versus 31.6 percent).*

3. *Fatalities involving a PADI diving professional (divemaster/assistant instructor/instructor) while at work — A total of 22 fatalities for instructors or divemasters at work were recorded for the 20-year period. Cause of death and a variety of contributing factors were identified. Description of activity and associated analysis to total population are included. The fatality rate per 100,000 members dropped from 1.4 in 1989-1998 to 1.1 in the 1999-2008 10-year period. The vast pool of data reflects an improvement in participant safety from the first decade to the second. This is a testimony to the commitment to the design of quality diver training and the effort put into upholding standards in the field.*

"The vast pool of data reflects an improvement in participant safety from the first decade to the second."

Introduction

Scuba diving has inherent risk, and, as a diver training and educational institution, the PADI organization exists to train scuba instructors and divers to mitigate risk so that scuba diving can be experienced in a reasonably safe manner.

We use the word "safe" quite loosely in our everyday lives. However, how we determine what is and is not safe is not as widely discussed. In his 1976 work, *Of Acceptable Risk: Science and the Determination of Safety*, W.W. Lowrance defined safety as a judgment of acceptable risk and risk as a measure of the probability and severity of harm (Richardson 2002). Nothing in life is risk free, and activities are judged safe only when their risks are judged acceptable. As there are degrees of risk, there are degrees of safety. Determining how safe things are requires two activities: (1) measuring risk, which is an objective scientific activity; and (2) judging the acceptability of that risk, which is a personal and/or social value judgment (Lowrance 1976). Using this as a baseline, one can apply objective input into improving safety or practice.

Gauging risk in diver training is a matter of estimating probabilities. This approach assesses the overall chance that an untoward event will occur but not a specific event. For example, gauging risk by estimating probabilities can determine the likelihood of decompression illness occurring for any given dive profile; however, this approach is limited in that it cannot predict which divers will have decompression illness. The same can be said of air embolism, drowning and diver fatality. The definition of risk includes both the probability of an adverse event as well as the severity of its consequences. Objective risk estimation is based on knowledge of past occurrence of injuries, their frequencies, numbers of persons exposed and measures of their exposure (Denoble, Pollock et al. 2008; Denoble, Caruso et al. 2008).

"Nothing in life is risk free, and activities are judged safe only when their risks are judged acceptable."

Recreational scuba diving is associated with hazards and risks related to all water activities in addition to hazards and risks specific to underwater breathing. A lack of understanding, inadequate training or choosing to ignore these risks can lead to morbidity and mortality. Injuries from these hazards can be fatal and can occur unpredictably (Denoble, Pollock et al. 2008; Denoble, Caruso et al. 2008).

The PADI organization systematically collects diving incident and fatality data as part of an internal and comprehensive quality and risk-management surveillance and monitoring system. PADI employs the largest full-time staff of risk- and quality-management personnel across its seven international offices in recreational diving. These employees manage and administer a robust quality-management system, both proactively and retrospectively monitoring PADI training program standards, conduct, implementation and outcomes around the world.

Bound by organizational standards and an annual membership agreement, PADI instructor, divemaster and dive center members in 175 countries across the world are required to follow a Code of Practice (Appendix 1 to this paper; Appendix 2 is the PADI Safe Diving Practice Statement and the RSTC Medical Statement) and to report any diving incident to the PADI organization. In certain markets, this is also a requirement of liability insurance coverage via a warranty of coverage. Because of these requirements, and a quality-management enforcement system, collection of diving incident and accident reports from PADI members is global.

Since its inception in 1967, the PADI organization has issued more than 18,400,000 diver certifications internationally (Table 1). The number of PADI-affiliated instructors and divemasters has also grown substantially during this time (2008: 134,959 worldwide). It is estimated that the PADI organization certifies 60-70 percent of the world's scuba divers on an annual basis.

Table 1: PADI certifications by year since inception

Year	Certifications Per Year	Cumulative Certifications	Growth Percentage
1967	3,226	3,226	
1968	8,442	11,668	161.69%
1969	12,168	23,836	44.14%
1970	23,736	47,572	95.07%
1971	36,490	84,062	53.73%
1972	51,842	135,904	42.07%
1973	60,120	196,024	15.97%
1974	49,834	245,858	-17.11%
1975	61,244	307,102	22.90%
1976	66,609	373,711	8.76%
1977	69,771	443,482	4.75%
1978	86,187	529,669	23.53%
1979	95,193	624,862	10.45%
1980	107,404	732,266	12.83%
1981	124,365	856,631	15.79%
1982	141,429	998,060	13.72%
1983	168,778	1,166,838	19.34%
1984	203,001	1,369,839	20.28%
1985	240,384	1,610,223	18.42%
1986	277,378	1,887,601	15.39%
1987	315,468	2,203,069	13.73%

Year	Certifications Per Year	Cumulative Certifications	Growth Percentage
1988	350,000	2,553,069	10.95%
1989	387,767	2,940,836	10.79%
1990	440,418	3,381,254	13.58%
1991	456,046	3,837,300	3.55%
1992	529,463	4,366,763	16.10%
1993	564,672	4,931,435	6.65%
1994	625,487	5,556,922	10.77%
1995	680,263	6,237,185	8.76%
1996	717,973	6,955,158	5.54%
1997	743,763	7,698,921	3.59%
1998	775,735	8,474,656	4.30%
1999	799,696	9,274,352	3.09%
2000	852,702	10,127,054	6.63%
2001	907,171	11,034,225	6.39%
2002	896,977	11,931,202	-1.12%
2003	907,722	12,838,924	1.20%
2004	954,049	13,792,973	5.10%
2005	927,529	14,720,502	-2.78%
2006	936,579	15,657,081	0.98%
2007	952,716	16,609,797	1.72%
2008	952,097	17,561,894	-0.06%
2009	897,401	18,459,295	-5.74%

Methodology

Annual records of certifications issued, resultant training dives conducted and reports of diving fatality cases collected by PADI were examined for two 10-year periods: 1989-1998 and 1999-2008, respectively.

Three sets of data were grouped and analyzed for each of these 10-year periods: (1) fatalities occurring during PADI-sanctioned training programs or under supervision of a PADI member while enrolled in a non-PADI program; (2) diving fatalities occurring outside of PADI-sanctioned training programs and involving a PADI-certified diver; and (3) fatalities involving a PADI diving professional (divemaster/assistant instructor/instructor) while at work.

In addition to statistical analyses, attempts to identify contributing factors to fatalities were extracted. Possible triggers, disabling agents, disabling injuries and causes of death were identified where possible; however, it was not unusual for one or more of these events to be unknown, unidentifiable or not present in the case reports.

1. *Fatalities occurring during PADI-sanctioned training programs or under supervision of a PADI member while enrolled in a non-PADI program: Data Set 1: A (1989-1998) and B (1999-2008).* For this diver training data set, it was possible to measure risk accurately in an objective and scientific manner. An accurate and reliable denominator for each training program was calculated by using the number of individual certifications issued annually and the total required training dives conducted. Diving risk exposure by program was therefore calculated with a high degree of confidence. Using these records, it was possible to establish a reliable denominator-based statistic and determine the risk of death associated within the training envelope.

"Possible triggers, disabling agents, disabling injury and cause of death were identified where possible; however, it was not unusual for one or more of these events to be unknown, unidentifiable or not present in the case reports."

2. *Diving fatalities occurring outside of PADI-sanctioned training programs and involving a PADI-certified diver: Data Set 2: A (1989-1998) and B (1999-2008).* For this nontraining data set, it was not possible to establish a reliable denominator-based statistic and determine the risk of death associated with diving. For these data, the author attempted to identify other nondenominator-based statistical analyses to identify contributing factors, cause of death and other interrelated variables.

3. *Fatalities involving a PADI diving professional (divemaster/assistant instructor/instructor) while at work. Data Set 3: A (1989-1998) and B (1999-2008).* For the diving professional at work data set, it was possible to measure the population of professionals at work for the period of study and correlate fatalities accordingly. Where possible, other statistical analyses were conducted.

"For the diving professional at work data set, it was possible to measure the population of professionals at work for the period of study and correlate fatalities accordingly."

RESULTS

A. 1989–1998 Data Results

For the 10-year period of 1989-1998, 409 unique records exist that break down as follows:

Data Set 1A

103 Number of training fatalities resulting in the death of a diver while enrolled in a PADI training course

8 Number of fatalities resulting in the death of a diver while under the supervision of a PADI Member in a non-PADI program

111 Total

Data Set 2A

290 Number of nontraining fatalities (death of a PADI diver while not under PADI member supervision or training)

Data Set 3A

8 Number of at-work fatalities (death of a PADI member while working)

Table 2 shows the geographical location of all fatalities; all categories for 1989-1998 with the top 10 locations in descending order for the period identified.

Table 2a: Geographic location of fatalities (US: 232 or other countries: 177), all categories (working, training and non-training) from 1989-1998

LOCATION	#				
AFRICA	1	GRENADA	2	OR	3
AL	1	GUAM	5	PA	10
ANTILLES	1	HI	21	PALAU	1
AR	3	HONDURAS	4	PHILIPPINES	4
ARUBA	2	IL	4	PUERTO RICO	5
AUSTRALIA	8	IN	2	RI	1
AZ	1	INDONESIA	1	SAIPAN	1
BAHAMAS	12	IRELAND	1	SAUDI ARABIA	4
BELIZE	2	ISRAEL	1	SC	2
BERMUDA	2	JAMAICA	4	SCOTLAND	1
BONAIRE	3	JAPAN - OKINAWA	3	SD	1
BORA BORA	1	KUWAIT	1	SEYCHELLES	1
BVI	3	KY	1	SOUTH AFRICA	2
BWI	9	MA	3	ST CROIX	1
CA	38	MALAYSIA	6	ST. LUCIA	1
CANADA	2	MALTA	2	THAILAND	4
CARIB	1	MARSHALL ISLANDS	2	TN	1
CAYMAN	1	ME	5	TOBAGO	3
CHILE	1	MEXICO	19	TURKEY	2
CHINA	1	MI	1	TX	11
CO	1	MN	1	UK	1
CT	1	MO	2	USVI	6
CYPRUS	2	MS	1	UT	1
DOMINICAN REP	1	NC	5	VA	3
EGYPT	15	NETH ANTILLES	2	VANUATU	3
ENGLAND	20	NH	1	VENEZUELA	1
FL	53	NJ	6	WA	9
FRANCE	1	NM	3	WI	6
GA	3	NV	1	WV	1
GRAND CAYMAN	2	NY	11	**Total**	**409**
GREECE	1	OH	4		
		OMAN	1		

Table 2b: Top 10 locations (descending order): 210 of 409 = 51.3% of all recorded fatalities between 1989-1998

Location	#
FL	53
CA	38
HI	21
ENGLAND	20
MEXICO	19
EGYPT	15
BAHAMAS	12
NY	11
TX	11
PA	10

A summary of fatalities by level of PADI diver certifications for 1989-1998 is shown in Table 3.

Table 3: Summary of fatalities by level of PADI certification or supervised experience (1989-1998)

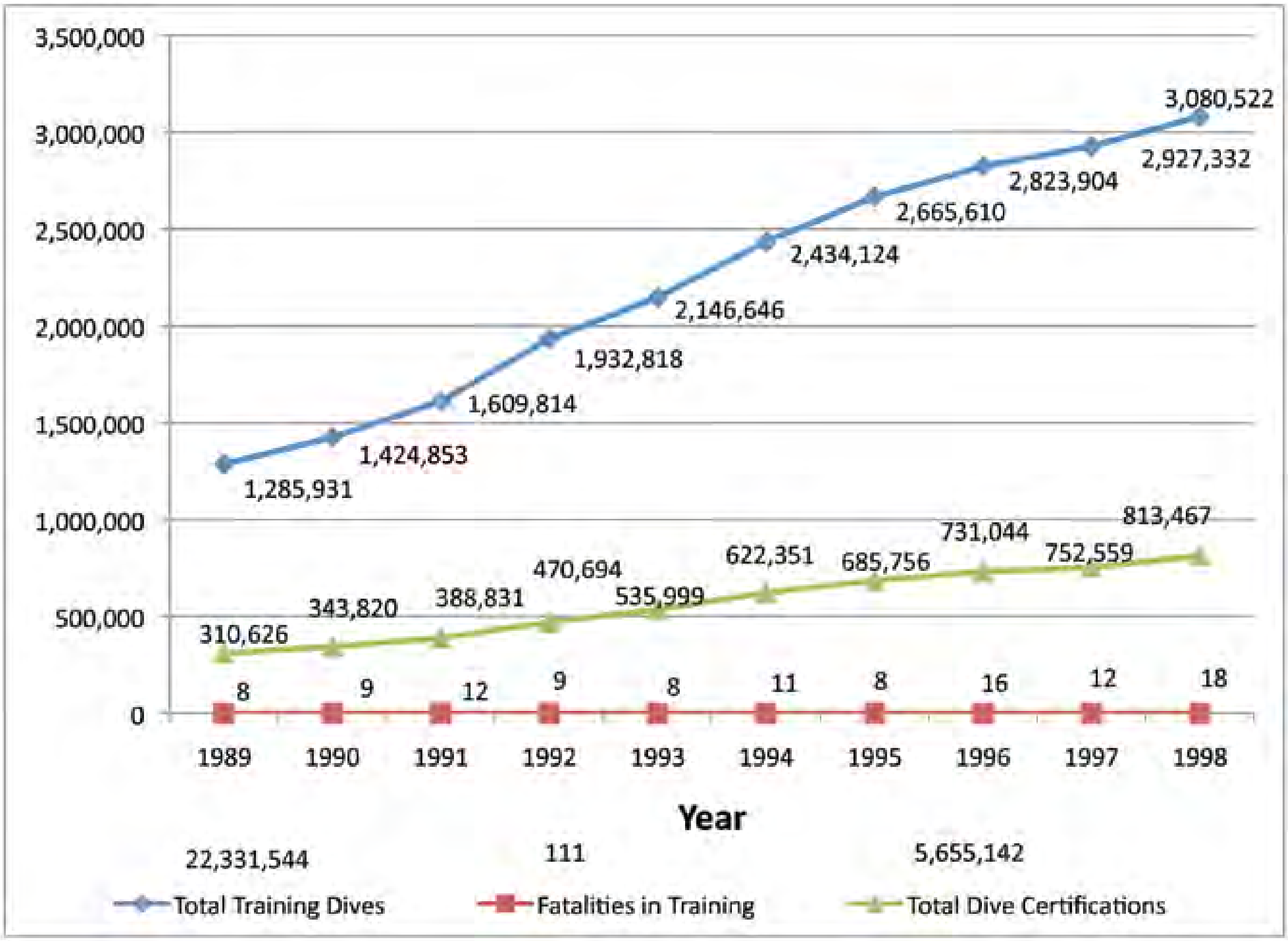
LEVEL	TRAINING	NON-TRAINING	WORKING	Total
Advanced Open Water	35	58		92
Assistant Instructor		3		3
Divemaster	3	15	2	20
Discover Scuba Diving	11	1		12
Instructor Examination, Assistant Instructor			1	1
Master Instructor		1	1	2
Master Scuba Diver		1		1
Master Scuba Diver Trainer		2		2
Open Water / Junior Open Water	50	158		203
Open Water Scuba Instructor		22	4	26
Rescue	2	27		28
Resort Experience (non-PADI)	7	1		8
Specialty: Altitude	1			1
Specialty: Underwater Hunter	1			1
Specialty: Wreck	1	1		2
Total	**111**	**290**	**8**	**409**

Data Set 1A. Fatalities Occurring During PADI-Sanctioned Training Programs or Under Supervision of a PADI Member While Enrolled in a Non-PADI Program (1989-1998)

A summary of the total number of certifications issued, training dives conducted and fatalities by year from 1989 to 1998 is presented in Figure 1. A total of 22,331,544 training dives were conducted, with 5,655,142 certifications issued and 111 associated fatalities occurred in training or supervision during this period.

An overall fatality rate for divers in training or under supervision for this 10-year period was calculated to be 1.821/100,000 divers with a range of 1.167 to 2.829 per 100,000 divers. The fatality rate for the 1989-1998 period for training dives was 0.461/100,000 dives with a range of 0.300 to 0.683 per 100,000 dives.

Figure 1: Number of PADI certifications, training dives and fatalities (1989-1998)



The geographic location of fatalities that occurred in training or under supervision only for 1989-1998 is presented in Table 4 with the top 10 locations in descending order for the period.

Table 4a: Geographic location of fatalities (US: 70 or other countries: 41): training or under supervision only from 1989-1998

AR	2	GUAM	1	OH	1
ARUBA	1	HI	6	OMAN	1
AUSTRALIA	3	IL	1	OR	2
AZ	1	IN	1	PA	5
BERMUDA	2	INDONESIA	1	PHILIPPINES	1
BVI	1	IRELAND	1	PUERTO RICO	2
BWI	1	ISRAEL	1	SAUDI ARABIA	1
CA	11	JAMAICA	1	SCOTLAND	1
CHINA	1	JAPAN - OKINAWA	1	SEYCHELLES	1
CO	1	KUWAIT	1	SOUTH AFRICA	2
CT	1	MA	1	TX	4
CYPRUS	1	MALAYSIA	1	USVI	2
DOMINICAN REP	1	MALTA	2	UT	1
EGYPT	1	ME	1	WA	4
ENGLAND	6	MEXICO	3	WI	3
FL	13	MN	1	Total	111
FRANCE	1	NJ	1		
GA	1	NM	3		
GREECE	1	NY	2		

Table 4b: Top 10 locations (descending order): 58 of 111 = 52.3% of all recorded fatalities (1989-1998)

Location	#
FL	13
CA	11
ENGLAND	6
HI	6
PA	5
TX	4
WA	4
WI	3
NM	3
MEXICO	3

A summary of fatalities occurring during training or supervision by course being conducted, gender and year is shown in Table 5.

Figure 2 presents a summary of fatalities in training or under supervision by age for 1989-1998. The age range was 14 to 67 years old with a median age of 41 years.

Figure 3 shows the number of fatalities in training or under supervision by year for the 10-year period 1989-1998.

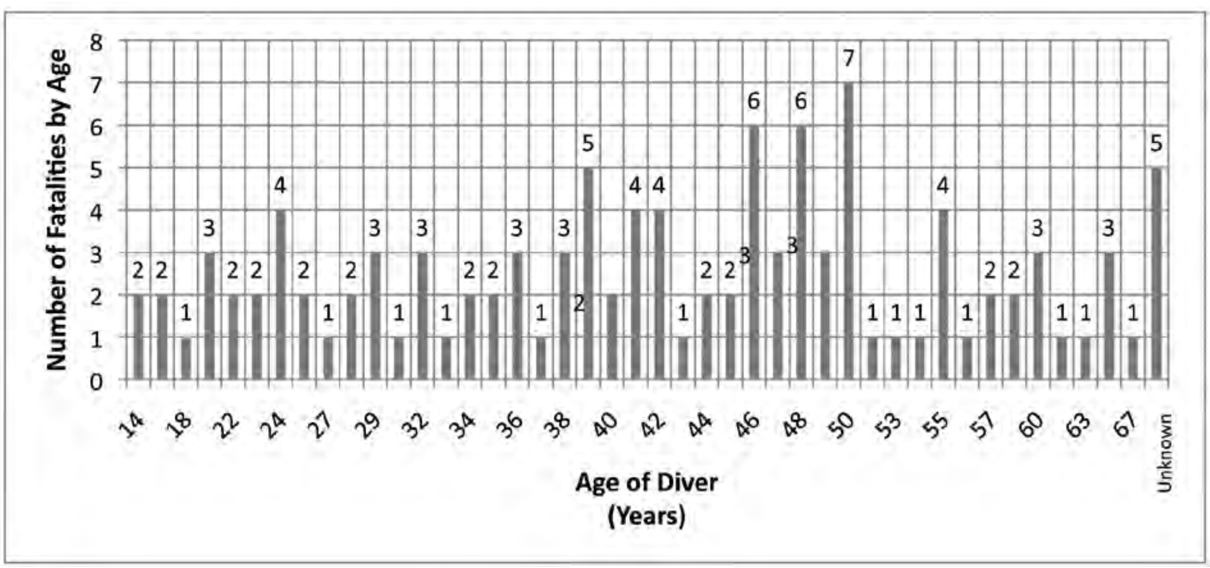
Figure 4 presents fatalities in training or under supervision by cause of death (N =111). Cardiac was the largest cause of death for the period (31.5 percent), followed by unknown causes (27.9 percent) and drowning (27 percent). Embolism was attributed to 11.7 percent of the deaths for the period.

Table 6 describes fatality sequential events analysis for fatalities in training or under supervision for 1989-1998 where it was possible to derive this information.

Table 5: Summary of fatalities by course, gender and year: training or under supervision only (1989-1998)

Course Being Conducted		SEX	89	90	91	92	93	94	95	96	97	98	Total
Advanced Open Water		F	1	2	1			1		3	1	2	11
		M			3	3	1	1	5	3	3	5	24
	Sub-Total		1	2	4	3	1	2	5	6	4	7	35
Divemaster		F										1	1
		M						1	1			1	3
	Sub-Total							1	1			2	4
Discover Scuba Diving		F						1	1	2		1	5
		M					1	1		1	1	2	6
	Sub-Total						1	2	1	3	1	3	11
Open Water / Junior Open Water		F		3	2	2	2		1		1		11
		M	5	3	4	1	3	5		7	5	5	38
	Sub-Total		5	6	6	3	5	5	1	7	6	5	49
Rescue		F										1	1
		M				1							1
	Sub-Total					1						1	2
Resort Experience (Non-PADI)		F			1	2							3
		M	2	1			1						4
	Sub-Total		2	1	1	2	1						7
Specialty: Altitude		M									1		1
	Sub-Total										1		1
Specialty: Underwater Hunter		M						1					1
	Sub-Total							1					1
Specialty: Wreck		M			1								1
	Sub-Total				1								1
Total			8	9	12	9	8	11	8	16	12	18	111
Total Females													32 = 28.8%
Total Males													79 = 71.2%

Figure 2: Summary of fatalities by age and injury type: training or under supervision only (1989-1998)



- Ages for training fatalities (N=118) range from 14 to 67, with 5 records being unknown
- Median fatality age is 41 years old

Figure 3: Fatalities during PADI training worldwide, except Japan (1989-1998)

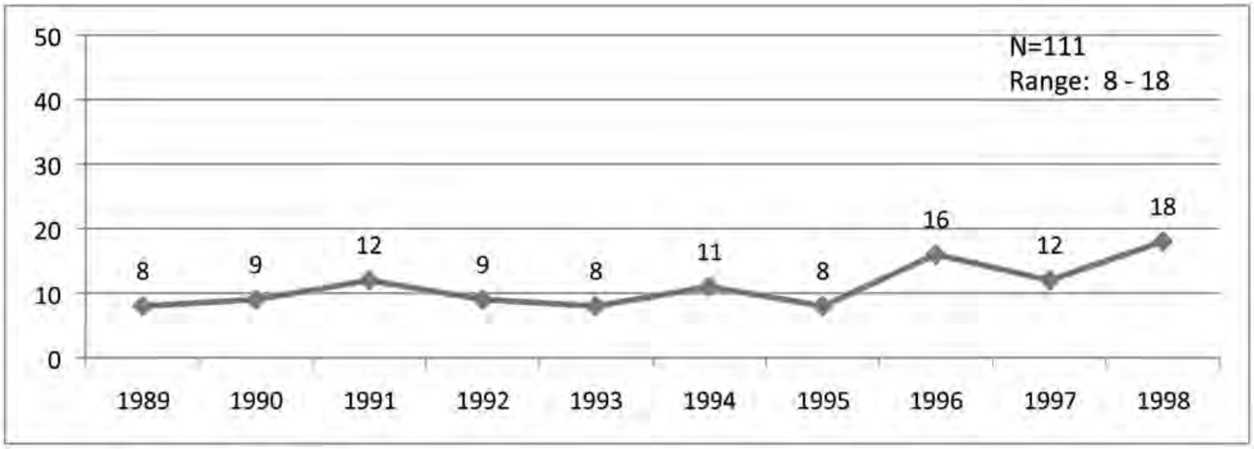


Figure 4: Training fatalities by cause of death worldwide, except Japan (1989-1998)

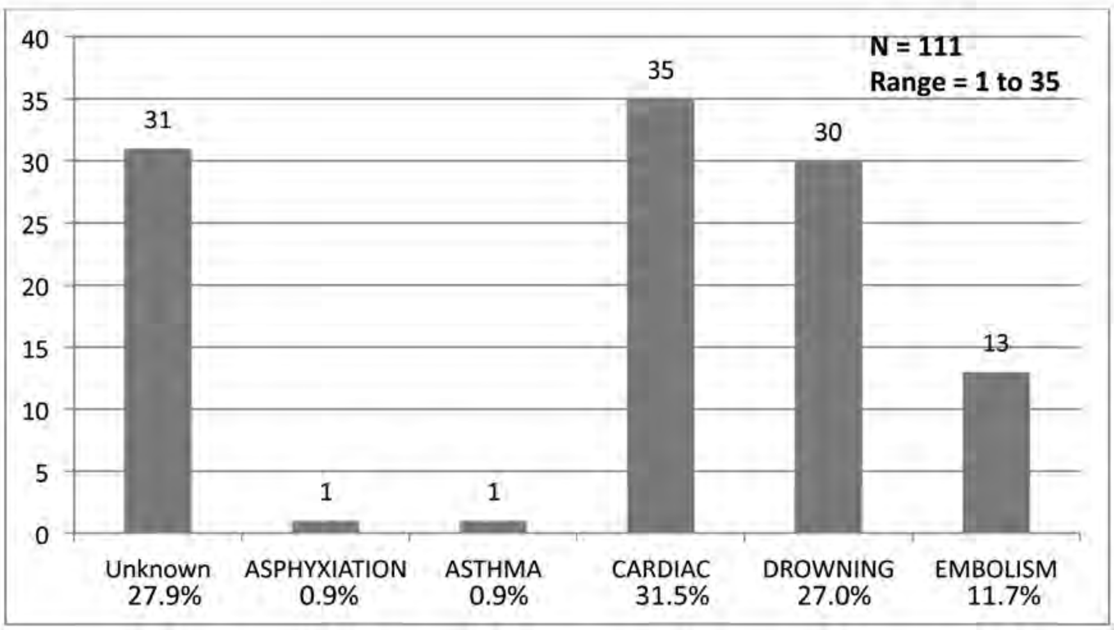


Table 6: Fatality sequential events analysis (1989-1998)

Triggers

Out of gas	Exertion
Entangled	Rapid Ascent
Overweight / Diabetic	Hypertension
Group / Buddy Separation	Asthma

Disabling Agents

Unreported previous brain surgery
Panic
Hypoxia / shallow water blackout

Disabling Injuries

Embolism
Heart attack
Post-dive heart attack

Causes of Death	#	% of Total
Cardiac Arrest	35	31.5%
Unknown	31	27.9%
Drowning	30	27.0%
Embolism	13	11.7%
Asphyxiation	1	0.9%
Asthma	1	0.9%
Total	111	100%

Table 7 shows the causes of death by gender and year for fatalities in training or under supervision for PADI courses and non-PADI affiliated supervised resort experience dives.

Table 7: Fatalities by gender and year: training or under supervision only (1989-1998)

PADI Entry-Level Courses: N=49

Cause of Death	SEX	89	90	91	92	93	94	95	96	97	98	Total
Unknown	F		1			1						2
	M	1	2						6	2		11
Total		1	3			1			6	2		13
Cardiac	F		1		1					1		3
	M	3	1	2	1	3	3		1	3	3	20
Total		3	2	2	2	3	3		1	4	3	23
Drowning	F		1	1	1	1		1				5
	M			1			2					3
Total			1	2	1	1	2	1				8
Embolism	F			1								1
	M	1		1							2	4
Total		1		2							2	5
Total		5	6	6	3	5	5	1	7	6	5	49

PADI Advanced Open Water Courses: N=35

Cause of Death	SEX	89	90	91	92	93	94	95	96	97	98	Total
Unknown	F	1	1	1			1		1			5
	M			3	1					1		5
Total		1	1	4	1		1		1	1		10
Cardiac	M							4	1	1	1	7
Total								4	1	1	1	7
Drowning	F		1						1	1	2	5
	M					1	1	1	2		4	9
Total			1			1	1	1	3	1	6	14
Embolism	F								1			1
	M				2					1		3
Total					2				1	1		4
Total		1	2	4	3	1	2	5	6	4	7	35

PADI DSD Experience: N=11

Cause of Death	SEX	1993	1994	1995	1996	1997	1998	Total
Unknown	F		1		1			2
	M		1					1
Total			2		1			3
Asphyxiation	M					1		1
Total						1		1
Asthma	F			1				1
Total				1				1
Cardiac	M						1	1
Total							1	1
Drowning	F				1		1	2
	M	1			1		1	3
Total		1			2		2	5
Total		1	2	1	3	1	3	11

Table 7 (continued)

PADI Rescue Courses: N=2

Cause of Death		SEX	1992	1998	Total
Cardiac		F		1	1
	Total			1	1
Drowning		M	1		1
	Total		1		1
Total			1	1	2

PADI Specialty Courses: N=3

Cause of Death		SEX	1991	1994	1997	Total
Unknown		M	1		1	2
	Total		1		1	2
Drowning		M		1		1
	Total			1		1
Total			1	1	1	3

PADI Divemaster Courses: N=3

Cause of Death		SEX	1994	1995	1998	Total
Cardiac		M	1		1	2
	Total		1		1	2
Embolism		F			1	1
	Total				1	1
Unknown		M		1		1
	Total			1		1
Total			1	1	2	4

Non-PADI Affiliated Resort Experience: Under Supervision only: N=7

Cause of Death		SEX	1989	1990	1991	1992	1993	Total
Unknown		F				1		1
		M	1					1
	Total		1			1		2
Cardiac		M	1					1
	Total		1					1
Drowning		M		1				1
	Total			1				1
Embolism		F			1	1		2
		M					1	1
	Total				1	1	1	3
Total			2	1	1	2	1	7

A comparison of cause of death in fatalities in training or under supervision to age was conducted. Table 8 shows the number, range of ages and median ages for unknown, asphyxiation-related, asthma-related, cardiac-related and drowning- and embolism-related deaths, respectively.

Table 8: Fatal training injuries by age and type (1989-1998)

Cause	Unknown	Asphyxiation	Asthma	Cardiac	Drowning	Embolism
Age Range	14-63	50	19	31-67	14-65	15-65
Median age	40	50	19	50	34	39
< 20 yrs	2		1	0	3	1
21-30 yrs	5			0	9	2
31-40 yrs	7			3	8	5
41-50 yrs	10	1		19	7	1
51+ yrs	4			12	2	3
Unknown	3			1	1	
Total	31	1	1	35	30	13

Table 9 shows a compilation of all PADI training courses conducted, number of certifications issued, training dives conducted and fatality rates per 100,000 divers and dives. The overall fatality rate for divers during this 10-year period was calculated to be 1.839/100,000 divers with a range of 1.167 to 2.829 per 100,000 divers. The fatality rate for this period for training dives was 0.466/100,000 dives with a range of 0.300 to 0.683 per 100,000 dives.

The Discover Scuba Diving (DSD) Program was introduced in 1992. The actual number of DSD experiences conducted is likely much larger because the denominator used to calculate these rates are based only upon registrations received at PADI. DSD causes of death were: unknown (2), asthma (1), drowning (5), cardiac (1) and asphyxiation (1). Related contributing factors were panic (1), loss of control/separation (2), out of air (1) and medical condition (1).

Further, Rescue Diver training experienced one drowning and one cardiac case; specialty training, two unknown and one drowning case; divemaster training, two cardiac and one embolism case.

Table 10 presents advanced open-water training fatality data with notes on deep diving.

Table 9: PADI worldwide certifications and fatalities (except Japan) for courses and programs (1989-1998)

Entry-Level (4 dives)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total Entry-Level Certifications	224,008	246,312	277,326	331,805	350,637	389,540	423,734	440,109	450,460	463,865	3,597,796
Total Entry-Level Training Dives	895,962	985,196	1,109,256	1,324,796	1,402,104	1,558,030	1,694,822	1,760,382	1,801,782	1,855,404	14,387,734
Fatalities in Entry-Level Training	5	6	6	3	5	5	1	7	6	5	49
Fatality Rate per 100K divers	2.232	2.436	2.164	0.904	1.426	1.284	0.236	1.591	1.332	1.078	1.362
Fatality Rate per 100K dives	0.558	0.609	0.541	0.226	0.357	0.321	0.059	0.398	0.333	0.269	0.341

Advanced Open Water (5 dives)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total AOW Certifications	47,668	54,196	61,858	77,133	87,698	101,561	114,278	125,281	133,875	142,034	945,582
Total AOW Training Dives	238,340	270,980	309,290	385,665	438,490	507,805	571,390	626,405	669,375	710,170	4,727,910
Fatalities in AOW Training	1	2	4	3	1	2	5	6	4	7	35
Fatality Rate per 100K divers	2.098	3.690	6.466	3.889	1.140	1.969	4.375	4.789	2.988	4.928	3.701
Fatality Rate per 100K dives	0.420	0.738	1.293	0.778	0.228	0.394	0.875	0.958	0.598	0.986	0.740

Discover Scuba Diving (1 dive)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total DSD Experiences	0	0	0	5,113	29,111	53,027	61,398	69,974	65,663	95,293	379,579
Total DSD Training Dives	0	0	0	5,113	29,111	53,027	61,398	69,974	65,663	95,293	379,579
Fatalities in DSD Training	0	0	0	0	1	2	1	3	1	3	11
Fatality Rate per 100K divers				0.000	3.435	3.772	1.629	4.287	1.523	3.148	2.898
Fatality Rate per 100K dives				0.000	3.435	3.772	1.629	4.287	1.523	3.148	2.898

Rescue Diver (5 dives)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total Rescue Certifications	16,008	17,828	20,377	24,186	26,997	30,618	32,512	35,580	37,042	38,329	279,477
Total Rescue Training Dives	80,040	89,140	101,885	120,930	134,985	153,090	162,560	177,900	185,210	191,645	1,397,385
Fatalities in Rescue Training	0	0	0	1	0	0	0	0	0	1	2
Fatality Rate per 100K divers	0.000	0.000	0.000	4.135	0.000	0.000	0.000	0.000	0.000	2.609	0.716
Fatality Rate per 100K dives	0.000	0.000	0.000	0.827	0.000	0.000	0.000	0.000	0.000	0.522	0.143

Specialties	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total Specialty Certifications	21,902	24,468	28,022	30,952	33,204	37,798	43,985	50,191	54,480	62,098	387,100
Total Specialty Training Dives	65,349	73,449	81,903	87,288	91,844	103,330	116,346	129,789	139,068	156,922	1,045,288
Fatalities in SpecialtyTraining	0	0	1	0	0	1	0	0	1	0	3
Fatality Rate per 100K divers	0.000	0.000	3.569	0.000	0.000	2.646	0.000	0.000	1.836	0.000	0.775
Fatality Rate per 100K dives	0.000	0.000	1.221	0.000	0.000	0.968	0.000	0.000	0.719	0.000	0.287

Divemaster (6 dives)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total DM Certifications	1,040	1,014	1,246	1,504	8,352	9,807	9,849	9,909	11,039	11,848	65,608
Total DM Training Dives	6,240	6,084	7,476	9,024	50,112	58,842	59,094	59,454	66,234	71,088	393,648
Fatalities in DM Training	0	0	0	0	0	1	1	0	0	2	4
Fatality Rate per 100K divers	0.000	0.000	0.000	0.000	0.000	10.197	10.153	0.000	0.000	16.880	6.097
Fatality Rate per 100K dives	0.000	0.000	0.000	0.000	0.000	1.699	1.692	0.000	0.000	2.813	1.016

Cumulative - All Courses	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total Certifications	310,626	343,818	388,829	470,693	535,999	622,351	685,756	731,044	752,559	813,467	5,655,142
Total Training Dives	1,285,931	1,424,849	1,609,810	1,932,816	2,146,646	2,434,124	2,665,610	2,823,904	2,927,332	3,080,522	22,331,544
Fatalities in Training	6	8	11	7	7	11	8	16	12	18	104
Fatality Rate per 100K divers	1.932	2.327	2.829	1.487	1.306	1.767	1.167	2.189	1.595	2.213	1.839
Fatality Rate per 100K dives	0.467	0.561	0.683	0.362	0.326	0.452	0.300	0.567	0.410	0.584	0.466

Activity (non-certified supervised participant) *	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Non-PADI-affiliated Resort Program	2	1	1	2	1	0	0	0	0	0	7

Table 10: Advanced open-water diver training fatalities worldwide (excluding Japan)

Training dive type	#	%
Deep	19	54.3
Night	7	20.0
Navigation	2	5.7
OW #5	1	2.9
Drift	2	5.7
Buoyancy	1	2.9
Boat	1	2.9
Drysuit	1	2.9
N/A (freedive)	1	2.9
TOTAL	35	100

Note: Deep-diving fatality locations and depths were TX-90', UT-80', CA-100', NY-100', England-105', CA-?, Israel-88', NJ-104', WI-70', NY-38', WA-80', China-?, WI-92', TX-90', England-51', GA-45', MA-95', England-90'. Deep diving (19) causes of death of the total AOW (35) were: unknown (9/10), drowning (6/14), embolism (2/4), cardiac (2/7). Related factors in deep diving fatalities were: separation from buddy (2), panic (1), rapid ascent (2), surface cardiac arrest (1), and double drowning-instructor and student.

B. 1999-2008 Data Results

For the 10-year period of 1999-2008, 725 unique records exist, which breakdown as follows:

Data Set 1B

192 Number of training fatalities resulting in the death of a diver while enrolled in a PADI training course

1 Number of fatalities resulting in the death of a diver while under the supervision of a PADI Member in a non-PADI program.

193 Total

Data Set 2B

518 Number of nontraining fatalities (death of a PADI diver while not under PADI member supervision or training)

Data Set 3B

14 Number of at-work fatalities (death of a PADI member while working)

Table 11 shows the geographical location of all fatalities; all categories for 1999-2008 with the top ten locations in descending order for the period indicated.

Table 11a: Geographic location of fatalities (US: 200 or other countries: 525), all categories from 1999-2008

LOCATION	Total
AK	2
AL	1
ANTARCTICA	1
AR	4
ARGENTINA	3
ARUBA	2
AUSTRALIA	38
AUSTRIA	2
BAHAMAS	19
BELIZE	8
BERMUDA	1
BONAIRE	5
BVI	2
BWI	2
CA	33
CAMBODIA	1
CANADA	33
CAYMAN ISLANDS	16
CO	1
COCO ISLANDS	2
COLOMBIA	1
COOK ISLANDS	2
COSTA RICA	1
CROATIA	1
CUBA	1
CURACAO	1
CYPRUS	2
DE	1
DOMINICAN REPUBLIC	6
EGYPT	46
ENGLAND	32
FIJI	4
FL	46
FRENCH POLYNESIA	3
GERMANY	5
GREECE	3
GUAM	2
HI	26
HONDURAS	8
HONG KONG	3
IA	1
IL	4
INDONESIA	13
IRELAND	3
ITALY	2
JAMAICA	2
JAPAN	25
KENYA	1
KOREA	2
KY	1
LEBANON	3
MA	5
MALAYSIA	13
MALDIVES	3
MALTA	9
MAURITIUS	2
ME	1
MEXICO	37
MI	6
MICRONESIA	1
MN	4
MO	2
MOZAMBIQUE	2
MT	1
NC	8
NETHERLAND ANTILLES	1
NETHERLANDS	2
NEW ZEALAND	12
NH	1
NJ	5
NM	1
NY	1
OH	2
OMAN	1
OR	1
PA	8
PALAU	4
PANAMA	1
PAPUA NEW GUINEA	2
PHILIPPINES	18
POLAND	3
PR	3
ROMANIA	1
RUSSIA	1
SABA	1
SAIPAN	5
SAUDI ARABIA	9
SC	1
SCOTLAND	9
SEYCHELLES	4
SOUTH AFRICA	1
SOUTH KOREA	1
SPAIN	9
ST MAARTEN	2
SWITZERLAND	3
TAIWAN	3
TANZANIA	8
THAILAND	32
TOBAGO	1
TURKEY	5
TURKS & CAICOS	3
TX	8
UNITED ARAB EMIR	2
Unknown	1
USVI	4
UT	3
VA	1
VENEZUELA	2
VIETNAM	1
VT	2
WA	13
WI	2
Total	**725**

Table 11b: Top 10 locations (descending order): 348 of 725= 48% of all recorded fatalities between 1999-2008

Location	#
Egypt	46
FL	46
Australia	38
Mexico	37
CA	33
Canada	33
England	32
Thailand	32
HI	26
Japan	25

A summary of fatalities by diver PADI certification level for 1999-2008 is shown in Table 12.

Table 12: Summary of fatalities by level of PADI certification (1999-2008)

LEVEL	TRAINING	NON-TRAINING	WORKING	Total
Assistant Instructor		2	2	4
Advanced Open Water	52	120		172
Atlantis Rebreather	1			1
Basic Scuba		4		4
Course Director		1		1
DEEP	4			4
Divemaster	1	29	4	34
DRY	1	2		3
Discover Scuba Experience (DSD)	24			24
DTR	1			1
EANX	1	5		6
IDCS		1		1
Master Instructor		3		3
Master Scuba Diver		7		7
Master Scuba Diver Trainer		10	3	13
NIGHT	2			2
Open Water	84	190		274
Open Water Scuba Instructor		21	5	26
PHOTO	1			1
Peak Performance Buoyancy	1			1
RESCUE	2	36		38
Resort	1	2		3
SCUBA Review	1			1
Scuba Diver	4	2		6
TEC	3			3
TEC DEEP Instructor		1		1
Adventure		1		1
WRECK	2	1		3
(Unknown)		78		78
ARCH RESEARCH		1		1
BOAT	1			1
CAVERN		1		1
DRIFT	3			3
DRY SUIT	1			1
FULL FACE MASK	1			1
TEC DEEP	1			1
Grand Total	**193**	**518**	**14**	**725**

Data Set 1B: Fatalities in training programs or under supervision (1999-2008)

Figure 5 represents the total number of certifications issued, training dives conducted and fatalities by year for 1999-2008. A total of 40,709,687 training dives were conducted, with 11,568,983 certifications issued and 193 associated fatalities in training during this period. An overall fatality rate for divers in this 10-year period was calculated to be 1.660/100,000 divers with a range of 0.918 to 2.698 per 100,000 divers. The fatality rate for the 1999-2008 period for training dives was 0.472/100,000 dives with a range of 0.283 to 0.692 per 100,000 dives.

Figure 5: Number of PADI certification, training dives and fatalities per year (1999-2008)

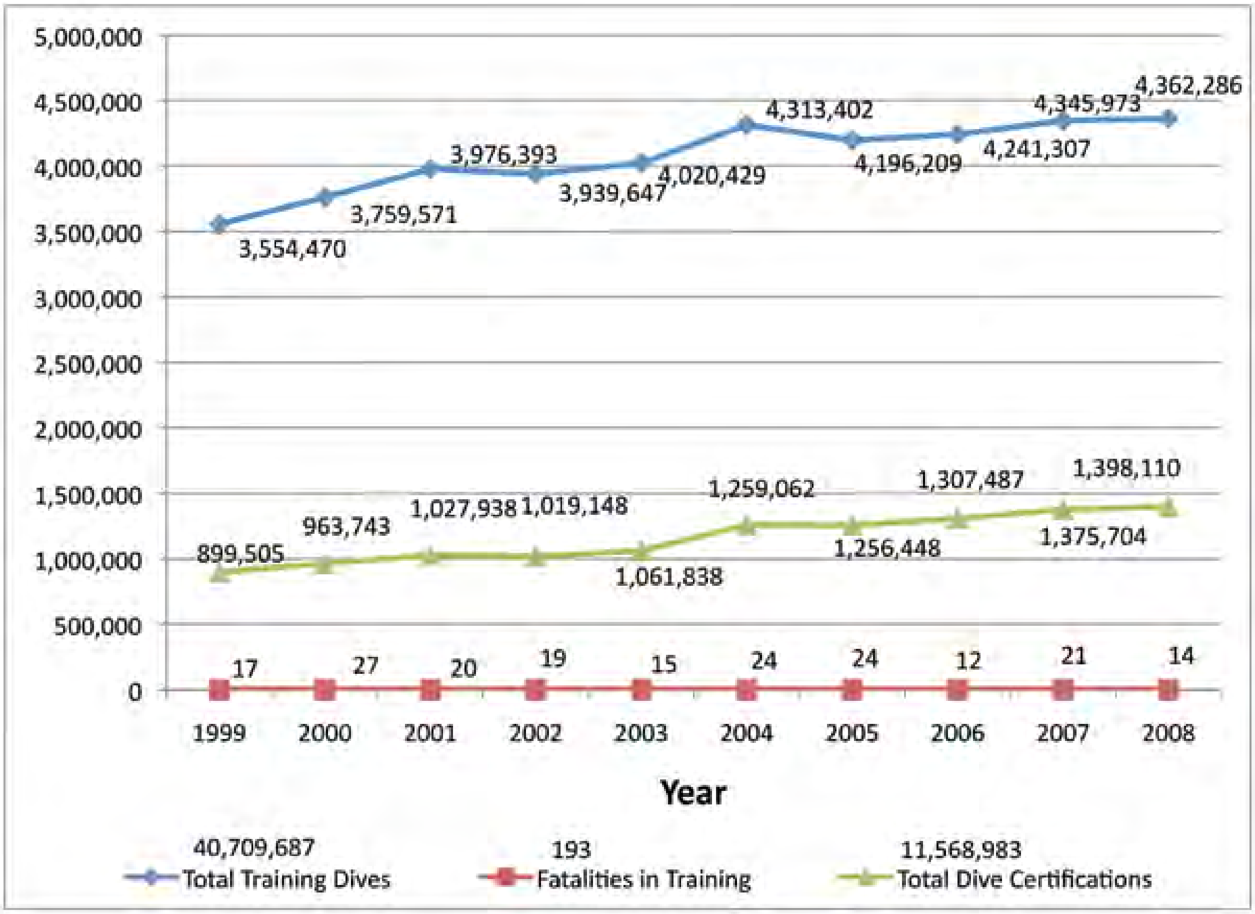


Table 13 identifies the geographic location of fatalities that occurred in training or under supervision only for 1999-2008 with the top 10 locations in descending order for the period.

Table 13a: Location of fatalities by U.S. state (63) or other countries (130): training or under supervision only (1999-2008)

LOCATION	Total
CANADA	17
HI	11
CA	11
JAPAN	11
FL	10
MEXICO	10
THAILAND	10
EGYPT	10
ENGLAND	9
AUSTRALIA	7
MALAYSIA	5
NEW ZEALAND	4
DOMINICAN REPUBLIC	4
PHILIPPINES	4
SAIPAN	3
TX	3
ARGENTINA	3
AR	3
WA	3
PA	2
GERMANY	2
SAUDI ARABIA	2
IL	2
UT	2
INDONESIA	2
CAYMAN ISLANDS	2
JAMAICA	2
SWITZERLAND	2
MN	2
NC	2
GREECE	2
KENYA	1
FRENCH POLYNESIA	1
SPAIN	1
MALDIVES	1
CYPRUS	1
BAHAMAS	1
SCOTLAND	1
IA	1
VT	1
MO	1
WI	1
MOZAMBIQUE	1
CO	1
GUAM	1
SC	1
COOK ISLANDS	1
SOUTH AFRICA	1
BELIZE	1
ST MAARTEN	1
NJ	1
TANZANIA	1
NM	1
TURKEY	1
OH	1
USVI	1
HONG KONG	1
CROATIA	1
NETHERLANDS	1
KOREA	1
AL	1
MA	1
Total	**193**

Table 13b: Top 10 locations (descending order): 106 of 193 = 54.9% of all recorded fatalities between 1999-2008

Location	#
Canada	17
HI	11
CA	11
Japan	11
FL	10
Mexico	10
Thailand	10
Egypt	10
England	9
Australia	7

A summary of fatalities by course being conducted, gender and year for training or under supervision only is shown in Table 14.

Table 14: Summary of fatalities by course, gender and year: training or under supervision only (1999-2008)

COURSE BEING CONDUCTED	SEX	99	00	01	02	03	04	05	06	07	08	Total
Advanced Open Water	F	2	2		3	1	1	1		3	1	14
	M	3	9	1	1	3	3	5	3	8	2	38
Sub-Total		5	11	1	4	4	4	6	3	11	3	52
Atlantis Rebreather	M						1					1
Sub-Total							1					1
Deep	M		1		2			1				4
Sub-Total			1		2			1				4
Divemaster	M		1									1
Sub-Total			1									1
Dry Suit	F			1								1
Sub-Total				1								1
Discover Scuba Experience (DSD)	F	1	1				2			1	2	7
	M	1	1	2	2		5	1	2	1	2	17
Sub-Total		2	2	2	2		7	1	2	2	4	24
DTR	F					1						1
Sub-Total						1						1
EANx	M							1				1
Sub-Total								1				1
Night	F						1					1
	M							1				1
Sub-Total							1	1				2
Open Water	F	3	2	5	3	2	1	3		2	3	24
	M	4	5	8	8	4	9	8	6	4	4	60
Sub-Total		7	7	13	11	6	10	11	6	6	7	84
Underwater Photo	F							1				1
Sub-Total								1				1
Peak Performance Buoyancy	F							1				1
Sub-Total								1				1
Rescue	M	1		1								2
Sub-Total		1		1								2
Resort	M		1									1
Sub-Total			1									1
Scuba Review	M									1		1
Sub-Total										1		1
Scuba Diver	F					1						1
	M	1				2						3
Sub-Total		1				3						4
Tec	F			1								1
	M			1					1			2
Sub-Total				2					1			3
Wreck	M					1	1					2
Sub-Total						1	1					2

Table 14 (continued)

COURSE BEING CONDUCTED		SEX	99	00	01	02	03	04	05	06	07	08	Total
Boat		F									1		1
	Sub-Total										1		1
Drift		F		1									1
		M		2									2
	Sub-Total			3									3
Dry Suit		M		1									1
	Sub-Total			1									1
Full Face Mask		M	1										1
	Sub-Total		1										1
Tec Deep		M							1				1
	Sub-Total								1				1
Total Females													54 = 28.1%
Total Males													139 = 71.9%
Total			17	27	20	19	15	24	24	12	21	14	193

Figure 6 presents a summary of fatalities by age and injury type during training or under supervision only. Figure 7 shows the number of fatalities in training or under supervision by year (range: 12-27) for 1999-2008.

Figure 6: Summary of fatalities by age and injury type: training or under supervision only (1999-2008)

- Ages for training fatalities range from 13 to 72, with 14 records being unknown
- N=193, median fatality age is 45 years old

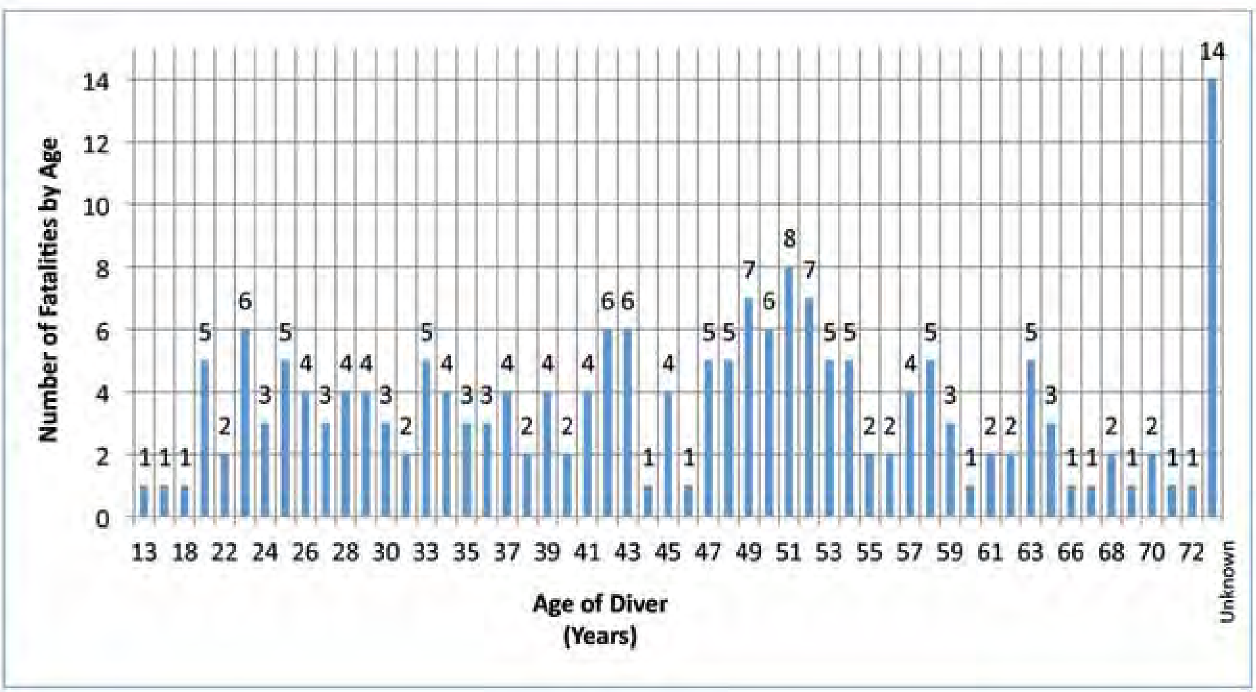


Figure 7: Fatalities during training or under supervision by year (1999-2008)

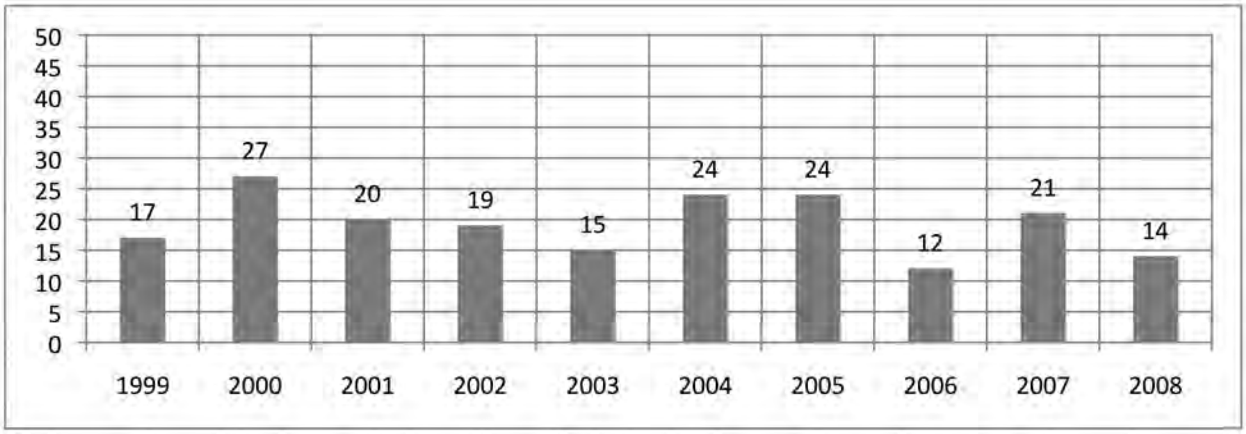


Figure 8 presents fatalities under training or under supervision by cause of death (n=193; range 1-61). Cardiac was the largest cause of death for the period (31.6 percent of total), followed by unknown causes (28 percent of total) and drowning (25.9 percent); embolism was attributed to 7.3 percent of the related deaths for the period.

Figure 8: Worldwide training fatalities by cause of death (1999-2008)

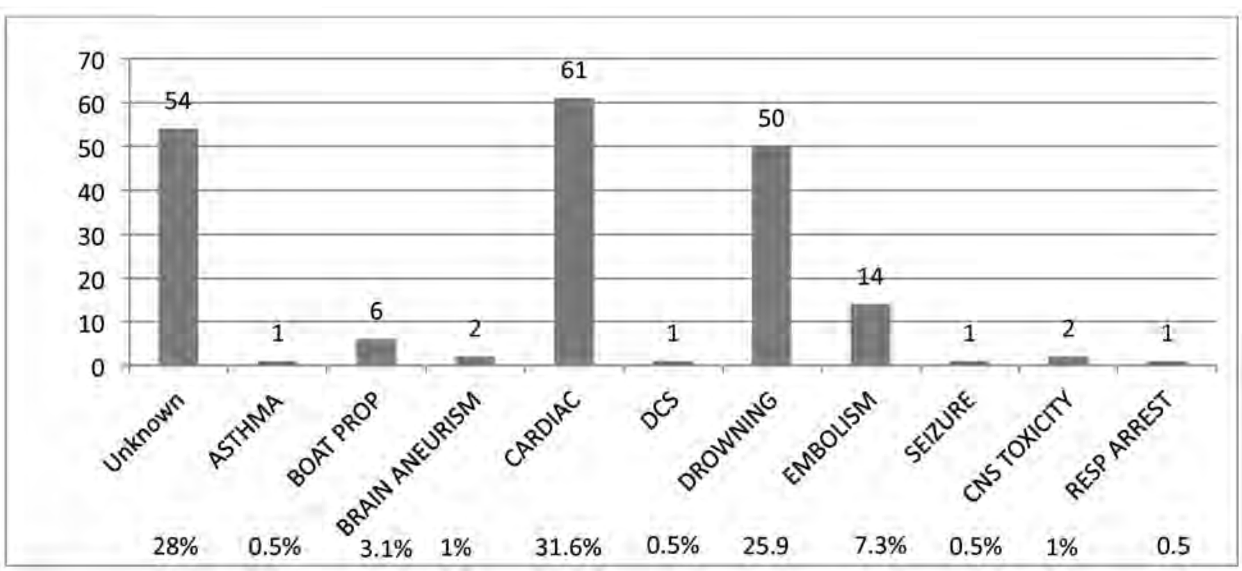


Table 15 describes fatality sequential events analysis for training or supervised dives for 1999-2008 where it was possible to derive this information.

Table 15: Fatality sequential events analysis:training or supervised dives (1999–2008)

Triggers	Disabling agents	Causes of Death	#	% Total
Out of gas	Ear problems	Cardiac Arrest	61	31.6
Entangled	Panic	Unknown	54	28.0
Obese/overweight	Seizure	Drowning	50	25.9
Diabetic		Embolism	14	7.3
Exertion		Boat Prop	6	3.1
Group/Buddy Separation		Brain Aneurysm	2	1.0
Rapid Ascent		CNS Toxicity	2	1.0
Hypertension		DCS	1	0.5
Cardiac Problem		Seizure	1	0.5
Depth		Respiratory Arrest	1	0.5
Difficulty with skill		Asthma	1	0.5
Rough water		Total	193	100
Buoyancy problems				
Anxiety or stress				
Hypertension				
Fatigue				
Rapid ascent				
Pre-existing medical condition				
Aspirated water				

Table 16 shows the causes of death by gender and year for training dives conducted in entry-level, Advanced Open Water, Discover Scuba Experience (DSD), Rescue Diver, Specialty training, Divemaster and non-PADI-affiliated resort experience dives, respectively.

Table 16: Fatalities by gender and year: training or under supervision only (1999-2008)

PADI Entry-Level Courses: N=89

CAUSE OF DEATH	SEX	99	00	01	02	03	04	05	06	07	08	Grand Total
Unknown	F					1		3		1	2	7
	M	1		2	1	1	2	3	2	3	2	17
Total		1		2	1	2	2	6	2	4	4	24
Asthma	M				1							1
Total					1							1
Boat prop	F			1			1				1	3
	M							1				1
Total				1			1	1			1	4
Brain aneurysm	F	1										1
	M		1									1
Total		1	1									2
Cardiac	F	1	1	2	1					1		6
	M	3	2		3	4	5	3	3	1	2	26
Total		4	3	2	4	4	5	3	3	2	2	32
Drowning	F			1	2	2						5
	M	1	1	5	2		1	1	1	1		13
Total		1	1	6	4	2	1	1	1	1		18
Embolism	F	1	1	1								3
	M		1			1	1					3
Total		1	2	1		1	1					6
Resp arrest	M				1							1
Total					1							1
Seizure	M			1								1
Total				1								1
Total		8	7	13	11	9	10	11	6	7	7	89

PADI Advanced Open Water Courses: N=52

CAUSE OF DEATH	SEX	99	00	01	02	03	04	05	06	07	08	Grand Total
Unknown	F	1			2					2		5
	M		2	1	1	1	2		1	2		10
Total		1			3	1	2		1	4		15
Boat prop	F										1	1
	M										1	1
Total											2	2
Cardiac	F				1					1		2
	M	1	2					1	1	2	1	8
Total		1	2		1			1	1	3	1	10
DCS	F						1					1
Total							1					1
Drowning	F	1	1			1		1				4
	M	1	5			2		3	1	3		15
Total		2	6			3		4	1	3		19
Embolism	F		1									1
	M	1					1	1		1		4
Total		1	1				1	1		1		5
Total		5	11	1	4	4	4	6	3	11	3	52

Table 16 (continued)

PADI DSD Experiences: N=24

CAUSE OF DEATH	SEX	99	00	01	02	04	05	06	07	08	Grand Total
Unknown	F					1				2	3
	M				1			1	1	1	4
Total					1	1		1	1	3	7
Cardiac	F		1						1		2
	M	1	1		1	5	1			1	10
Total		1	2		1	5	1		1	1	12
Drowning	F	1				1					2
	M			2				1			3
Total		1		2		1		1			5
Total		2	2	2	2	7	1	2	2	4	24

PADI Rescue Courses: N=2

CAUSE OF DEATH	SEX	1999	2001	Grand Total
Unknown	M	1		1
Total		1		1
Cardiac	M		1	1
Total			1	1
Total		1	1	2

PADI Specialty Courses: N=24

CAUSE OF DEATH	SEX	99	00	01	02	03	04	05	06	07	Grand Total
Unknown	F						1	1			2
	M		1		1		1	1	1		5
Total					1		1	2	1		7
Cardiac	F							1			1
	M	1				1		2			4
Total		1				1		3			5
CNS toxicity	F		1								1
	M		1								1
Total			2								2
Drowning	F			2						1	3
	M		2	1	1			1			5
Total			2	3	1			1		1	8
Embolism	F					1					1
	M						1				1
Total						1	1				2
Total		1	5	3	2	2	3	6	1	1	24

Table 16 (continued)

PADI Divemaster Courses: N=1

CAUSE OF DEATH	SEX	2000	Grand Total
Cardiac	M	1	1
	Total	1	1
Total		1	1

Non-PADI Affiliated Resort Experience: Under Supervision only : N=1

CAUSE OF DEATH	SEX	2000	Grand Total
Embolism	M	1	1
	Total	1	1
Grand Total		1	1

A comparison of cause of death in training or under supervision only by age was conducted. Table 17 shows the number, range of ages and median ages for unknown, asthma-related, boat prop injury, brain aneurism, cardiac-related, DCS, drowning, embolism, seizure, CNS toxicity and respiratory arrest, respectively.

Table 17: Fatal training injuries by age

Cause	Unknown	Boat prop	Asthma	Brain aneurism	Cardiac	Drowning	Embolism
Age Range	18-69	23-52	33	50-52	25-72	13-70	21-70
Median age	45	29	33	50	52	38	50
< 20 yrs	1	0			0	2	0
21-30 yrs	8	4			2	17	5
31-40 yrs	11	1	1		3	11	1
41-50 yrs	10	0		1	22	10	1
51+ yrs	16	1		1	32	6	7
Unknown	8	0			2	4	0
Total	54	6	1	2	61	50	14

Further, one 26-year-old experienced a DCS-related fatality, one 26-year-old experienced a seizure-related fatality, one 26-year-old had a respiratory-arrest-related fatality, and one 34- and one 41-year-old had CNS-toxicity-related fatalities.

Table 18 shows a compilation of all PADI training courses, number of certifications issued, training dives conducted and fatalities in the 10-year period 1999-2008. Associated fatality rate per 100,000 divers and also fatality rate per 100,000 dives for entry-level, Advanced Open Water Diver, Discover Scuba Diving, Rescue Diver, Specialty, Divemaster and non-PADI-affiliated supervised resort dives are calculated, respectively.

The overall fatality rate for training dives in this 10-year period was calculated to be 1.660/100,000 dives with a range of .918 to 2.698 per 100k dives. The fatality rate for the 1999-2008 period for divers was 0.472/100,000 divers with a range of 0.283 to 0.692 per 100,000 divers. Table 19 compares the fatality rates per training course and between the periods 1989-1998 and 1999-2008.

Table 18: PADI worldwide certifications and fatality rates for scuba courses and programs (1999-2008)

Entry-Level (4 dives)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total Entry-Level Certifications	512,993	543,598	572,722	554,132	556,149	576,492	541,534	542,022	548,509	548,495	5,496,646
Total Entry-Level Training Dives	2,036,482	2,140,570	2,247,190	2,166,798	2,169,430	2,237,760	2,098,202	2,094,992	2,117,726	2,117,316	21,426,466
Fatalities in Entry-Level Training	8	7	13	11	9	10	11	6	7	7	89
Fatality Rate per 100K divers	1.559	1.288	2.270	1.985	1.618	1.735	2.031	1.107	1.276	1.276	1.619
Fatality Rate per 100K dives	0.393	0.327	0.579	0.508	0.415	0.447	0.524	0.286	0.331	0.331	0.415
Advanced Open Water (5 dives)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total AOW Certifications	155,370	164,905	179,184	180,142	186,689	191,824	183,722	179,949	182,053	181,070	1,784,908
Total AOW Training Dives	776,850	822,365	885,460	889,192	920,305	945,982	905,898	888,359	898,799	893,646	8,826,858
Fatalities in AOW Training	5	11	1	4	4	4	6	3	11	3	52
Fatality Rate per 100K divers	3.218	6.671	0.558	2.220	2.143	2.085	3.266	1.667	6.042	1.657	2.913
Fatality Rate per 100K dives	0.644	1.338	0.113	0.450	0.435	0.423	0.662	0.338	1.224	0.336	0.589
Discover Scuba Diving (1 dive)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total DSD Experiences	65,706	75,325	85,220	83,890	112,920	263,696	289,681	332,554	384,966	410,408	2,104,366
Total DSD Training Dives	65,706	75,325	85,220	83,890	112,920	263,696	289,681	332,554	384,966	410,408	2,104,366
Fatalities in DSD Training	2	2	2	2	0	7	1	2	2	4	24
Fatality Rate per 100K divers	3.044	2.655	2.347	2.384	0.000	2.655	0.345	0.601	0.520	0.975	1.140
Fatality Rate per 100K dives	3.044	2.655	2.347	2.384	0.000	2.655	0.345	0.601	0.520	0.975	1.140
Rescue Diver (5 dives)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total Rescue Certifications	40,969	42,367	45,444	45,766	44,829	45,390	44,598	42,935	42,845	42,588	437,731
Total Rescue Training Dives	204,845	211,835	227,220	228,830	224,145	226,950	222,990	214,675	214,225	212,940	2,188,655
Fatalities in Rescue Training	1	0	1	0	0	0	0	0	0	0	2
Fatality Rate per 100K divers	2.441	0.000	2.201	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.457
Fatality Rate per 100K dives	0.488	0.000	0.440	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.091
Specialties	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total Specialty Certifications	77,506	88,488	95,946	101,806	106,018	125,424	139,697	153,050	159,882	157,905	1,205,722
Total Specialty Training Dives	188,821	215,116	234,771	250,465	262,231	301,598	336,142	368,865	385,563	382,110	2,925,682
Fatalities in SpecialtyTraining	1	5	3	2	2	3	6	1	1		24
Fatality Rate per 100K divers	1.290	5.650	3.127	1.965	1.886	2.392	4.295	0.653	0.625	0.000	1.991
Fatality Rate per 100K dives	0.530	2.324	1.278	0.799	0.763	0.995	1.785	0.271	0.259	0.000	0.820
Divemaster (6 dives)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total DM Certifications	46,961	49,060	49,422	53,412	55,233	56,236	57,216	56,977	57,449	57,644	539,610
Total DM Training Dives	281,766	294,360	296,532	320,472	331,398	337,416	343,296	341,862	344,694	345,864	3,237,660
Fatalities in DM Training	0	1	0	0	0	0	0	0	0	0	1
Fatality Rate per 100K divers	0.000	2.038	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.185
Fatality Rate per 100K dives	0.000	0.340	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031
Cumulative - All Courses	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Total Certifications	899,505	963,743	1,027,938	1,019,148	1,061,838	1,259,062	1,256,448	1,307,487	1,375,704	1,398,110	11,568,983
Total Training Dives	3,554,470	3,759,571	3,976,393	3,939,647	4,020,429	4,313,402	4,196,209	4,241,307	4,345,973	4,362,286	40,709,687
Fatalities in Training	17	26	20	19	15	24	24	12	21	14	192
Fatality Rate per 100K divers	1.890	2.698	1.946	1.864	1.413	1.906	1.910	0.918	1.526	1.001	1.660
Fatality Rate per 100K dives	0.478	0.692	0.503	0.482	0.373	0.556	0.572	0.283	0.483	0.321	0.472

Activity (non-certified supervised participant) *	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Non-PADI-affiliated Resort Program	0	1	0	0	0	0	0	0	0	0	1

** Ratio of fatalities to divers unknown.*

Table 19: Rate of fatality comparison: 1989–1998 versus 1999–2008

Entry-Level	1989 to 1998	1999 to 2008	+ / - Number
Total Entry-Level Certifications	3,597,796	5,496,646	1,898,850
Total Entry-Level Training Dives	14,387,734	21,426,466	7,038,732
Fatalities in Entry-Level Training	49	89	40
Fatality Rate per 100K divers	1.362	1.619	0.257
Fatality Rate per 100K dives	0.341	0.415	0.074
Advanced Open Water	**1989 to 1998**	**1999 to 2008**	**+ / -**
Total AOW Certifications	945,582	1,784,908	839,326
Total AOW Training Dives	4,727,910	8,826,858	4,098,948
Fatalities in AOW Training	35	52	17
Fatality Rate per 100K divers	3.701	2.913	-0.788
Fatality Rate per 100K dives	0.740	0.589	-0.151
Discover Scuba Diving	**1989 to 1998**	**1999 to 2008**	**+ / -**
Total DSD Certifications	379,579	2,104,366	1,724,787
Total DSD Training Dives	379,579	2,104,366	1,724,787
Fatalities in DSD Training	11	24	13
Fatality Rate per 100K divers	2.898	1.140	-1.758
Fatality Rate per 100K dives	2.898	1.140	-1.758
Rescue Diver	**1989 to 1998**	**1999 to 2008**	**+ / -**
Total Rescue Certifications	279,477	437,731	158,254
Total Rescue Training Dives	1,397,385	2,188,655	791,270
Fatalities in Rescue Training	2	2	0
Fatality Rate per 100K divers	0.716	0.457	-0.259
Fatality Rate per 100K dives	0.143	0.091	-0.052
Specialties	**1989 to 1998**	**1999 to 2008**	**+ / -**
Total Specialty Certifications	387,100	1,205,722	818,622
Total Specialty Training Dives	1,045,288	2,925,682	1,880,394
Fatalities in SpecialtyTraining	3	24	21
Fatality Rate per 100K divers	0.775	1.991	1.216
Fatality Rate per 100K dives	0.287	0.820	0.533
Divemaster	**1989 to 1998**	**1999 to 2008**	**+ / -**
Total DM Certifications	65,608	539,610	474,002
Total DM Training Dives	393,648	3,237,660	2,844,012
Fatalities in DM Training	4	1	-3
Fatality Rate per 100K divers	6.097	0.185	-5.912
Fatality Rate per 100K dives	1.016	0.031	-0.985

Table 19 (continued)

Cumulative - All Courses	1989 to 1998	1999 to 2008	+ / -
Total Certifications	5,655,142	11,568,983	5,913,841
Total Training Dives	22,331,544	40,709,687	18,378,143
Fatalities in Training	104	192	88
Fatality Rate per 100K divers	1.839	1.660	-0.179
Fatality Rate per 100K dives	0.466	0.472	0.006
Activity (non-certified supervised participant) *	**1989 to 1998**	**1999 to 2008**	**+ / -**
Non-PADI-affiliated Resort Program	7	1	-6.000
** Ratio of fatalities to divers unknown.*			

Data Set 2A. Diving fatalities occurring outside of PADI-sanctioned training or supervised programs and involving a PADI-certified diver (1989-1998)

Table 20 shows a summary of fatalities by certification level, gender and year: nontraining or supervised only.

Table 20: Summary of fatalities by certified level, gender and year: nontraining only (1989-1998; median age 38 years)

LEVEL	SEX	89	90	91	92	93	94	95	96	97	98	Total
Advanced Open Water	F	1	1		4		3	2	3	1	4	19
	M	3		2	5	2	7	3	3	3	11	39
Sub-Total		4	1	2	9	2	10	5	6	4	15	58
Assistant Instructor	M					1					2	3
Sub-Total						1					2	3
Divemaster	F									1		1
	M	1	1		1		4	2	2	1	2	14
Sub-Total		1	1		1		4	2	2	2	2	15
Discover Scuba Experience (DSD)	M								1			1
Sub-Total									1			1
Master Instructor	M			1								1
Sub-Total				1								1
Master Scuba Diver	M										1	1
Sub-Total											1	1
Master Scuba Diver Trainer	M							2				2
Sub-Total								2				2
Open Water / Junior Open Water	F	2	7	1	5	3	3	4	4	7	5	41
	M	8	9	10	9	11	13	14	19	19	5	117
Sub-Total		10	16	11	14	14	16	18	23	26	10	158
Open Water Scuba Instructor	M	1	4			2	2	3	5	3	2	22
Sub-Total		1	4			2	2	3	5	3	2	22
Rescue	M	2	4	1		1	3	5	5	1	5	27
Sub-Total		2	4	1		1	3	5	5	1	5	27
Wreck	M			1								1
Sub-Total				1								1
Unknown	M									1		1
Sub-Total										1		1
Total		18	26	16	24	20	35	35	42	37	37	290

Contributing Factors:	Cause of Death:	Count:	% of Total	Median Age:	Deep Dive (130+ feet):
Wreck penetration	Drowning	113	39.0%	38	11
Entanglement	Unknown	97	33.4%	40	22
Shallow water blackout	Cardiac	41	14.1%	50	2
Depth	Embolism	29	10.0%	37	2
Out of Gas	Boat Prop	6	2.1%	34.5	
Rapid Ascent	Asphyxiation	1	0.3%	25	
Hypothermia	Asthma	1	0.3%	48	
Lost/Buddy Separation	DCS	1	0.3%	42	
Overweight	Shark Attack	1	0.3%	42	
Previous Med Condition	**Total**	**290**	**100.0%**	**40**	
Panic					
Buoyancy Issues	Male	227	78.3%		
Poor Equipt. Maintenance	Female	63	21.7%	Total: 290	
Diving Alone					

Data Set 2B: Diving fatalities occurring outside of PADI-sanctioned training or supervised programs and involving a PADI-certified diver (1999-2008)

Table 21 shows a summary of fatalities by diver certification level, gender and year; nontraining and supervised only.

Table 21: Summary of fatalities by certification level, gender and year: nontraining only (1999-2008)

LEVEL	SEX	99	00	01	02	03	04	05	06	07	08	Total
Assistant Instructor	M		2									2
Sub-Total			2									2
Advanced Open Water	F	2	1	1	2	4	3	3	1	2	2	21
	M	7	9	3	12	13	10	17	8	10	10	99
Sub-Total		9	10	4	14	17	13	20	9	12	12	120
Basic Scuba	F			1								1
	M		1	1					1			3
Sub-Total			1	2					1			4
Course Director	M							1				1
Sub-Total								1				1
Divemaster	F	2		1	1							4
	M		1	2	2	5	5	2	5	2	1	25
Sub-Total		2	1	3	3	5	5	2	5	2	1	29
Dry Suit	F									1		1
	M									1		1
Sub-Total										2		2
EANx	M			1		2		1			1	5
Sub-Total				1		2		1			1	5
IDCS	M										1	1
Sub- Total											1	1
Master Instructor	M		1			1					1	3
Sub-Total			1			1					1	3
Master Scuba Diver	F										1	1
	M				2				3	1		6
Sub-Total					2				3	1	1	7
Master Scuba Diver Trainer	M	2	2	1	1	3				1		10
Sub-Total		2	2	1	1	3				1		10
Open Water	?		1									1
	F	5	8	6	5	7	4	3	5	8	5	56
	M	18	20	19	12	16	12	11	9	9	7	132
Sub-Total		23	29	25	17	23	16	14	14	17	12	188
Open Water	F	1					1				1	3
Scuba Instructor	M	3	3	2	3	1	1	4	1			18
Sub-Total		4	3	2	3	1	2	4	1		1	21
Rescue	F	2				1	1	1	2			7
	M	4	5	2	3	5	4	1	2	2	1	29
Sub-Total		6	5	2	3	6	5	2	4	2	1	36
Resort	F									1		1
	M								1			1
Sub-Total									1	1		2
Scuba Diver	M									2		2
Sub-Total										2		2
SPEC - ARCH RESEARCH	M		1									1
Sub-Total	1									1		

Table 21 (continued)

SPEC - CAVERN		M				1							1
	Sub-Total					1							1
TEC DEEP Instructor		M							1				1
	Sub-Total							1				1	
Adventure		M					1						1
	Sub-Total						1						1
WRECK		M								1			1
	Sub-Total									1			1
Unknown		?					3	2					5
		F						1	2		3	2	8
		M	3	2		2	9	6	13	11	8	11	65
	Sub-Total		3	2		2	12	9	15	11	11	13	78
Total			49	57	40	46	71	50	60	50	51	44	518

Table 22 shows a summary of nontraining fatalities occurring outside of a PADI-sanctioned training program and involving a PADI-certified diver by year and gender. The median age for the group was 45 years of age.

Table 22: Summary of nontraining fatalities involving a PADI-certified diver (1998-2008)

Contributing Factors:

- *Wreck penetration*
- *Entanglement*
- *Shallow water blackout*
- *Depth*
- *Out of Gas*
- *Rapid Ascent*
- *Hypothermia*
- *Lost/Buddy Separation*
- *Overweight*
- *Previous Med Condition*
- *Panic*
- *Buoyancy Issues*
- *Poor Equipt. Maintenance*
- *Diving Alone*

Cause of Death:	Count:	% of Total	Median Age:	Deep Dive (130+ feet):
UNKNOWN	216	41.7%	45.5	6
DROWNING	166	32.0%	41	18
CARDIAC	84	16.2%	55.5	
EMBOLISM	32	6.2%	45	5
BOAT PROP	8	1.5%	38	
DCS	2	0.4%	45	
ANEURISM	1	0.2%	Unknown	
ANOXIA & HYPERCAPNIA	1	0.2%	45	
ASTHMA	1	0.2%	42	
BLOOD CLOT LUNGS	1	0.2%	50	
CEREBRAL & PULMONARY EDEMA	1	0.2%	64	
CONTAMINATED AIR	1	0.2%	37	1
PNEMOTHORAX	1	0.2%	32	
RESP DISTRESS PULMONARY EDEMA	1	0.2%	45	1
RUPTURED ULCER	1	0.2%	53	
SHARK ATTACK	1	0.2%	49	
Total	**518**	**100.0%**	**45**	**2**

Male: N=409 (79%), Female: N= 103 (19.9%), Unknown: N=6 (1.2%)

Data Set 3A: Fatalities involving a PADI professional (divemaster/assistant instructor/instructor) while at work (1989-1998)

Table 23 shows that the cumulative fatality rate for PADI professionals at work for the 10-year period 1989-1998 was 1.4 per 100,000 members.

Table 23: Fatal injuries involving a PADI professional at work: worldwide (except Japan), 1989–1998

Calendar Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	TOTAL
Total PADI Member-ship	26,548	33,487	41,449	51,419	50,925	61,895	67,245	74,994	79,629	87,127	574,718
Other	1	1	0	0	0	0	0	0	0	0	2
During training	0	0	0	0	1	1	0	0	0	1	3
Supervising	0	1	1	0	0	0	0	0	0	1	3
Total Individuals	1	2	1	0	1	1	0	0	0	2	8
Fatality Rate for Member-ship	.004%	.006%	.002%	0%	.002%	.002%	0%	0%	0%	.002%	.00001%

Note: Members are Divemasters, Assistant Instructors, Instructors and Course Directors

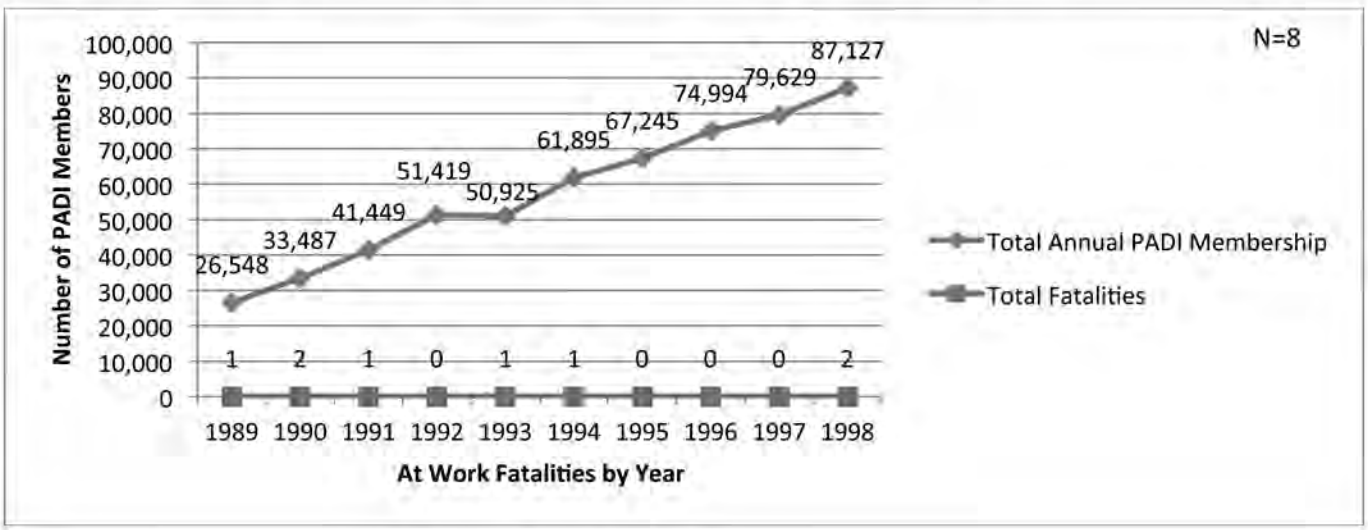


Table 24 provides detail regarding cause of death for fatalities involving a PADI professional at work for the 10-year period 1989-1998.

Table 24: Cause of death for fatalities involving a PADI professional at work

YEAR	GENDER	AGE	LEVEL	CAUSE OF DEATH	LOCATION	FATAL INJURY AT WORK BY CATEGORY	DETAILS
1989	F	Unknown	OWSI	BOAT PROP	BWI	Other	CREWHAND ON BOAT, ATTEMPTING TO UNTANGLE LINE. INJURY - LACERATION (HEAD)
1990	M	54	IE, AI	CARDIAC	TX	Other	WATERMANSHIP EVALS - TREAD
1990	M	Unknown	DM	Unknown	JAMAICA	Supervising	TRIPLE FATALITY, 1 NEAR DROWNING, 1 AGE OR DCS, DM WAS DIVE GUIDE FOR GROUP
1991	M	36	OWSI	DROWNING	IL	Supervising	SERVING AS SRFC DM, DOVE IN, FULLY CLOTHED, TO ASSIST DIVER, BODY RECOVERD DAYS LTR
1993	F	20	OWSI	DROWNING	WI	Training	INST & STDT DIED ON SAME DIVE
1994	M	35	OWSI	Unknown	UK	Training	CONDUCTING BB ASC W/STUDENT, MADE SUDDEN/RAPID ASC, STUDENT ATMPTD TO ASSIST, TO NO AVAIL-INST DIED, BODY RCVD 5 WKS LTR
1998	M	59	MI	CARDIAC	FL	Training	HE WAS CONDUCTING OW TRAINING.
1998	M	24	DM	UNRECOVERED BODY	TOBAGO	Supervising	LOST AT SEA, NEVER RECOVERED. THE SEARCH WENT ON FOR ONE WEEK WITH NO SIGN OF DIVERS OR EQUIPMENT.

Data Set 3B: Fatalities involving a PADI professional (divemaster/assistant instructor/instructor) while at work (1999-2008)

Table 25 shows that the cumulative fatality rate for PADI professionals at work for the 10-year period 1999-2008 was 1.1 per 100,000 members.

Table 25: Fatal injuries involving a PADI professional at work worldwide (including Japan), 1999-2008

Calendar Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	TOTAL
Total PADI Member-ship	100,699	106,978	109,958	118,892	123,741	127,077	130,47 2	131,714	133,526	134,95 9	1,218,016
Other	1	0	0	0	0	2	1	0	0	1	5
During training	0	0	0	0	1	1	2	1	1	2	8
Supervising	0	1	0	0	0	0	0	0	0	0	1
Total Individuals	1	1	0	0	1	3	3	1	1	3	14
Fatality Rate % for Member-ship	.00001	.000009	0	0	.000008	.00002	.00002	.000008	.000007	.00002	0.00001

Note: Members are Divemasters, Assistant Instructors, Instructors and Course Directors

Table 26 provides detail regarding cause of death for fatalities involving a PADI professional at work for the 10-year period 1999-2008.

Table 26: Fatalities Involving a PADI professional at work worldwide (including Japan), 1999–2008

YEAR	GENDER	AGE	LEVEL	CAUSE OF DEATH	LOCATION	FATAL INJURY CATEGORY	DETAILS
1999	M	27	OWSI	ELECTROCUTED	EGYPT	Other	ELECTROCUTED WHILE WORKING ON DIVE BOAT
2000	M	28	DM	EMBOLISM	PHILIPPINES	Supervising	HAD DIFFICULTY BREATHING 3 DAYS PRIOR. FELT BETTER & MADE DIVE. SURFACED, BEGAN CONVULSING. BOAT PICKED UP, BEGAN AR. NAVY DR ARRIVED & TOOK OVER.
2003	M	62	OWSI	UNKNOWN	PANAMA	Training	WAS TEACHING CW TRNG WHEN HE BECAME UNCONSCIOUS & STOPPED BREATHING. AR & CPR ADMIN. EMS ACTIVATED, TX TO HOSP WHERE HE EXPIRED. POSSIBLE HEART ATTACK OR STROKE.
2004	M	42	AI	UNKNOWN	EGYPT	Training	CASUALTY INDICATED HE WISHED TO ABORT DIVE, FELL UNCONSCIOUS WHILST BOARDING BOAT. RESCUED ONTO BOAT WHERE VENTILATIONS AND O2 WERE ADMINISTERED. EVACUATED BY EMS.
2004	M	51	DM	DROWNING	HI	Other	DM WENT IN WATER AFTR DIVE TO RETRIEVE ANCHOR W/OUT FINS, LATER DISCOVERED UNCON AT 100' AR & CPR, EMS TX TO HOSPITAL WHERE HE WAS PRONOUNCED DEAD.
2004	M	52	OWSI	UNKNOWN	FIJI	Supervising	REF AP04-222: TWO DIVERS WERE DROPPED OFF TO DRIFT DIVE TO MOORING WHERE BOAT HOOKED UP AND 4 CERTIFIED DIVERS WENT DIVING. AFTER THE DIVE, 2 DIVERS HAD NOT RETURNED AND SEARCH STARTED. ALARM RAISED UPON RETURN TO RESORT - SEA + AIR SEARCH STARTED NEXT DAY AND CONTINUED FOR SEVERAL DAYS - DIVERS STILL MISSING. DIVER EXPERIENCED MILITARY + COMMERCIAL DIVER WITH

Table 26 (continued)

YEAR	GENDER	AGE	LEVEL	CAUSE OF DEATH	LOCATION	FATAL INJURY CATEGORY	DETAILS
							MANY YEARS EXPERIENCE.
2005	M	32	DM	DROWNING	HONDURAS	Supervising	WAS FOUND ON THE BOTTOM UNCONSCIOUS W/O A REG BY ONE OF THE GUESTS. HE WAS BROUGHT TO THE SRFC, CPR ADMIN. DID NOT REVIVE. AUTOPSY PENDING COC ON DEATH CERT. DROWNING
2005	M	30	MSDT	UNRECOVERED BODY	TANZANIA	Training	GROUP FAILED TO SURFACE FROM DIVE. CIRCUMSTANCES UNKNOWN. PRESUMED DECEASED.
2005	F	25	OWSI	DROWINING	SAIPAN	Training	INSTRUCTOR WAS LEADING 6 DIVERS ON AOW DEEP DIVE. DIVER APPROACHED WITH A PROBLEM AND THEY BOTH STARTED ASCENDING. UNK WHAT HAPPENED AT THIS POINT. INSTRUCTOR WAS FOUND THE NEXT DAY
2006	M	48	MSDT	HEAD INJURY	EGYPT	Training	STUDENT SURFACED WITHOUT INST. DIVERS BEGAN SEARCH FOR INST. HE WAS FOUND LYING ON THE BOTTOM WITH HEAD INJURIES & NO MASK OR REGULATOR. DIVER BOUGHT HIM TO SURFACE, RESCUE BREATHS ADMIN WHILST TOWING THE VICTIM TO THE BOAT. HE WAS PRONOUNCED DEAD.
2007	M	44	AI	CARDIAC	PA	Training	AI WAS ESCORTING 2 STUDENTS UP THE ASCENT LINE AFTER COMPLEETING DEEP AOWD WHEN EXPERIENCED PROBLEMS. HE LEFT STUDENTS AT THEIR SAFETY STOP AND WENT TO SRFC, DROPPED HIS WB AND CALLED FOR HELP. CPR COMMENCED IMMEDIATELY WHEN REACHED SHORE.
2008	M	38	DM	UNKNOWN	TURKEY	Training	RESC ALERTED OF DIVER TAKEN TO HOSP WITH DCI & THE LEADER WAS MISSING. DIVERS SEARCHED & SAW THE VICTIM AT 32.5M WITH NO REG & NO SIGNS OF LIFE. DIVERS

Table 26 (continued)

YEAR	GENDER	AGE	LEVEL	CAUSE OF DEATH	LOCATION	FATAL INJURY CATEGORY	DETAILS
							ASCENDED & CALLED COAST GUARD TO RECOVER VICTIM.
2008	M	61	MSDT	CARDIAC	CANADA	Training	DIVER CONDUCTING AOW DEEP CLASS. APPARENTLY SHOWED DISTRESS U/W AND STUDENTS ASSISTED HIM TO SRFC AND TOWED HIM TO SHORE. CPR/FA PROVIDED AND EMS MEDIVACED BUT DECLARED DECEASED.
2008	M	35	OWSI	BOAT PROP	EGYPT	Other	INSTRUCTOR WAS HIT BY BOAT PROP IN SHALLOW WATER WHILE TRAINING AND OWD STUDENT. BOTH WERE FOUND INJURED & UNCONSCIOUS UNDER THE WATER. THEY WERE TOWED OUT OF THE WATER & CPR ADMIN BUT WERE NOT ABLE TO BE RESUSCITATED.

Discussion

Safety is the degree to which risks are judged acceptable. Scuba diving is a reasonably safe activity and is categorized as such based on the concept of acceptable risk. It is difficult to define precisely what is considered acceptable risk for all involved groups. Risk depends on the probability and severity of the injury, so the likelihood of a diver suffering an ear injury, near drowning, air embolism, DCS or a fatality all vary in probability and most certainly severity.

In addition, various personal and social value judgments affect the perception and reputation of any given activity. Acceptable risk is defined by several factors, including prevailing professional practices, reasonableness and the highest practical protection and lowest practicable exposure. The skill and experience level of the individual involved also affects the insight and ability of that person accepting a risk.

The PADI system of diver education along with various statements of understanding, safe diving practices waivers and liability releases (see Appendix 2 at the end of this paper) combine to present to an individual that diving has an element of risk and that the severity of that risk can have catastrophic consequences, however unlikely. Informing the diver of this is in everyone's best interest and the morally and ethically right thing to do. Intelligent people make the personal choice to accept risks on their own every day, and this also applies to scuba diving.

For the instructional and professional training community, adhering to standards and always being safety conscious when supervising or diving with others helps decrease the probability of an accident or incident from occurring, although it does not eliminate the probability altogether. A disciplined adherence to effective risk-management principles assists by increasing safety and minimizing risks to oneself and the divers under supervision.

Properly trained divers have skills, experience and knowledge that limit them to engage in diving conditions similar to their training environment with a buddy. The PADI organization recommends additional training to increase skill and experience levels and to become familiar with different conditions and environments. Quality training, continuing education and experience, proper attitude and judgment, environmental orientation and adherence to proven safe diving practices will all help ensure that scuba diving remains a reasonably safe activity. After certification, ultimate responsibility for safety rests with individual divers to take responsibility for themselves.

The vast majority of people who scuba dive do so without negative consequences. However, because of the probability of various injuries and risks involved, we must realize that accidents and injuries will occur despite best practices. It is incumbent upon divers to exercise prudent and wise judgment in every environment and circumstance they encounter, and that safety and personal well-being is placed above all else. Positive peer pressure, safety-conscious diving "tribes" and responsible diving community efforts can all be effective in mitigating risk. Additionally, fatalities for cardiac arrest were the cause of death in more than 31 percent of the cases examined.

Ideally, safety is freedom from risk. Unfortunately, this ideal is not possible, and risk is unavoidable in any sport or activity, and scuba diving is no exception. Good judgment, mental and physical readiness and adequate training will help ensure that risks are judged as acceptable and diving will remain reasonably safe as long as divers apply these practices. As professionals we must make these statistics as the basis for our personal commitment to diving safety and education. If we understand the risks that have caused or contributed to diver deaths, we may be more effective in influencing the attitude and judgment of those divers we train. While we may never be able to reduce the number of scuba-diving-related fatalities to zero, as a community we must never cease in our efforts to strive toward this goal.

Conclusion

The vast pool of data reflects an improvement in participant safety from the first decade to the second. This is a testimony of the commitment to the design, implementation, conduct and monitoring of quality diver training and the effort placed into upholding standards in the field.

References

Lowrance WW. *Of Acceptable Risk: Science and the Determination of Safety*. Los Altos: Kaufmann, 1976.

Richardson D. Dive Safety and Risk Management: Never Let Your Guard Down. *Undersea Journal* 2:14; 2002.

PADI Worldwide. *PADI Instructor Manual*. pp. 136-138; 2010.

Denoble P, Pollock N, Vaithiyanathan P, Caruso J, Dovenbarger J, Vann RD. Scuba Injury Death Rate Among Insured DAN Members. *Diving and Hyperbaric Medicine* 38(4): 182-188; 2008.

Denoble P, Caruso J, Dear G, Pieper C, Vann RD. Common Causes of Open-Circuit Recreational Diving Fatalities. *Undersea and Hyperbaric Medicine* 35(6):393-406; 2008.

PADI Worldwide. #10060 Standard Safe Diving Practices Statement of Understanding dated 5/09 version 2.0; 2009.

PADI Worldwide. #10072 Liability Release and Assumption of Risk Agreement dated 3/06 version 4.02; 2006.

PADI Worldwide. #10063 Medical Release dated 6/07 Version 2.01; 2007.

Appendix 1. PADI Code of Practice (PADI, 2010)

Membership Commitment — Code of Practice

As a PADI Professional, you enjoy a rewarding role — teaching and introducing others to scuba diving. You have the chance to change lives for the better and to experience things most humans will never have the opportunity to enjoy. With this ability comes a very important obligation to your students, clients and all those who come to you to be taught or led underwater: You are responsible for the safety of others.

As a PADI Member, you agree to the following:

1. Put the safety of diving clients and students as your first priority and responsibility. In doing so, abide by the requirements and intent of PADI Standards and Procedures in the PADI Instructor Manual, PADI's Guide to Teaching, Training Bulletin and other updates while applying your best judgment during the PADI courses and programs you conduct.
2. Although scuba diving is a reasonably safe activity when safety rules are followed, the risks/consequences of scuba diving can lead to very serious injuries. Be safety minded, safety conscious and practice instructing and divemastering professionally.
3. Perform a personal readiness self-assessment before you teach or lead others on dives. This includes evaluating your physical health and fitness for diving as well as your ability to supervise and respond to diver emergencies on that day and at that location. Evaluate the dive conditions and environment, and determine if you're ready and familiar enough with it to teach or lead dives there. Assess your knowledge readiness to teach or lead dives on any given day — to make sure that you are familiar with the standards, latest updates and teaching tools for that PADI program and that you're aware of the readiness and abilities of your student divers.
4. When teaching, repetition is good, and over-learning basic skills and breathing control in a variety of conditions takes time and practice. Help those you teach and supervise by guiding them through this learning process.
5. Each person has an individual state of mind and comfort level that may be very different from yours and may vary greatly between divers in a group. Be willing to cancel a dive for the group or an individual at any time to err on the side of safety.
6. Be watchful for signs of diver stress and anxiety, and act quickly and appropriately when you see them.
7. Employ effective group control measures in the water, particularly when supervising novices and children. Carry out frequent head counts.
8. Conduct yourself and your PADI-related activities in a professional manner.
9. Represent yourself as a PADI Instructor only when you are in Teaching Status.
10. Comply with the intent of the PADI Standard Safe Diving Practices Statement of Understanding while teaching and supervising.
11. Do not disparage the PADI organization, PADI Members or any other dive industry professionals.
12. Exhibit common honesty in your PADI-related activities.
13. Cooperate during PADI investigations by responding fully and promptly to inquiries.
14. Respect and reinforce the depth and supervisory restrictions as displayed on restricted PADI certification cards, such as PADI Scuba Diver and Junior Diver.
15. Follow a strict code of conduct and abide by the requirements and intent of the PADI Member Youth Leader's Commitment whenever teaching or supervising children.

16. Follow a professional code of practice toward the environment, and abide by the practices and intent of Project AWARE's Ten Ways a Diver Can Protect the Underwater Environment in all PADI-related activities. (See projectaware.org)
17. Accept that a criminal conviction involving abuse of a minor either during or prior to PADI Membership is grounds for denial or termination of PADI Membership.
18. Accept that a criminal conviction involving sexual abuse of an adult either during or prior to PADI Membership is grounds for denial or termination of PADI Membership.
19. Do not substitute other courses and programs for PADI, DSAT and EFR programs advertised.

If you breach the Code of Practice, your PADI Membership is at risk.

Appendix 2. PADI Safe Diving Practices Statement of Understanding, Release and Assumption of Risk Agreement and Medical Release

PADI®
padi.com

STANDARD SAFE DIVING PRACTICES STATEMENT OF UNDERSTANDING

Please read carefully before signing.

This is a statement in which you are informed of the established safe diving practices for skin and scuba diving. These practices have been compiled for your review and acknowledgement and are intended to increase your comfort and safety in diving. Your signature on this statement is required as proof that you are aware of these safe diving practices. Read and discuss the statement prior to signing it. If you are a minor, this form must also be signed by a parent or guardian.

I, ____ , understand that as a diver I should:
(Print Name)

1. Maintain good mental and physical fitness for diving. Avoid being under the influence of alcohol or dangerous drugs when diving. Keep proficient in diving skills, striving to increase them through continuing education and reviewing them in controlled conditions after a period of diving inactivity, and refer to my course materials to stay current and refresh myself on important information.
2. Be familiar with my dive sites. If not, obtain a formal diving orientation from a knowledgeable, local source. If diving conditions are worse than those in which I am experienced, postpone diving or select an alternate site with better conditions. Engage only in diving activities consistent with my training and experience. Do not engage in cave or technical diving unless specifically trained to do so.
3. Use complete, well-maintained, reliable equipment with which I am familiar; and inspect it for correct fit and function prior to each dive. Have a buoyancy control device, low-pressure buoyancy control inflation system, submersible pressure gauge and alternate air source and dive planning/monitoring device (dive computer, RDP/dive tables—whichever you are trained to use) when scuba diving. Deny use of my equipment to uncertified divers.
4. Listen carefully to dive briefings and directions and respect the advice of those supervising my diving activities. Recognize that additional training is recommended for participation in specialty diving activities, in other geographic areas and after periods of inactivity that exceed six months.
5. Adhere to the buddy system throughout every dive. Plan dives – including communications, procedures for reuniting in case of separation and emergency procedures – with my buddy.
6. Be proficient in dive planning (dive computer or dive table use). Make all dives no decompression dives and allow a margin of safety. Have a means to monitor depth and time underwater. Limit maximum depth to my level of training and experience. Ascend at a rate of not more than 18 metres/60 feet per minute. Be a SAFE diver – **S**lowly **A**scend **F**rom **E**very dive. Make a safety stop as an added precaution, usually at 5 metres/15 feet for three minutes or longer.
7. Maintain proper buoyancy. Adjust weighting at the surface for neutral buoyancy with no air in my buoyancy control device. Maintain neutral buoyancy while underwater. Be buoyant for surface swimming and resting. Have weights clear for easy removal, and establish buoyancy when in distress while diving. Carry at least one surface signaling device (such as signal tube, whistle, mirror).
8. Breathe properly for diving. Never breath-hold or skip-breathe when breathing compressed air, and avoid excessive hyperventilation when breath-hold diving. Avoid overexertion while in and underwater and dive within my limitations.
9. Use a boat, float or other surface support station, whenever feasible.
10. Know and obey local dive laws and regulations, including fish and game and dive flag laws.

I have read the above statements and have had any questions answered to my satisfaction. I understand the importance and purposes of these established practices. I recognize they are for my own safety and well-being, and that failure to adhere to them can place me in jeopardy when diving.

____ Participant's Signature ____________________ Date (Day/Month/Year)

____ Signature of Parent or Guardian (where applicable) ____________________ Date (Day/Month/Year)

PRODUCT NO. 10060 (Rev. 5/09) Version 2.0

LIABILITY RELEASE AND ASSUMPTION OF RISK AGREEMENT

Please read carefully and fill in all blanks before signing.

I, ____, hereby affirm that I am aware that skin and scuba diving have inherent risks which
Participant Name
may result in serious injury or death.

I understand that diving with compressed air involves certain inherent risks; including but not limited to decompression sickness, embolism or other hyperbaric/air expansion injury that require treatment in a recompression chamber. I further understand that the open water diving trips which are necessary for training and for certification may be conducted at a site that is remote, either by time or distance or both, from such a recompression chamber. I still choose to proceed with such instructional dives in spite of the possible absence of a recompression chamber in proximity to the dive site.

I understand and agree that neither my instructor(s), ____, the facility through which

I receive my instruction, ____, nor PADI Americas, Inc., nor its affiliate and sub-
Facility Name
sidiary corporations, nor any of their respective employees, officers, agents, contractors or assigns (hereinafter referred to as "Released Parties") may be held liable or responsible in any way for any injury, death or other damages to me, my family, estate, heirs or assigns that may occur as a result of my participation in this diving program or as a result of the negligence of any party, including the Released Parties, whether passive or active.

In consideration of being allowed to participate in this course (and optional Adventure Dive), hereinafter referred to as "program," I hereby personally assume all risks of this program, whether foreseen or unforeseen, that may befall me while I am a participant in this program including, but not limited to, the academics, confined water and/or open water activities.

I further release, exempt and hold harmless said program and Released Parties from any claim or lawsuit by me, my family, estate, heirs or assigns, arising out of my enrollment and participation in this program including both claims arising during the program or after I receive my certification.

I also understand that skin diving and scuba diving are physically strenuous activities and that I will be exerting myself during this program, and that if I am injured as a result of heart attack, panic, hyperventilation, drowning or any other cause, that I expressly assume the risk of said injuries and that I will not hold the Released Parties responsible for the same.

I further state that I am of lawful age and legally competent to sign this liability release, or that I have acquired the written consent of my parent or guardian. I understand the terms herein are contractual and not a mere recital, and that I have signed this Agreement of my own free act and with the knowledge that I hereby agree to waive my legal rights. I further agree that if any provision of this Agreement is found to be unenforceable or invalid, that provision shall be severed from this Agreement. The remainder of this Agreement will then be construed as though the un-enforceable provision had never been contained herein.

I understand and agree that I am not only giving up my right to sue the Released Parties but also any rights my heirs, assigns, or beneficiaries may have to sue the Released Parties resulting from my death. I further represent I have the authority to do so and that my heirs, assigns, or beneficiaries will be estopped from claiming otherwise because of my representations to the Released Parties.

I, ____________________________________, BY THIS INSTRUMENT AGREE TO EXEMPT AND RELEASE MY INSTRUCTORS,
Participant Name

____, THE FACILITY THROUGH WHICH I RECEIVE MY INSTRUCTION,

____, AND PADI AMERICAS, INC. AND ALL RELATED ENTITIES AS
Facility Name
DEFINED ABOVE, FROM ALL LIABILITY OR RESPONSIBILITY WHATSOEVER FOR PERSONAL INJURY, PROPERTY DAMAGE OR WRONGFUL DEATH HOWEVER CAUSED, INCLUDING BUT NOT LIMITED TO THE NEGLIGENCE OF THE RELEASED PARTIES, WHETHER PASSIVE OR ACTIVE.

I HAVE FULLY INFORMED MYSELF AND MY HEIRS OF THE CONTENTS OF THIS LIABILITY RELEASE AND ASSUMPTION OF RISK AGREEMENT BY READING IT BEFORE I SIGNED IT ON BEHALF OF MYSELF AND MY HEIRS.

____ ____________________________
Participant Signature Date (Day/Month/Year)

____ ____________________________
Signature of Parent of Guardian (where applicable) Date (Day/Month/Year)

PRODUCT NO. 10072 (Rev. 3/06) Version 4.02

MEDICAL STATEMENT

Participant Record (Confidential Information)

Please read carefully before signing.

This is a statement in which you are informed of some potential risks involved in scuba diving and of the conduct required of you during the scuba training program. Your signature on this statement is required for you to participate in the scuba training program offered

by____and
Instructor

____located in the
Facility

city of____________________, state/province of _____________.

Read this statement prior to signing it. You must complete this Medical Statement, which includes the medical questionnaire section, to enroll in the scuba training program. If you are a minor, you must have this Statement signed by a parent or guardian.

Diving is an exciting and demanding activity. When performed correctly, applying correct techniques, it is relatively safe. When established safety procedures are not followed, however, there are increased risks.

To scuba dive safely, you should not be extremely overweight or out of condition. Diving can be strenuous under certain conditions. Your respiratory and circulatory systems must be in good health. All body air spaces must be normal and healthy. A person with coronary disease, a current cold or congestion, epilepsy, a severe medical problem or who is under the influence of alcohol or drugs should not dive. If you have asthma, heart disease, other chronic medical conditions or you are taking medications on a regular basis, you should consult your doctor and the instructor before participating in this program, and on a regular basis thereafter upon completion. You will also learn from the instructor the important safety rules regarding breathing and equalization while scuba diving. Improper use of scuba equipment can result in serious injury. You must be thoroughly instructed in its use under direct supervision of a qualified instructor to use it safely.

If you have any additional questions regarding this Medical Statement or the Medical Questionnaire section, review them with your instructor before signing.

Divers Medical Questionnaire

To the Participant:

The purpose of this Medical Questionnaire is to find out if you should be examined by your doctor before participating in recreational diver training. A positive response to a question does not necessarily disqualify you from diving. A positive response means that there is a preexisting condition that may affect your safety while diving and you must seek the advice of your physician prior to engaging in dive activities.

Please answer the following questions on your past or present medical history with a **YES** or **NO**. If you are not sure, answer **YES**. If any of these items apply to you, we must request that you consult with a physician prior to participating in scuba diving. Your instructor will supply you with an RSTC Medical Statement and Guidelines for Recreational Scuba Diver's Physical Examination to take to your physician.

_____ Could you be pregnant, or are you attempting to become pregnant?

_____ Are you presently taking prescription medications? (with the exception of birth control or anti-malarial)

_____ Are you over 45 years of age and can answer YES to one or more of the following?
- currently smoke a pipe, cigars or cigarettes
- have a high cholesterol level
- have a family history of heart attack or stroke
- are currently receiving medical care
- high blood pressure
- diabetes mellitus, even if controlled by diet alone

Have you ever had or do you currently have…

_____ Asthma, or wheezing with breathing, or wheezing with exercise?

_____ Frequent or severe attacks of hayfever or allergy?

_____ Frequent colds, sinusitis or bronchitis?

_____ Any form of lung disease?

_____ Pneumothorax (collapsed lung)?

_____ Other chest disease or chest surgery?

_____ Behavioral health, mental or psychological problems (Panic attack, fear of closed or open spaces)?

_____ Epilepsy, seizures, convulsions or take medications to prevent them?

_____ Recurring complicated migraine headaches or take medications to prevent them?

_____ Blackouts or fainting (full/partial loss of consciousness)?

_____ Frequent or severe suffering from motion sickness (seasick, carsick, etc.)?

_____ Dysentery or dehydration requiring medical intervention?

_____ Any dive accidents or decompression sickness?

_____ Inability to perform moderate exercise (example: walk 1.6 km/one mile within 12 mins.)?

_____ Head injury with loss of consciousness in the past five years?

_____ Recurrent back problems?

_____ Back or spinal surgery?

_____ Diabetes?

_____ Back, arm or leg problems following surgery, injury or fracture?

_____ High blood pressure or take medicine to control blood pressure?

_____ Heart disease?

_____ Heart attack?

_____ Angina, heart surgery or blood vessel surgery?

_____ Sinus surgery?

_____ Ear disease or surgery, hearing loss or problems with balance?

_____ Recurrent ear problems?

_____ Bleeding or other blood disorders?

_____ Hernia?

_____ Ulcers or ulcer surgery ?

_____ A colostomy or ileostomy?

_____ Recreational drug use or treatment for, or alcoholism in the past five years?

The information I have provided about my medical history is accurate to the best of my knowledge. ***I agree to accept responsibility for omissions regarding my failure to disclose any existing or past health condition.***

Signature	Date	Signature of Parent or Guardian	Date

PRODUCT NO. 10063 (Rev. 06/07) Ver. 2.01

Page 1 of 6

Models for Estimating the Diver Population of the United States: An Assessment

Al Hornsby
PADI Worldwide
30151 Tomas Street
Rancho Santa Margarita, CA 92688 USA

The debate over the diver population in the United States is a significant and difficult issue, especially as it relates to the establishment of a reliable fatality rate for diving. The primary cause of this difficulty is the lack of a unified model in place for consistently discussing such a population. Part of the problem is that even the definition of this population varies; it has also been made even more difficult through arguments that the diver population has been overstated by the dive industry. The publication of such positions and the various assumptions supporting them have been more frequently (but not necessarily more appropriately) referenced in medical and scientific literature concerning the diver population and fatality rates. The purpose of the assessment reported by this paper is to compare the assumptions of the debates questioning the historical U.S. diver population estimates to the empirically derived population model developed by the National Underwater Accident Data Center (NUADC–McAniff), from which the estimates were originally derived. The goal was to determine which estimate methodology is the most credible for application to medical and scientific literature. An examination of the common debates' arguments and assumptions found that they typically lacked empirical bases and applied flawed assumptions; the NUADC model, by contrast, was found to have strong empirical bases and independent empirical support.

The Diver Population Debate

Various contentions that the U.S. diver population has been overstated draw upon arguably erroneous assumptions, which have been quoted popularly within the dive community over the past 25 years. These include:

"Various contentions that the U.S. diver population has been overstated draw upon arguably erroneous assumptions, which have been quoted popularly within the dive community over the past 25 years."

1. Diver drop-out rates

The assumption that divers in the United States "drop out" of diving (i.e., cease participation in diving) at a rate of 80 percent in the first year following entry-level certification enjoys an "urban-legend" level of acceptance within the dive industry despite a lack of established empirical or statistical bases. Two independent, large-scale and highly credible research studies — the Diagnostic Research Inc. (DRI) 1987 "Diver Erosion Study" and the Daniels and Roberts (D&R) 2006 "Profile of the Most Active Divers in the US: Lifestyle and Demographics Study," both commissioned by the Diving Equipment and Marketing Association (DEMA) — contradict this assumption.

The 1987 DRI study found divers becoming inactive ("dropping out") at a rate of 15 percent after 12 months from certification, 23 percent after 24 months, 33 percent after 36 months and 53 percent after 48 months. To remain in the population required the participant to have dived within the previous 12 months. D&R's 2006 findings, nearly 20 years later, were similar. It found a "half-life" for divers of five years, "meaning that 50 percent of the people certified in any given year will have stopped diving by the end of the fifth year." Further, the 2006 D&R study found that approximately one-third of divers had been certified prior to 1995, can be traced back for 20 years and can be considered "vestigial" divers.

A more recent study, the Tauchsport-Industrieverband (TIV) 2010 "FVSF-Research Report No. 31, Diving in the Future," further supported these findings, concluding that the erosion rate for divers in Germany was 10 percent per annum for divers who did not own their own equipment and 8.5 percent per annum for divers who did own their own equipment.

Similarly, the 1998 Leisure Trends "Track on Scuba" found that 14 percent of the diver population had been diving from 10 to 19 years.

The application of these empirically derived data to diver certification numbers over the years would support a sizeable, long-term diver population and contradicts an 80 percent first-year erosion rate.

2. Diver certification duplication

Another assertion has been of claims of significant duplication among certifications — that divers hold significant numbers of "dual" or multiple training organization certifications for the training, thereby inflating the estimated number of divers. However, the ongoing DEMA Certification Census appears to negate this contention. The current Certification Census is a third-party source for diver certification data, with present participation by the Professional Association of Diving Instructors (PADI), Scuba Schools International (SSI) and Scuba Diving International (SDI) and has included the National Association of Underwater Instructors (NAUI) in the past. Its process identifies and removes duplicate names and addresses across all organizations (and within each organization's reports) and has found the total duplication rate to average approximately 1 percent. These data show that dual certifications do not appear to exist in sufficient numbers to significantly overinflate diver population estimates.

"The application of these empirically derived data to diver certification numbers over the years would support a sizeable, long-term diver population and contradicts an 80 percent first-year erosion rate."

3. Inclusion of only "active divers"

Another confusing element has been the argument that only "active divers" — with some minimum number of dives per year — should be counted in a population model, resulting in a further debate about what level of activity an "active diver" must have. While this is a legitimate area of inquiry for other purposes, it has no application in establishing a population figure to be used as the denominator for overall diver fatality rates. In any fatality rate study, if an individual can be counted as a fatality, that same individual must be part of the population. For this reason, population models that count only those with some specified level of activity are inherently inappropriate for determining fatality rates that count all diver fatalities. When considering introductory scuba experiences, for example, (participants are not certified and therefore are not normally counted in diver population models), this is a significant omission. Based upon the results of a 2003 study by the Flexo Hiner & Partners research firm, PADI can estimate approximately 220,000 introductory scuba participants (those with U.S. residence addresses) annually within its program alone. This large group of diving participants (whose numbers refresh annually on an ongoing basis), while not typically counted in diver population estimates, are typically included in diver fatality counts when the unfortunate incident occurs. The result is a statistically invalid rate.

The overall result of applying these common, empirically flawed assumptions to U.S. diver population models has been the publication of diver estimates as low as 700,000. Obviously, the resulting effect on estimated fatality rates is significant.

The NUADC – McAniff Population Model

The most commonly referenced diver population figure historically used by the dive industry puts the U.S. diver population in the range of 2.7 to 3.5 million participants. This estimate was based on supporting and corroborative empirical elements. It was initially derived from recreational diving's longest-term diver fatality study, the University of Rhode Island's National Underwater Accident Data Center (NUADC) program carried out by John McAniff from 1970 through 1994. McAniff established both a population model and fatality rate, summarized in the report "An Analysis of Recreational, Technical and Occupational Populations and Fatality Rates in the United States, 1970–1994" (July 1995). Over the course of the NUADC program, McAniff (whose seminal work is frequently referenced in the literature regarding historical dive accident data) published a report annually, which included both fatality numbers and, as of 1980, rates calculated upon an ongoing diver population model of his design (retroactive to 1970). This work continued until the program was absorbed by Divers Alert Network (DAN); the population model and fatality-rate calculations were not carried forward by DAN.

For the U.S. diver population estimate, he used direct certification reporting from the major diver training organizations. (YMCA, NAUI and PADI cooperated with the NUADC study at various times; PADI, for example, contributed U.S. entry-level certification numbers annually throughout the program.) He also used other data, including an early study titled "An Analysis of the Civil Diving Population of the United States" (approximately 1975), insurance and membership information from the Underwater Society of America, and other sources. He also derived and applied an erosion curve. By maintaining the same approach over the 25 years of his study, McAniff established, at least within the parameters of his data and assumptions, a consistently based, empirically derived population model.

"McAniff's U.S. diver population estimate has performed remarkably well relative to other ongoing empirical diver population studies and reports."

In 1995, as referenced in "An Analysis of Recreational, Technical and Occupational Populations and Fatality Rates in the United States, 1970–1994," McAniff took the additional step of applying the 1987 DRI Diver Erosion Study data to his population data history to establish a new population range model. His original model was consistent with the new and fit within the new range. He subsequently estimated the population of scuba divers in the United States as of 1995 at 2.7 to 3.5 million. This has been the industry's most frequently quoted diver population figure.

McAniff's U.S. diver population estimate has performed remarkably well relative to other ongoing empirical diver population studies and reports.

- National Safety Council 1991 Accident Facts — 2.6 million
- National Sporting Goods Association (NSGA) 1994 "Sports Participation Study" — 2.378 million (but excludes Hawaii and Alaska)
- NSGA 1998 "Sports Participation Study" — 2.558 million
- American Sports Data Inc. 1999 "Superstudy of Sports Participation" — 3.2 million
- Media Mark Research Inc. 1999 "MRI Sports Trends: Total Scuba Diving Participation" — 2.5 million
- Sporting Goods Manufacturers Association (SGMA) 2006 "USA Sports Participation Study" — 2.96 million
- SGMA 2008 "USA Sports Participation Study" — 3.216 million

The Status of the McAniff Model Since 1995

With McAniff's retirement, the updating of his diver population and fatality rate model ceased. However, the empirical data available through ongoing diver population studies continue to support the model's last (as of 1995) population estimate. Further, given U.S. entry-level diver certifications since 1994, based on the DEMA Certification Census and PADI's entry-level diver certification history, it does not seem unreasonable to expect that the U.S. diver population as of 2010 remains within, or close to, the 2.7 to 3.5 million range estimated through McAniff's model in 1995.

Conclusion

While there have been varying opinions and assertions regarding estimates of the U.S. diver population, many of these lack empirical support and appear flawed with respect to their use in estimating diver incident and fatality rates. By contrast, the model created by McAniff is based on credible data and methodology and is empirically supported by a continuing series of independent, diver population estimates and corroborations of critical assumptions. Therefore, it appears that McAniff's estimate is currently the most suitable figure for use in scientific and medical analyses that require a diver population estimate. Further, it appears that the effort to update the model through the addition of the applicable diver certification data for the years since 1994 would be an important step in deriving an accepted diver population model and estimate for the United States.

"It appears that McAniff's estimate is currently the most suitable figure for use in scientific and medical analyses that require a diver population estimate."

Further Reading

McAniff J. "An Analysis of Recreational, Technical and Occupational Populations and Fatality Rates in the United States, 1970-1994," July 1995.

"Scuba injury death rate among insured DAN Members," *Diving and Hyperbaric Medicine*, 2008; 38: 182-188.

"How Many Divers Are There?" *Undercurrents*.

Diagnostic Research Inc. "Diver Erosion Study," 1987.

Daniels and Roberts. "Profile of the Most Active Divers in the U.S.: Lifestyle and Demographics Study," 2006.

Leisure Trends. "Track on Scuba," 1998.

National Sporting Goods Association. "Sports Participation Study," 1994.

National Sporting Goods Association. "Sports Participation Study," 1998.

American Sports Data Inc. "Superstudy of Sports Participation," 1999.

Media Mark Research Inc. "MRI Sports Trends: Total Scuba Diving Participation," 1999.

Sporting Goods Manufacturing Association. "USA Sports Participation Study," 2006.

Sporting Goods Manufacturing Association. "USA Sports Participation Study," 2008.

Tauchsport-Industrieverband (TIV). "FVSF-Research Report No.3.1 "Diving in the Future," January 2010.

Flexo Hiner and Partners. "2003 PADI Member Survey: Discover Scuba Diving And Discover the Reef Participation Estimate."

"The Editor's Offering," *Diving and Hyperbaric Medicine*, Vol. 37 No. 2, June 2007.

Richardson D. "Mortality for Recreational Scuba Diving," *Bennett and Elliott's Physiology and Medicine of Diving*, 5th Edition, 2003.

Richardson D. "Reflections on Diver Fatality and Safety Statistics," *SPUMS Journal*, Vol. 24 No. 3, September 1994.

National Safety Council. *Accident Facts*, 1991.

Discussion

UNIDENTIFIED SPEAKER: I have my ex-dive-shop owner hat on. The 225,000 "try" divers a year, where did they go? Because, you know what, I taught 197 to dive every year for seven years. Are we scaring them off in the try dive?

AL HORNSBY: I can tell you where a portion of them go. I do not know. It is a phenomenon that we are finding, a recent study we did, that some number of them are continuing to do try dives every year and consider themselves divers. We find they have done a DSD three or four years in a row. They like that supervised, comfortable diving experience, and that is what happened. We have others who tried it, did it, they are gone. It is hard to say.

KEN KURTIS: Mentioned earlier today, I enjoy looking at the statistics we have and comparing how each has their own way of validating each thing. I get the Leisure Trends quarterly reports. Some of you do not get that. That is an estimate of what the industry sells. I think the annual total now is around $750 million. If we take 3 million, round numbers, as the number of active divers and divide that into $750 million, which are all dollars that flow through dive shops, travel, masks, training, etc. — does not include stuff you book yourself — we have an average expenditure per diver of $250. Something we know about this industry is wrong. We are pretty sure that divers do not spend just $250 a year. Something is out of whack somewhere.

HORNSBY: Could be. I think one of the things with the Leisure Trends study — DEMA was involved with them back in my tenure there — and one of the reasons that the relationship ended is that their sample size was extremely small, these days fewer than 100 stores. So it is an extrapolation based on a very small sample size. Again, I am not to say it is not valid, but that could be a part of this. And, again, the estimate that we are working from, it also is based on — it is what it is. It is what it was based upon. I just think that going forward is the important part.

DR. RICHARD VANN: I have one final comment. All of John McAniff's diving fatality reports are now on the Rubicon website (*http://archive.rubicon-foundation.org*) and available to everyone.

Training and Operations

Michael A. Lang, B.Sc.
Smithsonian Institution
Washington, D.C., USA

Richard D. Vann, Ph.D.
Divers Alert Network
Center for Hyperbaric Medicine and Environmental Physiology
Department of Anesthesiology
Duke University Medical Center
Durham, N.C., USA

Participants in the training panel were concerned before the workshop that the discussions might increase their liability, and several training agencies declined to attend. To allay these worries insofar as possible, discussions by the panel were not recorded. The topics discussed are listed below.

"Running out of gas, emergency ascent, entanglement, equipment trouble, buoyancy trouble and rough water were risk factors associated with injuries leading to death."

1. Running out of gas
Running out of gas is strongly associated with fatalities due to asphyxia and cerebral arterial gas embolism (CAGE). What might be done regarding equipment, training, diving operations or community development to make insufficient gas less likely?

2. Dive computers
Should entry-level divers be trained to use only dive tables, only dive computers, both tables and computers or either tables or computers?

3. Entanglement and entrapment
Entanglement or entrapment is common in fatalities involving asphyxia. What might be done regarding equipment, training, diving operations or community development to reduce the occurrence of entanglement or entrapment?

4. Overtraining
Running out of gas, emergency ascent, entanglement, equipment trouble, buoyancy trouble and rough water were risk factors associated with injuries leading to death. These occurred despite training. Might "overtraining" (excess skill repetition during training to make skills automatic/instinctive in emergencies) during initial training be applied to some skills to reduce the occurrence of the risk factors listed above?

5. Deepest training dive
Should a dive instructor perform one or two shallow training dives with advanced open-water (AOW) students before the deep dive to allow assessment of skills and comfort in the water?

6. Refresher training
Diving inactivity reduces skills performance. Is there a minimal level of diving activity that should be maintained before a skills-refresher review or check-out dive is desirable? Might instructor refresher training be useful?

7. Dive conditions and dive site difficulty
Should dive sites be assigned categories to indicate the level of training, experience, health and physical condition needed for a particular site? (This might be similar to ski run categories: green circle, blue square, black diamond.) Could this put more responsibility on the diver in selecting a particular site? Might regional dive conditions be specified as part of certification levels?

8. Diver competency
Dive accident investigators indicate that diver competency is a frequent problem in diving fatalities. Are codes of safety-related principles (such as the Responsible Diver Program and similar agency efforts) effective? Can effectiveness be tracked?

9. Diving operations manuals
Might diving operations manuals (prepared by individual agencies, DEMA or RSTC) be useful for providing guidance to dive operators (vessels, resorts, shops, dive professionals, etc.) that might reduce the occurrence of risk factors associated with fatalities? ISO 24803 might be a model (see comments below).

10. Dive operators
Should dive operators and dive professionals play a stronger role in reinforcing critical dive skills during predive briefings?

11. Hazards and waiver/releases
How are candidate divers informed about specific hazards that can injure or kill them? What information should be in a release form that certified divers sign before participating in dives conducted by dive operators? Are health questions appropriate?

"Dive accident investigators indicate that diver competency is a frequent problem in dive fatalities."

12. Mishap rate comparison
How do the mishap rates for "resort experience" programs compare with those for open water certification courses? Might age (young or old) be a contributing factor?

13. Training statistics
Might training agencies submit their annual training statistics to an unbiased third party for analysis and reporting in total and without attribution?

14. Quality control
What are the key factors in dive instructor and dive leader quality-control systems for maintaining instructor skills and performance?

15. Instructor retention
How long (assuming a moderate teaching load) does a dive instructor need to work before gaining the experience to handle a wide range of students? Do instructors receive adequate motivation to encourage them to continue teaching for long enough to ensure that most active instructors have achieved an optimal level of experience?

16. Diver health and fitness assessment
Is it feasible to assess certified divers for health and fitness before diving operations commence?

Editorial Summary of the Training and Operations Consensus Discussion

Workshop participants were encouraged to base their comments on evidence rather than opinion, and a few unsupported opinions led to sharp exchanges. The points made were often useful, but the tone was not, so an editorial summary is provided below rather than the verbatim transcript.

- Apparent causes associated with diving fatalities have not changed over time in remembered history or available data. Causes include running out of gas, uncontrolled ascent, entanglement or entrapment, buoyancy trouble, buddy separation and lack of common sense. The training objectives divers are taught by the industry were agreed to be sensible, and data for training dives suggested greater safety than for dives after training, but divers who died often did not follow their lessons. Equipment was sometimes misused because accepted procedures were forgotten, weren't learned in the first place or the equipment had shortcomings. Reasons and solutions suggested for the problems are listed below.
- Longer training courses with more dives are needed. This was disputed, but evidence to settle the issue wasn't available.
- Skills refreshers were widely considered to be important. Methods for refreshing skills included check-out dives, buoyancy-control practice, alternate-air-source practice and briefings to emphasize avoiding buddy separation. Discussion of requalification for certified divers who had not dived in some time was unproductive.
- Entanglement could be prevented by carrying a cutting device. Entrapment could be prevented by avoiding overhead environments unless properly trained.
- Low-air and dive-computer alarms with triple redundancy (visual, vibration and audio) were suggested, but another opinion indicated that alarms rarely prevent problems.
- Instructors should be better role models for students and avoid setting bad examples. Certification cards were sometimes issued to inadequately prepared students. No supporting data were offered, and these opinions were disputed.
- As decompression table use is now rare, more training with dive computers was suggested.
- Instructors were encouraged to pre-assess their students for readiness prior to a deep dive in advanced courses.
- Individuals who dive infrequently after training may not retain their skills and may be at greater risk of dying, particularly in the first 20 dives after training. This opinion was offered without evidence. Dr. David Colvard reported surveys that indicated the number of dives made in the past 12 months was not a factor in panic (Colvard, 2003).
- Fatalities were sometimes associated with dive sites that were beyond the diver's training, experience and physical capability, particularly when an individual continued diving after a significant change in health. Discussion indicated that divers must make their own decisions about whether a given site was appropriate for them, but these decisions would be assisted if information on specific dive site challenges were available.

"Fatalities were sometimes associated with dive sites that were beyond the diver's training, experience and physical capability, particularly when an individual continued diving after a significant change in health."

- Suggestions for reducing poor judgment included emphasizing diving hazards and establishing a "safety culture" that used peer pressure to promote common sense and safe behaviors. Industry-wide information programs for the diving public were suggested, perhaps could be disseminated by the Recreational Scuba Training Committee (RSTC).

- Training agencies were encouraged to assemble statistics for investigation of diver and instructor erosion and to cooperate in developing diver population estimates. Periodic review of fatality data was suggested for investigating diver experience including the number of dives by individuals, the years diving and the interval since the most recent dive.

- The U.S. Underwater Diving Fatality Reports (McAniff, URI) are available for download on Rubicon (*www.rubicon-foundation.org*). The original data are stored at DAN America.

- Dive operators and trainers were encouraged to be familiar with ISO 24803, "Recreational diving services — requirements for recreational scuba diving service providers" (see *www.iso.org*). This document covers basic international standards for training and education, dive guiding and equipment rental.

- Diving fatality investigations need improvement to provide better data for understanding underlying causes. A course for first responders in diving fatality investigation might prepare more knowledgeable investigators. Central collection of fatality case data by each country was recommended with periodic data pooling and analysis.

- The U.S. Coast Guard (USCG) is developing an investigation checklist. Checklist distribution might be managed through USCG sectors who know the local diving and emergency response communities. Turnover of USCG personnel can make continuity difficult. Coordination with USCG Sector 545, Washington HQ, would be helpful as they receive data collected by regional sectors.

"Diving fatality investigations need improvement to provide better data for understanding underlying causes."

References

Colvard, DF and Colvard LY. A Study of Panic in Recreational Divers. *The Undersea Journal*, First quarter 2003, pp. 40-44.

The Cardiovascular System and Diving Risk*

Alfred A. Bove, M.D., Ph.D.
Emeritus Professor of Medicine
Cardiology Section
Temple University School of Medicine
Philadelphia, Pa. USA

Recreational scuba diving is a sport that requires a certain physical capacity in addition to consideration of the environmental stresses produced by increased pressure, low temperature and inert gas kinetics in tissues of the body. Factors that may influence ability to dive safely include age, physical conditioning, tolerance of cold, ability to compensate for central fluid shifts induced by water immersion and ability to manage exercise demands when heart disease might compromise exercise capacity. Patients with coronary heart disease, valvular heart disease, congenital heart disease and cardiac arrhythmias are capable of diving, but consideration must be given to the environmental factors that might interact with the cardiac disorder. Understanding of the interaction of the diving environment with various cardiac disorders is essential to providing a safe diving environment to individual divers with known heart disease.

"While both commercial and military diving have physicians trained and committed to supporting their operations, recreational divers often present themselves to community physicians who are not experts in this area of medicine."

The Diving Environment and the Cardiovascular System

Recreational scuba diving is a popular sport that had its beginnings in the early 1950s. It has grown over the past 60 years into a well-established recreational sport that involves an estimated 3 million divers in the United States. Besides recreational applications, diving has been an active commercial occupation for more than 100 years and is an important component of marine activity in the U.S. Navy and other navies around the world. Special training for physicians through academic and military programs has led to an identified specialty (American Board of Preventive Medicine 2010). While both commercial and military diving have physicians trained and committed to supporting their operations, recreational divers often present themselves to community physicians who are not experts in this area of medicine. Because of the high prevalence of cardiovascular disease (CVD) in our population, many recreational divers or potential divers seek advice from physicians regarding their ability to dive with various cardiovascular disorders.

To understand the interaction of the patient with cardiovascular system disease and the diving environment, it is important to elucidate the various stress factors that relate to this environment. Divers with CVD are particularly prone to complications of their disorders when there are excess physical exercise demands, when environmental factors result in increased blood pressure or when stresses result in increased sympathetic activation that can aggravate ischemia or induce abnormal and potentially harmful cardiac arrhythmias. In addition, the unique environment of water immersion adds thermal stress — usually cold stress — and the well-documented shifts of blood centrally (Arborelius et al. 1972) that can result in enough acute volume overload to a compromised heart to result in acute decompensated heart failure. Several diving-related disorders (lung barotrauma and arterial gas embolism, immersion pulmonary edema) are known to produce fatalities due to direct compromise of cardiac function or hypoxemia induced by pulmonary edema.

These are well known in the diving community, and specific precautions are provided to divers to help avoid their occurrence.

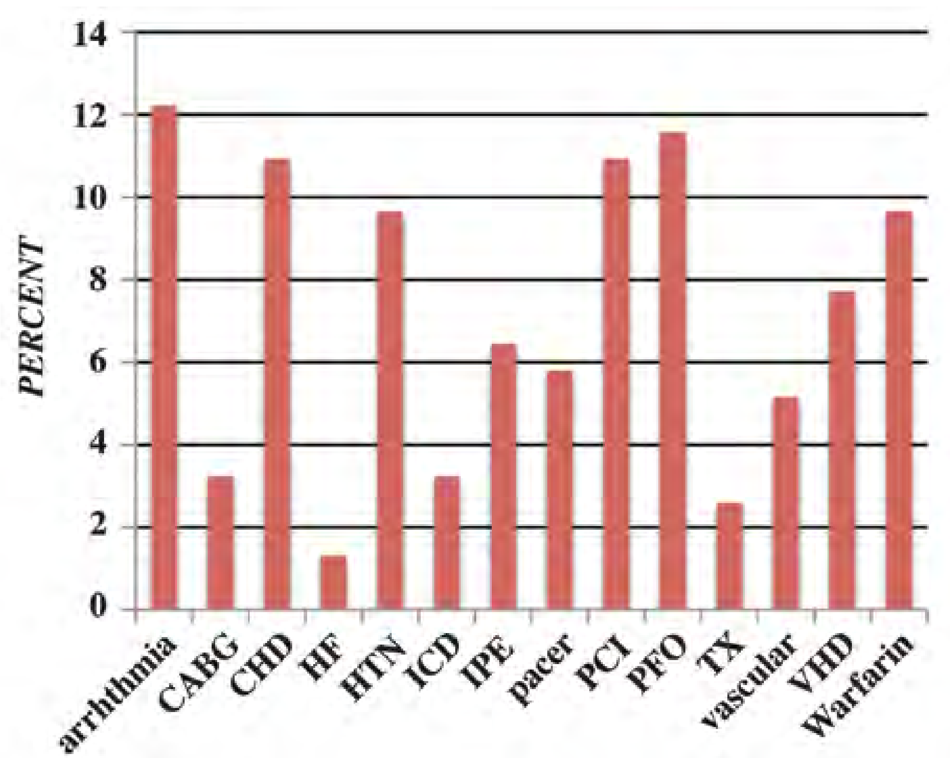
*This paper originally appeared in the *Undersea and Hyperbaric Medicine Journal* and is reprinted with permission from the Undersea and Hyperbaric Medical Society.

Bove A. The cardiovascular system and diving risk. *Undersea Hyperb Med.* 38(4):261-269; 2011.

Population Demographics

The recreational diving community in the United States is heterogenous, involving male and female divers ranging in age from 8 to 60-plus years old (Denoble, Caruso et al. 2008). The current practice of providing lifelong certification means that once certified, a diver can have a diving experience spanning many decades with no obligation to evaluate state of health or illness as it relates to diving. Many divers continue diving into their seventh and eighth decades. This aging population of divers has found means to control adverse environments to fit their capacity for safe diving in light of reduced physical capacity due to aging or chronic illness. Despite these precautions, data from the DAN insurance population (Denoble, Caruso et al. 2008) indicates that increased age is associated with a higher diving-related mortality from both cardiac and other causes. Figure 1 shows the distribution of cardiology-related health questions that were submitted by divers to a public dive medicine website (*www.scubamed.com*) and were answered directly by the author (AAB). All these cardiac disorders can result in a diving fatality related to heart disease based on the severity of the illness, co-morbidities and the environmental stress experienced during diving.

Figure 1: Cardiac-related queries to the website www.scubamed.com



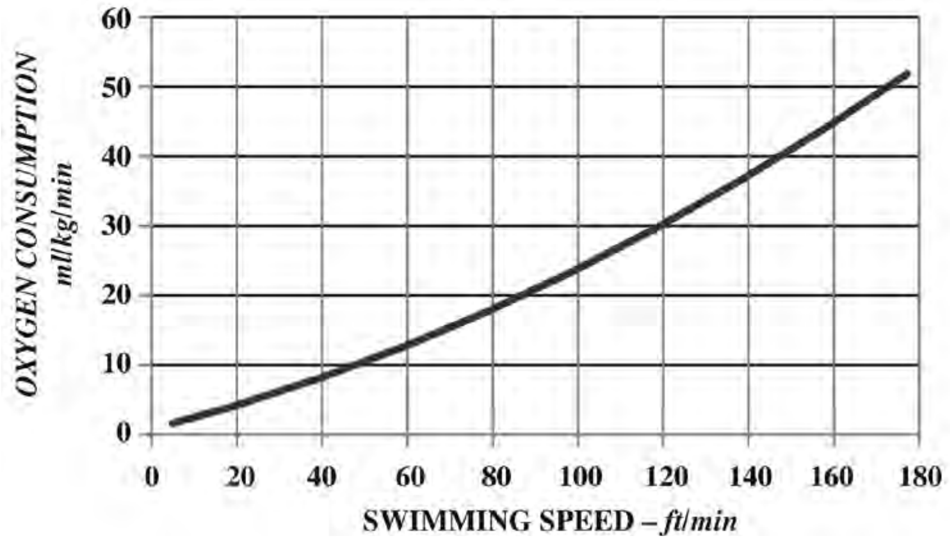
Note: Total queries over nine years were 750; 156 were related to cardiovascular disease. *CABG – coronary artery bypass surgery; CHD – congenital heart disease; HF – heart failure; HTN – hypertension; ICD – implanted cardioverter-defibrillator; IPE – immersion pulmonary edema; PCI – percutaneous coronary intervention; PFO – patent foramen ovale; TX – heart transplant; VHD – valvular heart disease*

"This aging population of divers has found means to control adverse environments to fit their capacity for safe diving in light of reduced physical capacity due to aging or chronic illness."

Physical Work Demands

The studies of Pendergast et al. (1996, 2003) documented the oxygen demands of swimming with scuba gear at various speeds. Of note is the nonlinear relation between swimming speed and work demand due to the well-known second-order relation between drag energy and velocity in water (Batchelor 1967). Pendergast et al. provided equations that would allow estimates of oxygen consumption at increasing swimming speeds (Figure 2).

Figure 2: Oxygen consumption vs. swimming speed for a scuba diver



Note: Curve based on data of Pendergast et al. (1996, 2003).

> "In most occupational exposures requiring increased physical activity, guidelines recommend maintaining workloads below 50 percent of maximal oxygen consumption."

The demands for swimming ability for safe diving are controversial. In most environments, diving exercise demand is not likely to exceed 15-20 feet/minute swimming speed and for recreational diving may reach speeds of only 4-5 feet/minute. However, in situations where current or distance is involved, demand could reach 100 feet/minute (about 1 knot). For a diver to manage usual contingencies (current of 0.4-0.5 knots), wind or surface action, oxygen consumption (VO_2) demands during diving can reach levels of 20 ml/kg/minute (6-7 metabolic equivalents or METs (U.S. Navy 2008)). The "maximal steady state" is a workload of about 50 percent of maximal oxygen consumption (Levine 2001; Baron et al. 2008) that allows continuous exercise without excess ventilation and without a progressively increasing blood lactate (Faude et al. 2009). This state can be sustained for 50-60 minutes, while exercise at 60-70 percent of maximal oxygen consumption in an average-conditioned diver cannot be sustained for more than 15-20 minutes (Lepretre et al. 2008). Thus a diver with a steady state exercise capacity of 6-7 METs can expect to manage most diving contingencies without concern for cardiovascular complications.

In most occupational exposures requiring increased physical activity, guidelines recommend maintaining workloads below 50 percent of maximal oxygen consumption (Levine 2001). Based on this relationship, a diver who is expected to minimize safety concerns related to environmental contingencies should have a maximum oxygen consumption of 12-13 METs. Divers with a peak exercise capacity below that level could expect to dive safely in low-stress conditions (i.e., warm water, minimal currents, minimal surface action) but could develop some evidence of cardiovascular limitations under stressful diving conditions. This is likely to be manifested as a high ventilation rate with the sensation of dyspnea while breathing through a mouthpiece — a situation that can induce a panic reaction. Very young, older or less well-conditioned divers and those with cardiovascular disorders that limit exercise capacity must develop plans that provide them support (e.g., buddy system) when diving conditions are expected to be adverse or plan diving in conditions where the likelihood of a high stress load is minimal.

Thermal Stress

Most divers are immersed in water below skin temperature and therefore lose body heat during their exposure. In this environment, thermal conduction and convection are the major pathways for heat loss, and minimizing surrounding water contact with the skin is the usual means of protection. The U.S. Navy has prescribed the methods for thermal protection of divers in different water temperatures (U.S. Navy 2008). In diving where water temperature is below 50°F, for prolonged exposures hot water is circulated to the diver's suit to maintain thermal stability. Recreational divers are exposed to a wide range of water temperatures. Diving in northern-hemisphere seas and lakes where water temperature may be 50°F requires special dive suit protection. However, even when diving in tropical regions where water temperature is 80°F, conductive and convective heat loss will occur without proper thermal protection.

Although the cardiac effects of extreme hypothermia are well described (Tipton et al. 2004), this situation is rare in recreational diving, and the more likely scenario involves the effect of moderately reduced body temperature on the heart and circulation. A reduced body temperature induces vasoconstriction in skin and skeletal muscle, with increased systemic resistance and increased blood pressure (Tipton et al. 2004). In individuals with coronary disease this reaction can induce myocardial ischemia with subsequent angina or ischemia-induced arrhythmias.

Immersion

When an individual is immersed in water to the neck, the pressure effects on the venous system result in a shift of 600-700 ml of blood centrally (Arborelius et al. 1972). This shift is managed in the normal heart by the well-described Starling mechanism (Sarnoff et al. 1960), but in a compromised left ventricle this amount of volume shift can result in acute heart failure. We have encountered a number of divers with reduced ejection fraction who developed acute pulmonary edema while diving or snorkeling. In addition to acute heart failure known to occur in patients with compromised left ventricular function, some divers with normal left ventricular function appear to be susceptible to a clinical syndrome similar to acute heart failure.

"Possible causes of IPE include negative airway pressure due to high inspiratory resistance."

This phenomenon has been described as immersion pulmonary edema (IPE), and presently its cause has not been identified (Slade et al. 2001; Wilmshurst et al. 1989). Possible causes of IPE include negative airway pressure due to high inspiratory resistance. This phenomenon, called negative-pressure pulmonary edema, has been described in anesthesia procedures (Bove 2004). Recent data also suggest that impairment of left ventricular relaxation can be involved in pulmonary edema by causing elevation of left ventricular end diastolic pressure during exercise and subsequent pulmonary venous hypertension (Kato et al. 2008). In most cases of immersion pulmonary edema, cardiac function is found to be normal (Slade et al. 2001).

Review of cardiovascular conditions relevant to diving

Congenital heart disease

The younger population (ages 9-35) is most likely to have cardiovascular-related disorders due to congenital heart disease. These can include surgically corrected complex congenital heart disease, channelopathies that risk sudden death and conduction abnormalities that can compromise normal heart function. Although a patent foramen ovale is congenital in origin, it does not contribute to risk for sudden death while diving.

Congenital heart disease encompasses a wide range of heart abnormalities, but the focus here is on the disorders that risk sudden death while diving. These include congenital aortic stenosis or insufficiency; aortic coarctation; and Marfans syndrome, which can result in acute heart failure or aortic rupture while diving. Although these disorders may go undetected until adolescence, it is more likely that prior examinations have revealed the presence of the disorder, and diving clearance involves assessment of severity related to risk. Mild valvular stenosis or regurgitation is usually well tolerated. The dilated ascending aorta of Marfans disease usually is considered a contraindication to sports, including diving if the aortic diameter exceeds 4 cm. The frequent use of the Valsalva maneuver (to equalize pressure in the middle ear) in the presence of a thoracic aortic aneurysm is risky, as the post-Valsalva surge of blood through the central circulation can result in sudden dilatation of the aorta and pose the risk for rupture (Hiratzka et al. 2010). Published criteria for sports participation with valvular heart disease provide useful guidelines for sport diver clearance (Maron, Zipes 2005).

Surgically corrected complex congenital heart disease

Survival of children with complex congenital heart disease has improved over the past 30 years primarily due to improved surgical methods for correcting the abnormalities. The population of adults with congenital heart disease is increasing, and many of these adults are well enough compensated with regard to their cardiac performance that they seek medical advice for sport diving. Usual diagnoses include Tetralogy of Fallot, pulmonary or right ventricular atresia and transposition of the great vessels. Surgical correction for Tetralogy of Fallot leaves the subject with adequate exercise tolerance for diving but at risk for serious arrhythmias or sudden death (Vignati et al. 1998; Silka et al. 1998).

"Both acquired and congenital abnormalities can threaten safety when diving."

Evaluation of these candidates for diving requires careful communication with the cardiologist in charge of their long-term care. Correction of transposition often leaves the right ventricle (RV) as the systemic ventricle. The RV often fails in the third or fourth decade of life due to the chronic mismatch of load (Szymański et al. 2009), and the patient may require heart transplantation. These patients with poor tolerance to central fluid shifts can develop acute heart failure when immersed to the neck. In general, exercise tolerance is limited. However, isolated incidences of low-stress diving have been completed successfully in these patients. Counseling about risk is essential in these patients if they plan to dive.

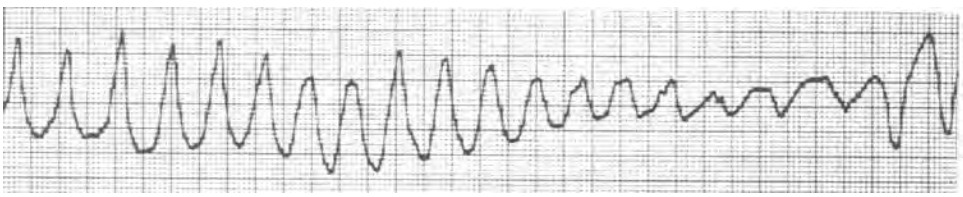
Patients with Fontan shunts from the right atrium to the pulmonary artery do not have a functioning right ventricle and are highly dependent on right-atrial pressure being maintained to a very close tolerance (Gewillig et al. 2010). They may develop acute heart failure from central fluid shifts, or they may develop a low cardiac output syndrome from even mild degrees of dehydration. Either situation can quickly degenerate into a lethal outcome. Patients with Fontan shunts have been advised to swim for exercise. However, the same fluid shift situation occurs in swimming, so those who can tolerate swimming should be able to tolerate low-stress diving safely.

Rhythm and conduction abnormalities

Both acquired and congenital abnormalities can threaten safety when diving. Dangerous acquired arrhythmias include ventricular tachycardia, often related to ischemia or cardiomyopathy and atrial fibrillation, or flutter with uncontrolled heart rate. Screening for these abnormalities should include careful physical examination of the heart and an electrocardiogram to document abnormal rhythms noted on examination.When there is concern for risk of a dangerous arrhythmia, continuous ECG monitoring, particularly during exercise, can also provide an assessment of risk.

Long QT syndrome
The work of Ackerman et al. (1999) demonstrated a form of the long QT syndrome that resulted in risk of sudden death when swimming or water-immersed. This effect was detected in a series of individuals who drowned. Clinical detection of the long QT syndrome is by electrocardiography, but most diving candidates do not have an electrocardiogram as a part of diving clearance. Because of the rarity of this disorder, routine screening of recreational diving candidates with an ECG is costly and impractical. In subjects with the long QT syndrome, the family history may be positive for sudden death in young family members. It is therefore important for screening to inquire about family history of sudden death in young family members, particularly in females, who are more prone to the syndrome. The channel abnormality in long QT triggers a particular form of ventricular tachycardia called torsades des pointes (Figure 3) that degenerates into ventricular fibrillation (Kaufman 2009).

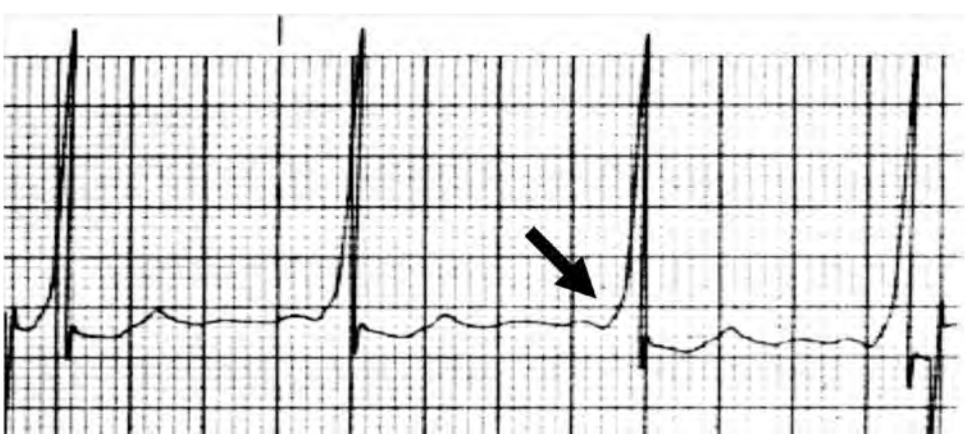
Figure 3: ECG showing torsades des pointes



Wolf-Parkinson-White Syndrome
An important congenital conduction defect that can cause sudden death is the Wolf-Parkinson-White (WPW) syndrome. This syndrome is the result of an accessory conduction fiber that crosses the atrioventricular (AV) ring and allows direct conduction of atrial impulses to the ventricle without delay through the AV node. A characteristic ECG pattern is noted (Figure 4). Patients with this accessory pathway have a history of palpitations and may develop rapid supraventricular tachycardias that can deteriorate into ventricular fibrillation. This disorder is readily cured by ablation of the accessory bundle, and individuals with normal conduction post-ablation are not prone to complications. A history of palpitations should trigger further inquiry and an ECG for evaluation. As noted previously, routine ECG screening of sport diving candidates would be impractical.

"A pacer may be implanted for a number of indications, and most pacers are tested to depths of 80-130 feet."

Figure 4: ECG showing WPW syndrome pattern



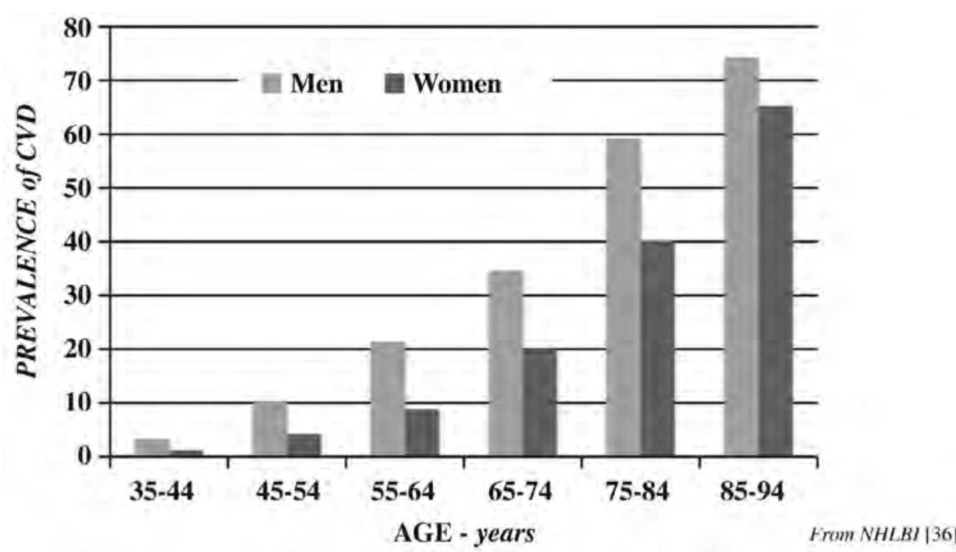
Note: The short P-R interval (see arrow) is due to pre-excitation.

Pacers and implanted cardioverter defibrillators
A pacer may be implanted for a number of indications, and most pacers are tested to depths of 80-130 feet (Lafay et al. 2008). Divers with pacemakers therefore will not damage the pacer at usual sport diving depths. However, the heart disorder that required an implanted pacer must be determined, as some disorders may put the diver at risk for a serious cardiac event. Cardioverter defibrillators (ICD) are implanted in patients at risk for lethal cardiac arrhythmias. Based on this indication, these patients are at risk for a serious arrhythmia while diving and subsequent firing of the ICD. This circumstance is likely to result in drowning, as the diver usually becomes disoriented either from the arrhythmia or from the ICD shock.

Heart failure and cardiomyopathy
Patients with significant reduction in left ventricular function (left ventricular ejection fraction (LVEF) < 35 percent) are at risk for exacerbation of heart failure while diving and development of the syndrome of acute decompensated heart failure (ADHF). This disorder, if untreated, will progress to severe metabolic derangement and death. As noted above, water immersion itself can provoke heart failure due to central blood shifts. Patients with severe reduction in LVEF (i.e., < 30 percent) are likely to note significant exercise impairment when diving. In general, safety considerations would prohibit diving with severe left ventricular dysfunction. However, a few divers have managed to perform short dives in low-stress conditions without developing ADHF. These patients are also prone to lethal arrhythmias, and many have implanted ICDs (see above). Patients with hypertrophic cardiomyopathy usually have normal systolic left ventricular function but are also prone to sudden death, and should be evaluated for risk during any form of exercise. A proportion of these patients have ICDs based on prior history or clinical assessment of sudden death risk.

"For divers older than age 35, the dominant risk for sudden death is from coronary disease."

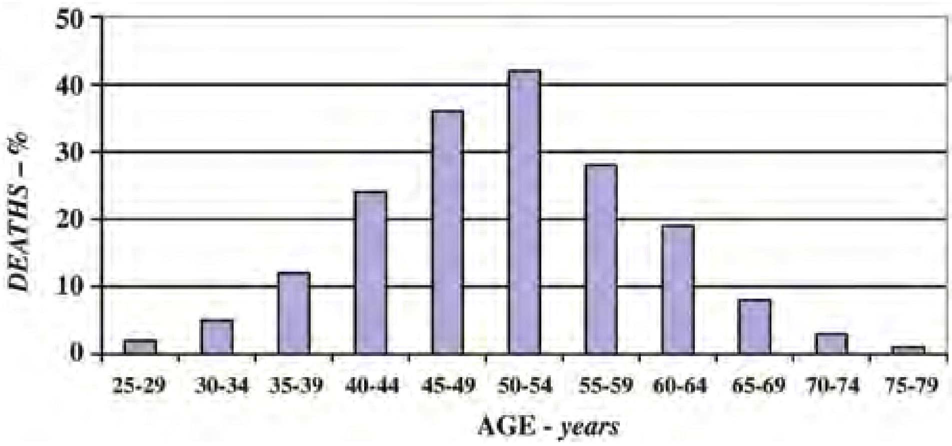
Figure 5: Age-related prevalence of CAD



Coronary disease
For divers older than age 35, the dominant risk for sudden death is from coronary disease. This disorder is the result of vascular injury and atherosclerosis that ultimately result in occlusion of a coronary artery, with sudden death in about one-third of patients who experience an acute myocardial infarction (AMI). Although the incidence of coronary disease death is falling (American Heart Association 2010), the rising incidence with age (Figure 5) makes this diagnosis

the most important consideration when clearing divers above 35 years old. The analysis of cardiovascular-related deaths from the DAN database (Caruso et al. 2001) indicated that CVD fatalities peaked in the 50- to 60-year age range. Figure 6 shows the age distribution of diving deaths from cardiovascular disease. The reduced number of deaths in the older divers is likely due to the lower number of divers above 60 years old. The data of Denoble, Pollock et al. (2008) indicates that age above 50 years and male sex are the principal predictors of cardiovascular death while diving. The relation between sudden cardiac death and exercise is well accepted (Mittleman et al. 1993; Willich et al. 1993). The common scenario is a male over age 40 with occult coronary disease, who is subjected to a high exercise stress, develops symptomatic ischemia, myocardial infarction or sudden death.

Figure 6: Diving-related CV deaths reported to DAN



Source: Caruso et al. 2001

"The common scenario is a male over age 40 with occult coronary disease, who is subjected to a high exercise stress, develops symptomatic ischemia, myocardial infarction or sudden death."

The exercise demands of recreational diving should be understood in this context, and for individuals suspected to be at risk for coronary disease, screening prior to diving is essential to prevent a lethal cardiovascular event.

Screening for coronary disease is based first on assessment of coronary disease risk factors (Table 1).

Table 1: CAD risk factors

Age
Sex
Blood pressure
Blood cholesterol
Smoking
Diabetes

Source: Wilson et al. 1998

A commonly used cardiovascular disease risk score is available from longitudinal studies in Framingham, Mass. (Wilson et al. 1998). The Framingham Risk Score defines the 10-year risk of developing cardiovascular disease: A risk score lower than 10 percent (i.e., less than 1 percent/year risk) is considered to be a low score. If a subject is assessed to be at low risk in general, that individual is not likely to have an acute coronary event while diving. On the other hand, high-risk individuals (Framingham score >20 percent) could be at considerable risk and should have further evaluation to evaluate whether diving will be safe.

Intermediate-risk individuals with a Framingham score between 10 percent and 20 percent should have further risk stratification to assess their risk for an acute coronary event while diving. There are several choices for defining risk in these individuals, but one method that should be incorporated is exercise stress testing, as the concern is for an adverse cardiac event during the exercise demands of diving. For most divers in need of risk assessment, an exercise stress test with ECG monitoring is adequate to identify concerns related to exercise activity. Added imaging (myocardial perfusion or echocardiography) can be used in selected cases to improve accuracy of the stress test. Other methods (biomarkers, coronary calcium scoring, CT angiography) can be used to assess population-based risk, but for an individual, assessment of individual risk under conditions of increased stress is best done by functional testing. Individuals who show ischemic changes during exercise, particularly if corroborated with a concurrent imaging result, are likely to be at increased risk during diving and should have further evaluation, and possibly intervention, before considering diving.

Patients with known coronary disease often have been subject to revascularization either by coronary bypass surgery or by percutaneous catheter intervention, currently with implantation of one or more stents in the affected coronary arteries. The degree of revascularization can determine safety in diving. With complete revascularization, low-stress diving can be accomplished successfully, but diving in rough seas, fast currents or cold water would be risky. There are many divers who have returned to diving after either coronary bypass surgery or stenting. Success in return to diving is based on restored exercise capacity without ischemia after revascularization and choosing diving environments that do not produce excess stress on the cardiovascular system.

"Cardiovascular disease is the third most common cause of death while diving and remains the principal cause of death in the general population."

Conclusions

Cardiovascular disease is the third most common cause of death while diving (Denoble, Caruso et al. 2008; Divers Alert Network 2004) and remains the principal cause of death in the general population (National Institutes of Health 2011). While the majority of cardiac disorders are compatible with safe diving, in divers with cardiovascular disease consideration of the stress created by adverse diving environments must be considered. There are several unique situations that involve central blood shifts due to water immersion, arrhythmias induced by the aquatic environment and increased exercise demands caused by an adverse diving environment that must be considered in individuals with heart disease. Inappropriate exposure in an individual with heart disease can lead to a diving fatality. Collaboration between dive physicians and cardiologists caring for patients with complex cardiac disorders can often resolve risks and determine the safety of diving for individuals with cardiovascular disorders.

References

Ackerman MJ, Tester DJ, Porter CJ. Swimming, a gene-specific arrhythmogenic trigger for inherited long QT syndrome. *Mayo Clin Proc.* 1999; 74:1088-94.

American Board of Preventive Medicine. *https://www.theabpm.org/uhm.cfm,* accessed May 4, 2010.

American Heart Association. Heart Disease and Stroke Statistics 2010 Update: A Report From the American Heart Association, *Circulation.* 2010; 121; e46-e215.

Arborelius M Jr., Balldin UI, Lilja B and Lundgren CEG. Hemodynamic changes in man during immersion with the head above water. *Aerospace Med* 1972; 43: 592-598.

Baron B, Noakes TD, Dekerle J, Moullan F, Robin S, Matran R, Pelayo P. Why does exercise terminate at the maximal lactate steady state intensity? *Br J Sports Med.* 2008; 42:828-33.

Batchelor GK. *An Introduction to Fluid Dynamics.* London: Cambridge University Press, pp. 231-237, 1967.

Bove AA. Cardiovascular Disorders and Diving. In Bove AA (ed): *Bove and Davis' Diving Medicine.* Philadelphia: W.B. Saunders, 2004: 485-506.

Caruso JL, Bove AA, Uguccioni DM, Ellis JE, Dovenbarger JA, Bennett PB. Recreational diving deaths associated with cardiovascular disease (abstract). *Undersea and Hyperb. Med*. 28:76, 2001.

Denoble PJ, Caruso JL, deL. Dear G, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med* 2008; 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 and Hyperbaric Medicine* 2008; 38:182-188.

Divers Alert Network. *Report on Decompression Illness, Diving Fatalities and Project Dive Exploration.* Durham, NC: Divers Alert Network, 2004; pp77-87.

Faude O, Kindermann W, Meyer T. Lactate threshold concepts: how valid are they? *Sports Med.* 2009; 39:469-90.

Gewillig M, Brown SC, Eyskens B, Heying R, Ganame J, Budts W, Gerche AL, Gorenflo M. The Fontan circulation: who controls cardiac output? *Interact Cardiovasc Thorac Surg.* 2010; 10:428-33.

Hiratzka LF, Bakris GL, Beckman JA, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM Guidelines for the Diagnosis and Management of Patients with Thoracic Aortic Disease. *J. Am. Coll. Cardiol.* 2010; 55:e27-e129.

Kato S, Onishi K, Yamanaka T, Takamura T, Dohi K, Yamada N, Wada H, Nobori T, Ito M. Exaggerated hypertensive response to exercise in patients with diastolic heart failure. *Hypertens Res.* 2008; 31:679-84.

Kaufman ES. Mechanisms and clinical management of inherited channelopathies: long QT syndrome, Brugada syndrome, catecholaminergic polymorphic ventricular tachycardia, and short QT syndrome. *Heart Rhythm* 2009;6 (8 Suppl):S51-5.

Lafay V, Trigano JA, Gardette B, Micoli C, Carre F. Effects of hyperbaric exposures on cardiac pacemakers. *Br J Sports Med.* 2008; 42:212-6.

Lepretre PM, Lopes P, Koralsztein JP, Billat V. Fatigue responses in exercise under control of VO_2. *Int J Sports Med.* 2008 March; 29:199-205.

Levine BD. Exercise physiology for the clinician. In Tompson PD: *Exercise and Sports Cardiology*. New York: McGraw-Hill, 2001, 3-29.

Maron BJ, Zipes DP. 36th Bethesda Conference: Eligibility recommendations for competitive athletes with cardiovascular abnormalities. *J Am Coll Cardiol* 2005; 45:2-64.

Mittleman MA, Maclure M, Tofler GH, Sherwood JB, Goldberg RJ, Muller JE. Triggering of acute myocardial infarction by heavy physical exertion: protection against triggering by regular exertion. *N Engl J Med* 1993; 329:1677-1683.

National Institutes of Health, National Heart, Lung, and Blood Institute. *Incidence and Prevalence: 2006 Chart Book on Cardiovascular and Lung Diseases.* Bethesda, Md.: National Heart, Lung, and Blood Institute, 2006. Available at *http://www.nhlbi.nih.gov/resources/docs/06a_ip_chtbk.pdf;* accessed April 11, 2011.

Pendergast DR, Mollendorf J, Logue C, Samimy S. Evaluation of fins used in underwater swimming. *Undersea Hyperb Med.* 2003; 30:57-73.

Pendergast DR, Tedesco M, Nawrocki DM, Fisher NM. Energetics of underwater swimming with scuba. *Med Sci Sports Exerc.* 1996; 28:573-80.

Sarnoff SJ, Mitchell JH, Gilmore JP, Remensnyder JP. Homeometric autoregulation in the heart. *Circ Res.* 1960; 8:1077-91.

Silka MJ, Hardy BG, Menashe VD, Morris CD. A population-based prospective evaluation of risk of sudden cardiac death after operation for common congenital heart defects. *J Am Coll Cardiol.* 1998; 32:245-51.

Slade JB Jr., Hattori T, Ray CS, Bove AA, Cianci P. Pulmonary edema associated with scuba diving: case reports and review. *Chest*; 120:1686-1694, 2001.

Szymański P, Klisiewicz A, Lubiszewska B, Lipczyńska M, Michałek P, Janas J, Hoffman P. Application of classic heart failure definitions of asymptomatic and symptomatic ventricular dysfunction and heart failure symptoms with preserved ejection fraction to patients with systemic right ventricles. *Am J Cardiol.* 2009; 104:414-8.

Tipton, M, Mekjavic, I, Golden, F. Hypothermia. In Bove AA (ed). *Bove and Davis' Diving Medicine.* Philadelphia: W.B. Saunders, 2004: Elsevier 2004, Chapter 13.

U.S. Navy, *U.S. Navy Diving Manual, Rev 6*. Washington, D.C.: U.S. Government Printing Office, 2008; pp. 3-11-3-12, 6-18.

Vignati G, Mauri L, Figini A, Pomè G, Pellegrini A. Immediate and late arrhythmia in patients operated on for tetralogy of Fallot. *Pediatr Med Chir.* 1998; 20:3-6.

Willich SN, Lewis M, Lowel H, Arntz H-R, Schubert F, Schroder R. Physical exertion as a trigger of acute myocardial infarction. *N Engl J Med* 1993; 329:1684-1690.

Wilmshurst PT, Nuri M, Crowther A, Webb-Peploe MM. Cold-induced pulmonary oedema in scuba divers and swimmers and subsequent development of hypertension. *Lancet*. 1989; 1(8629):62-5.

Wilson PW, D'Agostino RB, Levy D, Belanger AM, Silbershatz H, Kannel WB. Prediction of coronary heart disease using risk factor categories. *Circulation* 1998 May 12; 97(18):1837-47.

www.scubamed.com, accessed May 4, 2010.

The Cardiovascular Risks of Diving*

Paul D. Thompson, M.D.
Section of Cardiology
Henry Low Heart Center
Hartford Hospital
Hartford, Conn., USA

Cardiovascular disease may be responsible for a quarter of diving fatalities, but there are few studies on the cardiovascular complications of this activity. In contrast, there is a rich literature on land-based, exercise-related cardiac events. These studies document that exercise can increase the risk of acute cardiac events, but that absolute risk is small for healthy individuals. There are no proven strategies to reduce exercise-related cardiac events and consequently no proven strategies that could be confidently applied to diving. Nevertheless, requiring a pre-diving medical evaluation and clearance for those with known cardiac disease, training dive personnel to elicit possible cardiac prodromal symptoms, and frequent emergency training for diving supervisors are prudent approaches to this problem.

Introduction

Cardiovascular disease (CVD) has been identified as a possible contributing event to 156 of 590 (26 percent) diving-related fatalities (Denoble, Caruso et al. 2008). There are few studies on the cardiovascular complications of diving, however, and many of those available deal with issues related to patent foramen ovale and systemic emboli.

"Cardiovascular disease may be responsible for a quarter of diving fatalities, but there are few studies on the cardiovascular complications of this activity."

A PubMed search performed in February 2010 using the terms "diving" and "cardiac events" yielded 25 publications of which only one (Denoble, Caruso et al. 2008) was directly relevant. In contrast, a search using the terms "exercise" and "cardiac events" yielded 3,051 publications. Consequently, the present manuscript will discuss nondiving exercise-related cardiovascular complications in an attempt to suggest strategies that may be useful in reducing diving-related cardiac events. This extrapolation of exercise-related cardiovascular events to diving is necessary given the paucity of data on cardiac events during diving, but it should be recognized that diving includes additional cardiovascular stressors such as cold exposure, changes in pulmonary compliance and vascular pressures, and centralization of blood volumes that do not attend routine exercise.

Habitual physical activity has repetitively been associated with a reduced incidence of atherosclerotic cardiovascular disease events (Powell et al. 1987; Fletcher et al. 1996; Lee, Paffenbarger 2001; Thompson, Buchner, et al. 2003). Nevertheless, vigorous physical activity can acutely, albeit transiently, increase the risk of acute myocardial infarction (AMI) (Giri et al. 1999; Mittleman et al. 1993) and sudden cardiac death (SCD) in young (Corrado et al. 2003) and older (Siscovick et al. 1984; Albert et al. 2000) susceptible individuals.

Exercise-related cardiac events are usually defined as those occurring during, or within one hour of the cessation of sports participation in young subjects or vigorous physical exertion in older individuals (Rai, Thompson 2009).

Vigorous exercise is usually defined as exercise requiring ≥6 metabolic equivalents (METs). Six METs is approximately equal to an oxygen uptake (VO_2) of 21 ml/kg/minute or the energy required for activities such as jogging. This is an absolute

*This paper originally appeared in the *Undersea and Hyperbaric Medicine Journal* and is reprinted with permission from the Undersea and Hyperbaric Medical Society.

Thompson P. The cardiovascular risks of diving. *Undersea Hyperb Med.* 38(4):271-277; 2011.

workrate, however, and the cardiovascular stress of exercise is more closely related to the VO_2 requirements of exercise relative to the individual's maximal exercise capacity. Consequently, exercise workrates under 6 METs may still place considerable stress on the cardiovascular systems of unfit and older individuals.

Causes of Exertion-Related Cardiovascular Events

Exercise-associated acute cardiac events require some pathological substrate and do not occur in normal hearts. This substrate may be structural, such as hypertrophic cardiomyopathy or acute coronary thrombosis, or cellular, such as inherited ion channel disease. The causes of exercise-related deaths are different in young individuals, defined as ages younger than 30 to 40 years (Van Camp et al. 1995; Maron, Shirani et al. 1996; Corrado et al. 1990), and older subjects. The pathological findings in young individuals suffering an exercise-related cardiac death are primarily inherited or congenital cardiovascular abnormalities (Table 1) (Van Camp et al. 1995; Maron, Shirani et al. 1996; Corrado et al. 1990). Myocarditis is also associated with exercise-related deaths in young individuals. Ventricular fibrillation is assumed to be the immediate cause of death except in Marfan syndrome, where aortic rupture is responsible.

Coronary artery disease (CAD) is the cause of most exercise-related cardiac events in older individuals (Thompson, Stern, et al. 1979; Burke, Farb, et al. 1999). Acute coronary artery plaque rupture or erosion producing thrombotic occlusion is the proximate cause of these events in previously asymptomatic individuals (Burke et al. 1999), whereas either plaque disruption or an arrhythmia produced by ischemia or myocardial scar is the presumed proximate cause of such events in individuals with previously diagnosed CAD (Cobb, Weaver 1986).

"The causes of exercise-related deaths are different in young individuals, defined as ages younger than 30 to 40 years, and older subjects."

The mechanism by which vigorous exercise destabilizes coronary plaques is not defined, but increased arterial wall stress from increases in heart rate and blood pressure, exercise-induced coronary artery spasm in diseased artery segments (Gordon et al. 1989) and increased flexing of atherosclerotic epicardial coronary arteries (Black, Black, Gensini 1975) have been suggested as etiologic factors.

The Frequency of Exercise-Related Acute Cardiovascular Events

The frequency of exercise-related cardiovascular events varies with the prevalence of diagnosed or occult CVD in the study population. A 27-year registry of young U.S. athletes who died or survived cardiac arrest identified only 1,339 cases of which 1,049 were attributed to definite (n=690) or probable (n=359) cardiac disease (Maron, Doerer et al. 2009). The majority (61 percent) of events occurred in the final collection period between 1994 and 2002 and averaged only 66 cardiovascular deaths per year, or an estimated 0.6 deaths per 100,000 person-years (1 death per year per 166,666 athletes). Only 11 percent of these events occurred in women.

Others using some of the same data sources have published similar death rates for young U.S. athletes of only one per 133,000 men and 769,000 women, respectively (Van Camp et al. 1995). These later estimates include all sports-related nontraumatic deaths and are not restricted to cardiovascular events. These numbers are extremely low and consistent with the general safety of athletic participation in young individuals.

The incidence of cardiac death associated with vigorous physical exertion is considerably higher in adults, especially adult males, given their much higher prevalence of occult CAD. We estimated an incidence of only one death per 396,000 person-hours of jogging, or one death per year for every 7,620 joggers

(Thompson, Funk et al. 1982). Because half of the victims had known or readily diagnosed CAD, the hourly and annual rates for previously healthy individuals were one death per 792,000 hours and 15,260 subjects, respectively. Siscovick and colleagues estimated a similar annual rate of exercise-related cardiac arrest of one per 18,000 healthy men (Siscovick et al. 1984).

Table 1: Cardiovascular causes (%) of exercise-related sudden death in young athletes*

	Van Camp (n=100)+ (1995)	Maron (n =134) (1996)	Corrado (n =55)# (2003)
Hypertrophic cardiomyopathy (CM)	51	36	1
Probable hypertrophic CM	5	10	–
Coronary anomalies	18	23	9
Valvular and subvalvular aortic stenosis	8	4	–
Possible myocarditis	7	3	5
Dilated & non-specific CM	7	3	1
Atherosclerotic CAD	3	2	10
Aortic dissection/rupture	2	5	1
Arrhythmogenic right ventricular CM	1	3	11
Myocardial scarring	–	3	–
Mitral valve prolapse	1	2	6
Other congenital abnormalities	–	1.5	–
Long QT syndrome	–	0.5	1
Wolff-Parkinson-White syndrome	1	–	1
Cardiac conduction disease	–	–	3
Cardiac sarcoidosis	–	0.5	–
Coronary artery aneurysm	1	–	–
Normal heart at necropsy	7	2	1
Pulmonary thromboembolism	–	–	1

* Ages ranged from 13-24 (Van Camp 1995), 12-40 (Maron 1996) and 12-35 (Corrado 2003). Van Camp (1995) and Maron (1996) used the same database and include many of the same athletes. All (Van Camp 1995), 90 percent (Maron 1996) and 89 percent (Corrado 2003) had symptom onset during or within an hour of training or competition.

+ Total exceeds 100 percent because several athletes had multiple abnormalities.

Includes some athletes whose deaths were not associated with recent exertion. Includes aberrant artery origin and course, tunneled arteries and other abnormalities.

CAD=coronary artery disease; CM=cardiomyopathy; Reproduced with permission (Thompson et al. 2007).

Both studies have wide confidence limits because the rates were calculated using only 10 (Thompson et al. 1982) and nine (Siscovick et al. 1984) exercise-related deaths. All victims in both studies were men. These studies were also performed almost 30 years ago, but more recent studies confirm the low absolute risk of exercise-related SCD and the low rate among women. The absolute incidence of sudden death during and up to 30 minutes after vigorous exertion in the Physicians' Health Study was only one death per 1.51 million episodes of exercise (Albert et al. 2000). In the Nurses' Health Study there was only one death per 36.5 million hours of moderate to vigorous exertion (Whang et al. 2006). The explanation for the lower rates of exercise SCD in adult women is probably related to the delayed development of CAD in women and less participation in vigorous exercise among older females.

"The explanation for the lower rates of exercise SCD in adult women is probably related to the delayed development of CAD in women and less participation in vigorous exercise among older females."

Vigorous exercise can also precipitate AMI (Willich et al. 1993; Mittleman et al. 1993; Giri et al. 1999), but the absolute incidence of exercise-related MI in the the general population has not to our knowledge been carefully determined. Approximately 11 percent of individuals with AMI treated with primary angioplasty suffered an exertion-related event (Giri et al. 1999). Also, using the observation that exercise MI is 6.75 more frequent than exercise-related SCD (Siscovick et al. 1991) and confidence limits for SCD (Thompson et al. 1982), one can estimate that the 95 percent confidence limits for an exercise-related MI is one per year for every 593 to 3,852 apparently healthy middle-aged joggers. This number should be viewed cautiously, however, given that the SCD rate is based on only 10 cases (Thompson et al. 1982).

The incidence of exercise-related cardiovascular complications is considerably higher among those patients participating in supervised exercise-based cardiac rehabilitation programs (Table 2). An analysis of four reports estimates one cardiac arrest per 116,906 patient-hours, one myocardial infarction per 219,970 patient-hours, one fatality per 752,365 patient-hours and one major complication per 81,670 patient-hours of rehab participation (Van Camp, Peterson 1986; Digenio et al. 1991; Franklin et al. 1998; Vongvanich, Paul-Labrador, Merz 1996). This fatality rate applies only to medically supervised programs that are equipped to handle emergencies, since the death rate would be sixfold higher without the successful management of cardiac arrest. Cardiac rehabilitation patients also undergo a medical evaluation that often includes exercise stress testing, and they are under staff supervision. Consequently, it is likely that the rate of events, and especially fatal events, is considerably higher among patients with CAD exercising in unsupervised situations.

"The high putative rate of nonfatal exercise-related AMI is of concern, because some of these nonfatal events could become a "disabling event," leading to a fatality because of pain or panic during submersion."

Table 2: Summary of contemporary exercise-based cardiac rehabilitation program complication rates

PATIENT EXERCISE

Investigator	Year	Hours	Cardiac arrest	Myocardial infarction	Fatal events	Major complications*
Van Camp/Peterson (1986)	1980-1984	2,351,916	1/111,996†	1/293,990	1/783,972	1/81,101
Digenio *et al.* (1991)	1982-1988	480,000	1/120,000‡		1/160,000	1/120,000
Vongvanich *et al.* (1996)	1986-1995	268,503	1/89,501§	1/268,503§	0/268,503	1/67,126
Franklin *et al.* (1998)	1982-1998	292,254	1/146,127§	1/97,418§	0/292,254	1/58,451
Average			1/116,906	1/219,970	1/752,365	1/81,670

* MI and cardiac arrest; †Fatal 14%; ‡Fatal: 75%; §Fatal 0%. *Reproduced with permission (Thompson et al. 2007).*

This discussion on the incidence of exercise-related events has several messages important to diving. The high putative rate of nonfatal exercise-related AMI provided above is of concern, because some of these nonfatal events could become a "disabling event," leading to a fatality (Denoble, Caruso et al. 2008) because of pain or panic during submersion. Indeed, among 590 diving fatalities, 159 — or 27 percent — had a possible cardiac event leading to disability and ultimately drowning (Denoble, Pollock et al. 2008). Also, the group most at risk for an exercise-related event are by far those with established CVD. Nevertheless, the cardiac complication rate of diving seems very low. Using the reported seven-year diving fatality rate of 16.4 per 100,000 persons (Denoble, Pollock et al. 2008) and the estimate that 26 percent are related to cardiac disease (Denoble, Caruso et al. 2008), one can calculate an annual rate of only 0.6 per 100,000 divers.

It is also important to note that several of the above studies have documented a decrease in both AMI (Willich et al. 1993; Mittleman et al. 1993; Giri et al. 1999) and SCD (Siscovick et al. 1984) in the most habitually active subjects, meaning that exercise-related cardiac events are more frequent among those performing unaccustomed physical exertion.

Strategies to Reduce Exercise-Related Cardiovascular Events

A variety of strategies have been suggested to prevent exercise-related acute cardiovascular events (Thompson et al. 2007), but none have been sufficiently studied to evaluate their efficacy or to be required practice for health providers. Also, any prevention strategy must consider the rarity of exercise-related cardiac events in ostensibly healthy individuals and the cost of falsely positive screening strategies when these are applied to low-risk populations.

The medical screening of young athletes prior to organized sports participation is endorsed by multiple organizations including the American Heart Association (AHA) (Maron, Thompson et al. 1996; Maron et al. 1998; Maron et al. 2007) and the study group on sports cardiology of the European Society of Cardiology (Corrado et al. 2005). There is considerable and sometimes vitriolic (Myerburg, Vetter 2007) debate as to what constitutes effective screening. The European group recommends routine echocardiograms (ECGs) as part of the screening paradigm, whereas the AHA does not. A recent cost-effectiveness analysis of both approaches favored ECG use (Wheeler et al. 2010) but will probably not be readily accepted by both sides since it estimated the annual death rates in young athletes as 1 death per 42,000 participants, a value higher than most other estimates' symptoms prior to death.

"Any prevention strategy must consider the rarity of exercise-related cardiac events in ostensibly healthy individuals and the cost of falsely positive screening strategies when these are applied to low-risk populations."

Preparticipation screening and the restriction of higher-risk subjects could also be applied to adults. Most exercise-related cardiac events in adults are due to atherosclerotic CVD (ASCVD). The population risk of ASCVD can be predicted using tools such as the Framingham Risk Score, which predicts the 10-year risk of SCD and AMI. Potential participants with a specific score could be identified and excluded The problem with this approach is that ASCVD is prevalent among lower-risk subjects. Also, extremely high-risk subjects are only a small part of the total population. Consequently, the largest absolute number of acute events occurs not in the highest-risk subjects but in the moderate- and lower-risk groups. Excluding the highest-risk group would likely have little effect on the total number of deaths.

Many physicians routinely perform preparticipation exercise testing in adults prior to vigorous exercise. Both the American College of Cardiology/American Heart Association (ACC/AHA) Guidelines on Exercise Testing (Gibbons et al. 2003) and the American College of Sports Medicine (ACSM) (ACSM 2005) recommend exercise testing for adults with increased risk of CVD, generally based on age or the presence of two or more CVD risk factors. Both groups recommend such testing in persons wth diabetes primarily because diabetics may not experience angina induced by exercise. In contrast, the U.S. Preventive Services Task Force (USPSTF 2004) states that there is insufficient evidence to determine the benefits and harm of exercise stress testing prior to an exercise training program (USPSTF 2004). Furthermore, a recent decision analysis recommended against exercise testing at all levels of risk because the numbers of exercise-related deaths prevented by exercise testing were fewer than the deaths produced by medical intervention (Lahav, Leshno, Brezis 2009).

In addition to such concerns, there are two largely underappreciated limitations to routine exercise testing. First, a positive exercise test result, by either ECG or imaging criteria, requires a flow-limiting coronary lesion. Most acute cardiac events in previously asymptomatic subjects are due to vulnerable plaque disruption, and so a normal exercise test does not exclude a nonflow-limiting, vulnerable plaque. Second, a positive exercise test in asymptomatic subjects is a better predictor of subsequent angina than of the events of most concern, AMI and SCD (McHenry et al. 1984). This is possibly because asymptomatic, flow-limiting lesions prompt the development of collateral vessels that limit the severity of any acute cardiac event.

Exclusion of subjects with established cardiovascular disease from sports participation or activities such as diving would likely be the single most effective technique to decrease exercise-related cardiac events. A careful case-controlled study identified a prior history of cardiovascular disease as the single most discriminating factor differentiating the 57 cases of exercise-related cardiac events from the controls (Van Teeffelen et al. 2009). The odds ratio in multivariate analysis suggests that those with prior CVD had a 32-fold higher (95 percent CI=7 to 143) risk of suffering a cardiac event. Since the risk of an exercise-related cardiac event is so much higher in patients with diagnosed CVD, excluding such participants, or requiring more extensive testing in this group, may reduce cardiac complications.

"Exclusion of subjects with established cardiovascular disease from sports participation or activities such as diving would likely be the single most effective technique to decrease exercise-related cardiac events."

Educating patients, exercise attendants and physicians about possible cardiac prodromal symptoms and their need for prompt evaluation has been advocated to reduce exercise-related cardiac events. In the case-controlled study mentioned above (Van Teeffelen et al. 2009), fatigue or flulike symptoms over the past month increased the risk of a cardiac event by 12- and 13-fold respectively (95 percent CIs: 1.2-118 and 1.4-131). Among adults who died from CAD during exertion, 50 percent of joggers (Thompson et al. 1979), 75 percent of squash players (Northcote, Flannigan, Ballantyne 1986) and 81 percent of distance runners (Noakes, Opie, Rose 1984) had probable cardiac symptoms prior to death (Table 3). Many of these symptoms were assumed to be gastrointestinal in origin and were not reported to medical personnel.

Table 3: Prodromal symptoms reported by 45 subjects within one week of their sudden death

Symptom	Number of reports
Chest pain/angina	15
Increasing fatigue	12
Indigestion/heartburn/gastrointestinal symptoms	10
Excessive breathlessness	6
Ear or neck pain	5
Vague malaise	5
Upper respiratory tract infection	4
Dizziness/palpitations	3
Severe headache	2

Note: Adapted from Northcote, Flannigan, Ballantyne 1986 and reproduced with permission (Thompson et al. 2007).

Also, among 159 diving fatalities attributed to cardiac disease, 10 percent of the victims had reported dyspnea, fatigue, chest pain, distress or some illness prior to their fatal dive (Denoble, Caruso et al. 2008). The specificity of such complaints is probably poor, given the prevalence of nonspecific complaints in the general population. Nevertheless, training exercise professionals to solicit new complaints and to refer subjects for appropriate evaluation seems prudent but, as with most of these interventions, is untested.

There is excellent evidence that training for cardiovascular emergencies reduces exercise-related cardiac deaths. This is demonstrated by the observation that the rates of cardiac arrest in cardiac rehabilitation programs is considerably lower than the fatality rate. Prompt resuscitation is not readily applicable to diving because most deaths occur during the dive, but it is reasonable that diving facilities be encouraged to establish and maintain emergency plans, periodic drills and training to address cardiac emergencies.

Suggested Approach to the Problem of Cardiac Events with Diving

Any requirements of diving participants should be cognizant of the rarity of exercise-related events in asymptomatic individuals, the poor predictive accuracy of most cardiac testing techniques and the absence of data that any method, except medical supervision, actually improves prognosis. Nevertheless, it does seem prudent to do the following:

1. Require medical clearance for individuals with known cardiac disease since this is the highest-risk subgroup. The group requiring medical clearance could be expanded to those providing positive responses to questionnaires designed for preparticipation evaluation, but this would greatly increase the participant burden without documented benefit.

2. Train diving personnel to elicit possible cardiac prodromal symptoms, and restrict those individuals with such symptoms until cleared by a medical professional.

3. Require cardiac emergency training, and scheduled drills for diving supervisors.

"There is excellent evidence that training for cardiovascular emergencies reduces exercise-related cardiac deaths."

References

Albert CM, Mittleman MA, Chae CU, Lee IM, Hennekens CH, Manson JE. Triggering of sudden death from cardiac causes by vigorous exertion. *N Engl J Med.* 2000; 343:1355-1361.

American College of Sports Medicine. Guidelines for Exercise Testing and Prescription. 7th ed. Baltimore, Md.: Lippincott Williams & Wilkins, 2005.

Black A, Black MM, Gensini G. Exertion and acute coronary artery injury. *Angiology*. 1975; 26:759-783.

Burke AP, Farb A, Malcom GT, Liang Y, Smialek JE, Virmani R. Plaque rupture and sudden death related to exertion in men with coronary artery disease. *JAMA*. 1999; 281:921-926.

Cobb LA, Weaver WD. Exercise: a risk for sudden death in patients with coronary heart disease. *J Am Coll Cardiol.* 1986;7:215-219.

Corrado D, Basso C, Rizzoli G, Schiavon M, Thiene G. Does sports activity enhance the risk of sudden death in adolescents and young adults? *J Am Coll Cardiol.* 2003; 42:1959-1963.

Corrado D, Pelliccia A, Bjornstad HH, Vanhees L, Biffi A, Borjesson M, Panhuyzen-Goedkoop N, Deligiannis A, Solberg E, Dugmore D, Mellwig KP, Assanelli D, Delise P, van Buuren F, Anastasakis A, Heidbuchel H, Hoffmann E, Fagard R, Priori SG, Basso C, Arbustini E, Blomstrom-Lundqvist C, McKenna WJ, Thiene G. Cardiovascular pre-participation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol. Consensus Statement of the Study Group of Sport Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. *Eur Heart J.* 2005; 26:516-524.

Corrado D, Thiene G, Nava A, Rossi L, Pennelli N. Sudden death in young competitive athletes: clinicopathologic correlations in 22 cases. *Am J Med.* 1990; 89:588-596.

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

Denoble PJ, Pollock NW, Vautgutabatgab P, Caruso JL, Dovenbarger JA, Vann PD. Scuba injury death rate among insured DAN members. *Diving and Hyperbaric Medicine.* 2008; 38:182-188.

Digenio AG, Sim JG, Dowdeswell RJ, Morris R. Exercise-related cardiac arrest in cardiac rehabilitation. The Johannesburg experience. *S Afr Med J.* 1991; 79:188-191.

Fletcher GF, Balady G, Blair SN, Blumenthal J, Caspersen C, Chaitman B, Epstein S, Sivarajan Froelicher ES, Froelicher VF, Pina IL, Pollock ML. Statement on exercise: benefits and recommendations for physical activity programs for all Americans. A statement for health professionals by the Committee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association. *Circulation.* 1996; 94:857-862.

Franklin BA, Bonzheim K, Gordon S, Timmis GC. Safety of medically supervised outpatient cardiac rehabilitation exercise therapy: a 16-year follow-up. *Chest.* 1998; 114:902-906.

Gibbons RJ, Balady G J, Bricker J T, Chaitman, BR, Fletcher G., Froelicher VF, Mark D., McCallister BD, Mooss A., O'Reilly M., Winters WL, Jr., Antman EM, Alpert JS, Faxon DP, Fuster V, Gregorato G, Hiratzka LF, Jacobs AK, Russell RO, and Smith SC, Jr. ACC/AHA 2002 guideline update for exercise testing: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing). *www.acc.org/clinical/guidelines/exercise/dirIndex.htm*. 2003. Ref Type: Internet Communication

Giri S, Thompson PD, Kiernan FJ, Clive J, Fram DB, Mitchel JF, Hirst JA, McKay RG, Waters DD. Clinical and angiographic characteristics of exertion-related acute myocardial infarction. *JAMA.* 1999; 282:1731-1736.

Gordon JB, Ganz P, Nabel EG, Fish RD, Zebede J, Mudge GH, Alexander RW, Selwyn AP. Atherosclerosis influences the vasomotor response of epicardial coronary arteries to exercise. *J Clin Invest.* 1989; 83:1946-1952.

Lahav D, Leshno M, Brezis M. Is an exercise tolerance test indicated before beginning regular exercise? A decision analysis. *J Gen Intern Med.* 2009; 24:934-938.

Lee IM, Paffenbarger Jr. RS. The role of physical activity in the prevention of coronary artery disease. In: *Exercise & Sports Cardiology.* Thompson PD, ed. McGraw-Hill, 2001.

Maron BJ, Doerer JJ, Haas TS, Tierney DM, Mueller FO. Sudden deaths in young competitive athletes: analysis of 1866 deaths in the United States, 1980-2006. *Circulation.* 2009; 119:1085-1092.

Maron BJ, Shirani J, Poliac LC, Mathenge R, Roberts WC, Mueller FO. Sudden death in young competitive athletes. Clinical, demographic, and pathological profiles. *JAMA.* 1996; 276:199-204.

Maron BJ, Thompson PD, Ackerman MJ, Balady G, Berger S, Cohen D, Dimeff R, Douglas PS, Glover DW, Hutter AM, Jr., Krauss MD, Maron MS, Mitten MJ, Roberts WO, Puffer

JC. Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. *Circulation.* 2007; 115:1643-455.

Maron BJ, Thompson PD, Puffer JC, McGrew CA, Strong WB, Douglas PS, Clark LT, Mitten MJ, Crawford MH, Atkins DL, Driscoll DJ, Epstein AE. Cardiovascular preparticipation screening of competitive athletes. A statement for health professionals from the Sudden Death Committee (clinical cardiology) and Congenital Cardiac Defects Committee (cardiovascular disease in the young), American Heart Association. *Circulation.* 1996; 94:850-856.

Maron BJ, Thompson PD, Puffer JC, McGrew CA, Strong WB, Douglas PS, Clark LT, Mitten MJ, Crawford MD, Atkins DL, Driscoll DJ, Epstein AE. Cardiovascular preparticipation screening of competitive athletes: addendum: an addendum to a statement for health professionals from the Sudden Death Committee (Council on Clinical Cardiology) and the Congenital Cardiac Defects Committee (Council on Cardiovascular Disease in the Young), American Heart Association. *Circulation.* 1998; 97:2294.

McHenry PL, O'Donnell J, Morris SN, Jordan JJ. The abnormal exercise electrocardiogram in apparently healthy men: a predictor of angina pectoris as an initial coronary event during long-term follow-up. *Circulation.* 1984; 70:547-551.

Mittleman MA, Maclure M, Tofler GH, Sherwood JB, Goldberg RJ, Muller JE. Triggering of acute myocardial infarction by heavy physical exertion. Protection against triggering by regular exertion. Determinants of Myocardial Infarction Onset Study Investigators. *N Engl J Med.* 1993; 329:1677-1683.

Myerburg RJ, Vetter VL. Electrocardiograms should be included in preparticipation screening of athletes. *Circulation.* 2007; 116:2616-2626.

Noakes TD, Opie LH, Rose AG. Marathon running and immunity to coronary heart disease: fact versus fiction. In: *Symposium on Cardiac Rehabilitation.* Franklin BA, Rubenfire M, eds. 1984. WB Saunders, Philadelphia, PA.

Northcote RJ, Flannigan C, Ballantyne D. Sudden death and vigorous exercise — a study of 60 deaths associated with squash. *Br Heart J.* 1986; 55:198-203.

Powell KE, Thompson PD, Caspersen CJ, Kendrick JS. Physical activity and the incidence of coronary heart disease. *Annu Rev Public Health.* 1987; 8:253-287.

Rai M, Thompson PD. The definition of exertion-related cardiac events. *Br J Sports Med.* 2009.

Siscovick DS, Ekelund LG, Johnson JL, Truong Y, Adler A. Sensitivity of exercise electrocardiography for acute cardiac events during moderate and strenuous physical activity. The Lipid Research Clinics Coronary Primary Prevention Trial. *Arch Intern Med.* 1991; 151:325-330.

Siscovick DS, Weiss NS, Fletcher RH, Lasky T. The incidence of primary cardiac arrest during vigorous exercise. *N Engl J Med.* 1984; 311:874-877.

Thompson PD, Buchner D, Pina IL, Balady GJ, Williams MA, Marcus BH, Berra K, Blair SN, Costa F, Franklin B, Fletcher GF, Gordon NF, Pate RR, Rodriguez BL, Yancey AK, Wenger NK. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease: a statement from the Council on Clinical Cardiology (Subcommittee on Exercise, Rehabilitation, and Prevention) and the Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity). *Circulation.* 2003; 107:3109-3116.

Thompson PD, Franklin BA, Balady GJ, Blair SN, Corrado D, Estes NA, III, Fulton JE, Gordon NF, Haskell WL, Link MS, Maron BJ, Mittleman MA, Pelliccia A, Wenger NK, Willich SN, Costa F. Exercise and acute cardiovascular events placing the risks into perspective: a scientific statement from the American Heart Association Council on

Nutrition, Physical Activity, and Metabolism and the Council on Clinical Cardiology. *Circulation.* 2007; 115:2358-2368.

Thompson PD, Funk EJ, Carleton RA, Sturner WQ. Incidence of death during jogging in Rhode Island from 1975 through 1980. *JAMA.* 1982; 247:2535-2538.

Thompson PD, Stern MP, Williams P, Duncan K, Haskell WL, Wood PD. Death during jogging or running. A study of 18 cases. *JAMA.* 1979; 242:1265-1267.

U.S. Preventive Services Task Force, Screening for coronary heart disease: recommendation statement, *Ann Intern Med.* 2004; 140:569-572.

Van Camp SP, Bloor CM, Mueller FO, Cantu RC, Olson HG. Nontraumatic sports death in high school and college athletes. *Med Sci Sports Exerc.* 1995; 27:641-647.

Van Camp SP, Peterson RA. Cardiovascular complications of outpatient cardiac rehabilitation programs. *JAMA.* 1986; 256: 1160-1163.

Van Teeffelen WM, de Beus MF, Mosterd A, Bots ML, Mosterd WL, Pool J, Doevendans PA, Grobbee DE. Risk factors for exercise-related acute cardiac events. A case-control study. *Br J Sports Med.* 2009; 43:722-725.

Vongvanich P, Paul-Labrador MJ, Merz CN. Safety of medically supervised exercise in a cardiac rehabilitation center. *Am J Cardiol.* 1996; 77:1383-1385.

Whang W, Manson JE, Hu FB, Chae CU, Rexrode KM, Willett WC, Stampfer MJ, Albert CM. Physical exertion, exercise, and sudden cardiac death in women. *JAMA.* 2006; 295:1399-1403.

Wheeler MT, Heidenreich PA, Froelicher VF, Hlatky MA, Ashley EA. Cost-effectiveness of preparticipation screening for prevention of sudden cardiac death in young athletes. *Ann Intern Med.* 2010; 152:276-286.

Willich SN, Lewis M, Lowel H, Arntz HR, Schubert F, Schroder R. Physical exertion as a trigger of acute myocardial infarction. Triggers and Mechanisms of Myocardial Infarction Study Group. *N Engl J Med.* 1993; 329:1684-1690.

Cardiovascular Screening in Asymptomatic Adults: Lessons for the Diving World*

Pamela S. Douglas M.D., MACC, FASE, FAHA, FACSM
Division of Cardiovascular Medicine
Duke Clinical Research Institute
Duke University
Durham, N.C., USA

At the broadest level, consensus preparticipation recommendations for athletes of all ages focus on performance of a history and physical examination, with the additional performance of a screening test being more controversial. Depending upon athlete age and the associated prevalence of etiologies of cardiac death, differences exist regarding specific targets for the history and physical and for the type of testing considered. This paper provides a summary of the estimated relative value of the components of a screening program for both younger and older athletes.

Introduction

Unexpected death is always a tragedy but is perhaps more poignant when it occurs during sport. Athletes, even recreational ones, are felt to be "healthier" than the rest of the population, and exercise is often prescribed to improve cardiovascular health. Yet it is clear that exercise itself is a cardiovascular stressor and that the majority of nontraumatic deaths during exercise are cardiac in origin.

Many organizations have sought to define principles for the early detection of those who might be at risk, with the hope that these individuals can then undergo further evaluation, treatment to reduce risk or limitation of risk by reducing exposure to exercise. Recent data indicating that about one-quarter of diving deaths are related to cardiovascular disease (Denoble, Caruso et al. 2008; Denoble, Pollock et al. 2008) has provided the impetus to examine whether more could be done to prevent cardiovascular events in divers. This review will address the principles of screening in asymptomatic individuals; available screening tools and tests; current recommendations regarding screening promulgated by other organizations; experience with screening programs, including diving; and conclude with some issues that should be considered in designing a screening program.

"Recent data indicating that about one-quarter of diving deaths are related to cardiovascular disease has provided the impetus to examine whether more could be done to prevent cardiovascular events in divers."

Principles and Goals of Preparticipation Screening

The World Health Organization (WHO) has developed a generally accepted set of principles for any disease screening program (Wilson 1968) (Table 1). Consideration of these may be helpful in designing a preparticipation screening program.

Several additional points are worth considering: Screening programs are generally designed to detect asymptomatic individuals. Further, most screening programs for athletes are not designed to detect disease per se but are designed to detect those individuals who need further evaluation. While this may seem like a fine distinction, it is important to recognize this goal, as it dictates that sensitivity is far more important than specificity in designing and evaluating a screening program.

*This paper originally appeared in the *Undersea and Hyperbaric Medicine Journal* and is reprinted with permission from the Undersea and Hyperbaric Medical Society.

Douglas P. Cardiovascular screening in asymptomatic adults: lessons for the diving world. *Undersea Hyperb Med.* 38(4):279-287; 2011.

Table 1: WHO screening principles

- There should be an important problem.
- There should be an accepted treatment.
- Facilities must exist for diagnosis and treatment.
- There should be a recognizable latent or early symptom stage.
- A suitable test or examination must exist.
- The test must be acceptable to the population.
- The natural history must be understood.
- There must be an agreed policy on treatment.
- Cost must be related to other medical care expenditure.
- There must be a continuing process.

Note: Adapted from Wilson JM. The evaluation of the worth of early disease detection. *J R Coll Gen Pract.* 1968 Nov; 16 Suppl 2:48-57.

All screening programs use standardized tools, whether questionnaires, specific physical exam elements or diagnostic tests. The ideal tools for a screening program are (Grimes, Schulz 2002):

- easy, inexpensive and comfortable
- valid for diagnosis
- high sensitivity/specificity
- valid for prognosis
- reliable, with low variability of test results

"In individuals over the age of 35 years, the overwhelming cause of death is unrecognized coronary artery disease.…"

Causes of Death During Exercise

Critical to designing any screening program is a clear understanding of what disease or diseases can cause exercise-related deaths and are therefore "under suspicion" in a screening evaluation. In the case of exercise-related sudden death, this depends critically on age. Individuals under the age of 35 years are most likely to die from inherited structural heart disease, most commonly hypertrophic cardiomyopathy (Maron et al. 2009). Less important but still significant are coronary anomalies, Marfan syndrome, other cardiomyopathies and myocarditis. These diseases are generally best recognized by family history, rest echocardiogram (ECG) and rest echocardiography.

In individuals over the age of 35 years, the overwhelming cause of death is unrecognized coronary artery disease (CAD), detection of which is best approached through evaluation of risk factors and perhaps subclinical atherosclerosis and provocative stress testing.

In short, the approach and tools used for testing will vary significantly depending on the disease(s) for which the screening is being performed.

Impact of a Positive Screening Study

An important complement to any screening program is a plan for how to manage those individuals who are eventually found to have significant disease. The most authoritative source is the American College of Cardiology's (ACC) 26th Bethesda Conference recommendations regarding participation in competitive sport for individuals (American College of Cardiology 1994). The limitation of these recommendations to competitive sports is purposeful, as it was felt that, in comparison to recreational sports, competitive sports may limit the ability of an athlete to recognize and act on early symptoms — a situation that may well be analogous to the diving environment. Further, while diving was not included, the approach to classifying sports may be helpful as a framework. Sports are classified by the tertile of intensity of their dynamic (percent VO_2max: <50 percent, 50-70 percent, >70 percent) and static (percent maximal voluntary contraction: <10 percent, 10-30 percent, >30 percent) components as well as the danger of bodily injury from collision and consequences of syncope. Recommendations regarding participation are based on the likely tolerance to these stresses and dangers in specific cardiovascular diseases.

Younger Athletes

Most of the attention related to preparticipation screening in sport has focused on competitive athletes and therefore on the diseases that are most important in a younger age group. Many organizations have developed recommendations for screening programs, which can vary substantially. In the United States, the most prominent guidelines issued by the American Heart Association (AHA) recommend a targeted 12-point history and physical exam with no routine testing (Maron et al. 1996, 1998, 2007).

There is currently no national requirement for preparticipation screening in the United States, although several states do require screening for high school and collegiate athletes. Individual sports organizations (schools, teams) have implemented these programs or, for elite or professional athletes, created their own more rigorous programs. In contrast, the European Society of Cardiology (ESC) guidelines call for the addition of a screening ECG, a strategy that is required by law by many countries (Corrado et al. 2005; Douglas 2008).

"Most of the attention related to preparticipation screening in sport has focused on competitive athletes and therefore on the diseases that are most important in a younger age group."

While a prospective comparison of screening programs with or without ECG would be logistically impossible, observational data are available. Most relevant is the well-documented 20-year experience in Italy showing a dramatic reduction in incidence of sudden death after implementation of a mandatory screening program administered by sports cardiologists that includes an ECG (Corrado et al. 2006). While these results have been called into question because the baseline rate of sudden death was much higher in Italy than in the United States (Pelliccia et al. 2008), visual inspection of data from the most recent years of this program suggest a lower sudden death rate associated with the more rigorous Italian screening program.

Other relevant data include a Harvard study of 510 students in whom the addition of ECG to a history and physical substantially increased the sensitivity of screening from 45 percent to 91 percent. However, the specificity fell slightly from 94 percent to 83 percent (Baggish et al. 2010). Other investigators performing cost-effectiveness modeling suggests that the addition of a rest ECG is within the generally accepted range of value for cost of life years saved (Wheeler et al. 2010). The authors found that implementation of a history and physical screening at an estimated cost of $199US per athlete would add 2.6 life years per 1,000 young athletes at a cost per year of $76,100US. Addition of an ECG to the screening program (estimated additional cost: $89US) was calculated to save an additional two life years, at a cost per year of $42,900US.

In the absence of any prospective testing of different strategies, the design of the optimal program has not been established. However, it is clear that a careful history is very important and should include family history, exertional symptoms and syncope. A physical exam is also important, as murmurs reflective of the hemodynamic abnormalities are often present at rest (Table 2). Given the accumulating data, addition of a noninvasive test such as a rest ECG may become more accepted in the United States over time, especially if financial and logistic hurdles can be overcome (Maron 2010).

Table 2: CV risk assessment: suitability/acceptabiity of tests for screening

	< 35 years	> 35 years
History	+++	+++
Physical Exam	+++	+++
Noninvasive Testing		
Resting ECG	+++	+
Exercise ECG	+	++
Stress Imaging	-	+
CIMT	-	+++
CAC	-	+++
CTA	-	+

CIMT: carotid intima medial thickening;
CAC: coronary artery calcification;
CTA: coronary computed tomographic angiography.

"Since most individuals are asymptomatic, the history is often more helpful in identifying risk factors rather than symptoms."

Older Athletes

In comparison to younger individuals, far less attention has been paid to designing screening programs for older, usually recreational, athletes. Few detailed preparticipation guidelines exist, and there is little reported experience in this age group. Instead most authorities focus on strategies used in clinical medicine for the early detection of atherosclerotic diseases, as these are the most common cause of death in this age group.

Since most individuals are asymptomatic, the history is often more helpful in identifying risk factors rather than symptoms. Similarly, there may be few detectable abnormalities at rest or even with exercise, as events are often due to spontaneous rupture of nonobstructive plaque (Table 2).

The AHA statement issued recommendations for preparticipation screening in older athletes in 2007 (Maron, Thompson et al. 2007). This document recommends that older competitive athletes (>35 to 40 years) be "knowledgeable" regarding their personal history of CAD risk factors and family history of premature CAD. Further, stress testing should be performed selectively for individuals engaging in vigorous training and competitive sports and who meet the following criteria: men >40 years or women >55 years with diabetes mellitus, or at least two risk factors or one severe risk factor other than age. Finally, the document recommends education regarding prodromal cardiac symptoms, such as exertional chest pain.

The recommendations regarding the use of stress testing are derived from the 2002 ACC/AHA guideline, which recommends using exercise testing in the following individuals (Gibbons et al. 2002) and are similar to those of the American College of Sports Medicine (Armstrong et al. 2009). These include:

1. Evaluation of asymptomatic persons with diabetes mellitus who plan to start vigorous exercise *(Class IIa; Level of Evidence: C)*.

2. Evaluation of asymptomatic men > 45 years and women > 55 years who plan to start vigorous exercise (especially if sedentary) *(Class IIb)*.

3. Evaluation of asymptomatic men > 45 years and women > 55 years with occupations in which impairment might impact public safety *(Class IIb)*.

In contrast, the guideline recommends against routine screening of asymptomatic men or women *(Class III)* since such individuals will have a low pretest probability and be more likely to have a false positive than a true positive test. Use of a stress test as the screening strategy could result in making many normal individuals undergo unnecessary follow-up tests or procedures.

Risk Stratification

Most recommendations for preparticipation screening in older individuals begin with screening for CAD risk factors. In addition to the AHA guideline on primary prevention (Pearson et al. 2002), the ACC/AHA recently issued a set of performance measures in this area (Redberg et al. 2009). Performance measures are distilled from the strongest evidence, represent "must do" recommendations endorsed by national-quality organizations and often reinforced by public reporting and pay for performance programs. The 13 recommended performance measures for primary prevention are:

- lifestyle/risk factor screening
- dietary intake counseling
- physical activity counseling
- smoking/tobacco use assessment
- smoking/tobacco cessation
- weight/adiposity assessment
- weight management
- blood pressure measurement
- blood pressure control
- blood lipid measurement
- blood lipid therapy and control
- global risk estimation
- aspirin use

"Most recommendations for preparticipation screening in older individuals begin with screening for CAD risk factors."

Implementation of these measures requires performance of a careful history and physical examination, laboratory testing for lipids and formal assessment of cardiovascular risk. Unfortunately, there are several risk scores available whose results may differ widely (Berger et al. 2010).

A recent review presented a case vignette of a 56-year-old woman with several risk factors; estimates of risk varied from 2 percent for 10-year Framingham Risk Score (heart attack and death) to an overall lifetime risk as high as 50 percent. Nevertheless, risk assessment is most often accomplished using the Framingham Risk Score (FRS) (National Cholesterol Education Program 2001). This score classifies individuals into high, medium and low 10-year risk for cardiovascular events and stroke. Individuals with known CAD and those with diabetes and peripheral vascular disease (considered to be "CAD-equivalents") are placed in the highest risk category. In other individuals, risk is calculated using a weighted combination of age, sex, total cholesterol, HDL cholesterol, smoking history and blood pressure. Calculators are available online at *http://hp2010.nhlbihin.net/atpIII/calculator.asp*.

Preventive interventions are recommended based on these estimates of 10-year risk. Individuals classified as having low 10-year risk, defined as an event rate of <10 percent, should be treated with reassurance, and further risk assessments should not be performed for five years. Individuals estimated to be at high risk, defined as a 10-year risk >20 percent, should be treated with aggressive risk-factor modification to secondary prevention goals. It is less clear how individuals classified as having an intermediate 10-year risk (event rate of 10-20 percent) should be treated. ACC/AHA recommendations suggest considering referral for further tests, such as atherosclerosis imaging (see below) for reclassification into either low- or high-risk groups (Greenland et al. 2007).

Although carefully validated, there is widespread concern that the Framingham Risk Score is flawed. In addition to the ambiguity in intermediate-risk individuals, it fails to capture important risk factors such as family history, the severity of risk factors and emerging risk factors such as inflammation as manifested in hs-CRP (Kannel et al. 1961). Risk in some demographic categories, such as younger women, is underestimated. More important, it is clear that events do occur in individuals estimated to be at low risk (Akosah et al. 2003). For example, National Health and Nutrition Examination Survey data classify 85 percent of healthy adults between ages 20 and 79 years as low risk by Framingham Risk Score, with only 2 percent as high risk, although epidemiological data suggests that more than one-third will die from cardiovascular disease (American Heart Association 2010; Ajani, Ford 2006).

"Although carefully validated, there is widespread concern that the Framingham Risk Score is flawed."

Atherosclerosis Imaging and Stress Testing

As a result, some have suggested the use of additional testing to detect atherosclerosis, often termed subclinical disease. While there are several techniques available (Crouse 2006), the most prominent tests are ultrasound evaluation of the carotid intima media thickness (CIMT) and CT-based coronary artery calcium scoring (CAC). Both tests have been studied extensively in large community-based studies and accurately predict both prevalent and incident cardiac events (Kaul, Douglas 2009). However, no prospective studies have been performed comparing the clinical impact of strategies incorporating the use of either test as a guide to a risk reduction treatment to that of the use of a Framingham Risk Score alone.

CIMT: Measurement of carotid intima media thickness was developed in the 1980s and is typically carried out using high-frequency ultrasound transducers. The rationale for using CIMT to refine CAD risk assessment is based on multiple large (>1000 patients) prospective studies that have been reviewed in detail in a recent meta-analysis (Lorenz et al. 2007). Each study demonstrated a statistically significant association between CIMT and the risk for myocardial infarction, CAD death and stroke. The age- and sex-adjusted overall estimate of the risk of myocardial infarction was 1.15 (95 percent CI, 1.12 to 1.17) per 0.10 mm CIMT difference. Further, CIMT progression is well documented to slow with risk-factor-targeted interventions, and this slowing is associated with a reduced risk of future CHD events (Hodis et al. 1998; Espeland et al. 2005). The major limitations of CIMT are cost, as it is generally not reimbursed, its operator dependence and lack of widespread availability. Nevertheless, CIMT is a well-established surrogate marker for atherosclerosis and coronary artery disease.

CAC: A newer test, CAC appears to also be of independent and additive value in predicting CAD events, although data are limited in women and nonwhites. The best data come from the NHLBI MultiEthnic Study of Atherosclerosis (MESA) observational trial, which uses multiple imaging modalities to describe the characteristics and progression of subclinical atherosclerosis in a population-based sample of 3,601 women and 3,213 men aged 45-84 years and without known CVD (Bild et al. 2002). Detrano et al. (2008) found that MESA subjects with a CAC score >300 had a hazard ratio of 9.67 (95 percent CI, 5.20 to 17.98, P<0.001) for cardiovascular events compared with those with a CAC of 0. The addition of CAC significantly increased the discriminant accuracy for predicting all CAD events from a c-index of 0.77 for risk factors alone to 0.82 for risk factors plus CAC.

Similar results have been obtained by others. A meta-analysis of six studies showed strong incremental relationships between increasing CAC scores and higher event rates (Greenland et al. 2007). In particular, patients with intermediate FRS but a CAC score >400 had an elevated annual CAD death or myocardial infraction rate of 2.4 percent. These data support the proposed strategy of using CAC to reclassify intermediate risk individuals into either high- or low-risk categories. Those recategorized as high-risk (>20 percent 10-year risk of estimated coronary events, i.e., CAD equivalent risk status) would then receive more intensive preventive treatment. In contrast, while individuals with a CAC of 0 may have obstructive disease (Gottlieb et al. 2010), they have generally been found to have a low event rate (Hecht 2010) and low conversion rate to a positive CAC score, with a "warranty period" of at least four years (Min et al. 2010). The major limitations to CAC are cost, as it is generally not reimbursed, and radiation, which is generally 1-2 milliSieverts (mSv).

The MESA study provides the best head-to-head comparison of CIMT and CAC in predicting CAD risk (Folsom et al. 2008). In almost 6,700 subjects followed over a maximum of 5.3 years, both tests were associated with risk of incident events (CAD, stroke, fatal CAD). However, CAC was associated more strongly than CIMT with a hazard ratio for an incident event of 2.1 (95 percent CI, 1.8 to 2.5) per standard deviation (SD) increment of CAC score as compared to 1.3 (95 percent CI, 1.1 to 1.4) per SD increment of CIMT. Receiver operating characteristic curve analysis also suggested that CAC scoring was a better predictor of events than CIMT, with an area under the curve of 0.81 versus 0.78. However, a separate cost-effectiveness analysis of CAC scoring as a CAD risk prediction tool suggests that its use in an asymptomatic population is expensive and not cost-effective, with a cost per identification of a new "at risk" case of $9,789US and a cost per QALY of $86,700US (O'Malley et al. 2004).

CCTA: The newest test to identify atherosclerosis is coronary computed tomographic angiography (CCTA). This test uses modified CT technology to produce high temporal and spatial resolution, noninvasive images of the coronary artery lumen and walls, enabling detection and characterization of critical stenoses and nonobstructive plaque with high sensitivity and specificity (Budoff et al. 2008). Recent longitudinal data suggest that both stenosis and plaque burden provide independent, incremental prognostic value to conventional risk assessment (Chow et al. 2010). Limitations to use of CCTA are cost, as it is generally not reimbursed, and radiation, which is generally 10-20 mSv.

"Recent longitudinal data suggest that both stenosis and plaque burden provide independent, incremental prognostic value to conventional risk assessment."

Exercise testing: Although the ACC/AHA guidelines recommend preparticipation stress testing in selected circumstances, there are few data supporting its ability to risk-stratify in an asymptomatic population. This is not surprising, as a positive test requires the presence of coronary lesions severe enough to cause ischemia when workload is increased, and the target population for screening generally does not have such advanced disease. However, a study of 25,927 healthy men (aged 20-82 years) who underwent stress echocardiography and were subsequently followed for an average of 8.4 years suggests there is some value. While stress testing did not significantly enhance the prediction of prognosis in individuals without cardiac risk factors, in those with risk factors a positive stress echo added incremental information. Nevertheless, less than 6 percent of tests were positive, and the sensitivity of a positive stress ECG was only 61 percent (Gibbons et al. 2000). There is no indication that the addition of imaging to exercise stress adds actionable, additional information in asymptomatic low- or intermediate-risk individuals or even in otherwise low-risk diabetics (Young et al. 2009).

In considering the use of any of these tests, it is critically important to remember that all available data are observational and descriptive. No risk-assessment strategy, whether formal calculation of FRS, atherosclerosis testing or exercise testing, has been studied prospectively as a strategy to improve outcomes (Douglas et al. 2009). Since the addition of tests adds to costs and in some cases increases risk through radiation, their widespread, routine use is not generally recommended. For example in 2004, the United States Preventive Services Task Force (USPSTF) released its recommendations regarding use of rest ECG, stress test, CIMT and CAC as screening tests for CAD (USPSTF 2004). In formulating their recommendations, the USPSTF defined possible benefits as a reduction in CAD events through the detection of high-risk individuals who would benefit from more-aggressive risk-factor modification or detection of individuals with severe CAD whose life would be prolonged by CABG.

"There is no indication that the addition of imaging to exercise stress adds actionable, additional information in asymptomatic low- or intermediate-risk individuals or even in otherwise low-risk diabetics."

An additional potential benefit would be for those engaged in occupations endangering the health of others, in whom considerations other than health benefits to the individual may influence the decision to screen for CAD. Possible harms identified were a lack of evidence of improved health outcomes and possible false positive tests, which may lead to unnecessary invasive procedures, overtreatment and labeling. False negative tests were also of concern, as the majority of events in low-risk individuals will occur in those with negative tests.

As a result of this formulation, the USPSTF advised against the use of testing in adults at low risk as a Class D recommendation (at least fair evidence that the service is ineffective or that harms outweigh the benefits). Their use in adults at increased risk was deemed to have insufficient evidence, or Class I (evidence that the service is effective is lacking, of poor quality or conflicting and the balance of benefits and harms cannot be determined). In part as a consequence of the USPSTF recommendations, Medicare coverage for risk stratification in asymptomatic individuals is provided only for determination of total cholesterol, HDL and triglycerides once every five years. All other testing (rest ECG, stress test, CIMT, CAC, CCTA) are not covered (Medicare.com 2010).

Issues to Consider in Designing a Preparticipation Screening Program for Divers

Screening Program Experience in Diving

In contrast to younger individuals, there are few published experiences with preparticipation screening programs in older individuals. However, there is a small published literature on screening programs in diving outlining their "yield." The first used the records of three British organizations with identical requirements for divers to complete an annual questionnaire (which was held to be a legal declaration) and to undergo regular examinations by their primary care physician according to the following schedule:

- every five years for those <40 years
- every three years for those aged 40-50 years
- annually for those over 50 years (Glen et al. 2000)

Data on 2,962 exams on 2,094 divers were analyzed and showed cardiovascular symptoms in 1.2 percent, a murmur in 1 percent and cardiovascular medication use in 4 percent. A mere 2 percent were felt to have "failed" the exam, and 1 percent received a referral to a cardiologist. Overall, no significant unknown abnormalities were detected. A second study relied on New Zealand Department of Labour records requiring in-depth interview, testing and medical examination every five years for registered divers. Of 336 divers undergoing at least two exams, only 10 were cited, with five receiving a conditional certificate of fitness, four were considered temporarily unfit for diving, and only one was declared permanently unfit — for a spinal injury detected by questionnaire (Sames et al. 2009).

Design Considerations

There are many considerations in designing a screening program. These include addressing the following questions: Whom to screen? When to screen? How often? What disease to screen for? What screening questions and tests to use? Who will perform screening? Who will perform any needed additional evaluation? What will additional evaluation consist of? How will results be translated into clearance for diving? What happens if someone "fails"? Finally, who will pay for all this? The answers to these questions can be complex and must be addressed individually by each program to ensure alignment with goals and resources.

The screening experience and the literature suggest that individuals of all ages be asked about their fitness level assessment, cardiovascular history, symptoms and signs, and undergo a brief physical exam. For those under 35 years of age the AHA Preparticipation checklist can serve as a template (Maron 1996, 1998, 2007). For those over 35 years, assessment of CAD risk factors, symptoms and signs can follow the recommendations in the ACC/AHA primary prevention guidelines and performance measures (Pearson et al. 2002; Redberg et al. 2009). In those over 35 years with at least intermediate risk, it is reasonable to recommend selective testing of some kind. However, it is unclear if this should be stress testing or CAC score. To date, the evidence does not favor the use of CIMT or CCTA over these other options.

"The screening experience and the literature suggest that individuals of all ages be asked about their fitness level assessment, cardiovascular history, symptoms and signs, and undergo a brief physical exam."

It is important to note that, regardless of age, all symptomatic individuals should be required to have a full medical evaluation before diving. Indeed 10 percent of those experiencing a fatal event had prior symptoms (Denoble, Caruso et al. 2008). Any screening recommendations are critically predicated on the willingness to implement a program to exclude individuals with positive screens or even identified disease from participation in diving.

Other aspects of a screening program include the education of divers, diving staff and physicians about possible prodromal cardiac symptoms and the importance of their recognition in preventing events (Maron et al. 2007). This is especially true in the unforgiving undersea environment, in which the ability to respond in an emergency is severely limited. Similarly, divers and diving staff should be trained to handle cardiovascular emergencies.

The design of any sport-specific screening program should consider the unique stresses associated with its pursuit. In the case of diving, paramount among the concerns is the limited ability to recognize and respond to an emergency. In addition, the hyperbaric environment can alter intracardiac hemodynamics, changing flow across a patent foramen ovale or causing pulmonary hypertension. It can also alter drug metabolism in unpredictable ways. Professional diving carries additional risk but even different types of recreational diving can have very different risks. In instituting any new program, there should be a reasonable expectation that it would both change behavior and improve outcomes.

"In the case of diving, paramount among the concerns is the limited ability to recognize and respond to an emergency."

References

Ajani UA, Ford ES. Has the risk for coronary heart disease changed among U.S. adults? *J Am Coll Cardiol.* 2006; 48:1177-1182.

Akosah KO, Schaper A, Cogbill C, Schoenfeld P. Preventing myocardial infarction in the young adult in the first place: how do the National Cholesterol Education Panel III guidelines perform? *J Am Coll Cardiol.* 2003; 41:1475-1479.

American College of Cardiology. 26th Bethesda Conference: recommendations for determining eligibility for competition in athletes with cardiovascular abnormalities. January 6-7, 1994. *J Am Coll Cardiol.* 1994; 24:845-899.

American Heart Association. AHA Heart Disease and Stroke Statistics — 2010 Update. [cited March 19, 2010 March 19]; *http://www.americanheart.org/presenter.jhtml?identifier=3000090*. Accessed March 3000019, 3002010]. Available from: *http://www.americanheart.org/presenter.jhtml?identifier=3000090*

Armstrong LE, Whaley MH, Brubaker PH, Otto RM. *American College of Sports Medicine: guidelines for exercise testing and prescription,* 8th. Philadelphia, PA: Lippincott Williams & Wilkins, 2009.

Baggish AL, Hutter AM Jr., Wang F, Yared K, Weiner RB, Kupperman E, et al. Cardiovascular screening in college athletes with and without electrocardiography: a cross-sectional study. *Ann Intern Med.* 2010; 152:269-275.

Berger JS, Jordan CO, Lloyd-Jones D, Blumenthal RS. Screening for cardiovascular risk in asymptomatic patients. *JACC.* 2010; 55:1169-1177.

Bild DE, Bluemke DA, Burke GL, Detrano R, Diez Roux AV, Folsom AR, et al. Multi-ethnic study of athero-sclerosis: objectives and design. *Am J Epidemiol.* 2002; 156:871-881.

Budoff MJ, Dowe D, Jollis JG, Gitter M, Sutherland J, Halamert E, et al. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. *J Am Coll Cardiol.* 2008; 52:1724-1732.

Chow BJ, Wells GA, Chen L, Yam Y, Galiwango P, Abraham A, et al. Prognostic value of 64-slice cardiac computed tomography severity of coronary artery disease, coronary atherosclerosis, and left ventricular ejection fraction. *J Am Coll Cardiol.* 2010; 55:1017-1028.

Corrado D, Basso C, Pavei A, Michieli P, Schiavon M, Thiene G. Trends in sudden cardiovascular death in young competitive athletes after implementation of a preparticipation screening program. *JAMA*. 2006; 296:1593-1601.

Corrado D, Pelliccia A, Bjornstad HH, Vanhees L, Biffi A, Borjesson M, et al. Cardiovascular preparticipation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol. Consensus statement of the study group of sport cardiology of the working group of cardiac rehabilitation and exercise physiology and the working group of myocardial and pericardial diseases of the European Society of Cardiology. *Eur Heart J.* 2005; 26:516-524.

Crouse JR, 3rd. Thematic review series: patient-oriented research. Imaging atherosclerosis: state of the art. *J Lipid Res.* 2006; 47:1677-1699.

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

Denoble PJ, Pollock NW, Vautgutabatgab P, Caruso JL, Dovenbarger JA, Vann PD. Scuba injury death rate among insured DAN members. *Diving and Hyperbaric Medicine.* 2008; 38:182-188.

Detrano R, Guerci AD, Carr JJ, Bild DE, Burke G, Folsom AR, et al. Coronary calcium as a predictor of coronary events in four racial or ethnic groups. *N Engl J Med.* 2008; 358:1336-1345.

Douglas PS. Saving athletes' lives — a reason to find common ground? *J Am Coll Cardiol.* 2008; 52:1997-1999.

Douglas PS, Taylor A, Bild D, Bonow R, Greenland P, Lauer M, et al. Outcomes research in cardiovascular imaging: report of a workshop sponsored by the National Heart, Lung, and Blood Institute. *JACC Cardiovasc Imaging.* 2009; 2:897-907.

Espeland MA, O'Leary D H, Terry JG, Morgan T, Evans G, Mudra H. Carotid intimal-media thickness as a surrogate for cardiovascular disease events in trials of HMG-CoA reductase inhibitors. *Curr Control Trials Cardiovasc Med.* 2005; 6:3.

Folsom AR, Kronmal RA, Detrano RC, O'Leary DH, Bild DE, Bluemke DA, et al. Coronary artery calcification compared with carotid intima-media thickness in the prediction of cardiovascular disease incidence: the Multi-Ethnic Study of Atherosclerosis (MESA). *Arch Intern Med.* 2008; 168:1333-1339.

Gibbons LW, Mitchell TL, Wei M, Blair SN, Cooper KH. Maximal exercise test as a predictor of risk for mortality from coronary heart disease in asymptomatic men. *Am J Cardiol.* 2000; 86:53-58.

Gibbons RJ, Balady GJ, Bricker JT, Chaitman BR, Fletcher GF, Froelicher VF, et al. ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines (committee to update the 1997 exercise testing guidelines). *Circulation.* 2002; 106:1883-1892.

Glen S, White S, Douglas J. Medical supervision of sport diving in Scotland: reassessing the need for routine medical examinations. *Br J Sports Med.* 2000; 34:375-378.

Gottlieb I, Miller JM, Arbab-Zadeh A, Dewey M, Clouse ME, Sara L, et al. The absence of coronary calcification does not exclude obstructive coronary artery disease or the need for revascularization in patients referred for conventional coronary angiography. *J Am Coll Cardiol.* 2010; 55:627-634.

Greenland P, Bonow RO, Brundage BH, Budoff MJ, Eisenberg MJ, Grundy SM, et al. ACCF/AHA 2007 clinical expert consensus document on coronary artery calcium scoring by computed tomography in global cardiovascular risk assessment and in evaluation of patients with chest pain: a report of the American College of Cardiology Foundation Clinical Expert Consensus Task Force (ACCF/AHA writing committee to update the 2000 expert consensus document on electron beam computed tomography) developed in collaboration with the Society of Atherosclerosis Imaging and Prevention and the Society of Cardiovascular Computed Tomography. *J Am Coll Cardiol.* 2007; 49:378-402.

Grimes DA, Schulz KF. Uses and abuses of screening tests. *Lancet.* 2002; 359:881-884.

Hecht HS. A zero coronary artery calcium score: priceless. *J Am Coll Cardiol.* 2010; 55:1118-1120.

Hodis HN, Mack WJ, LaBree L, Selzer RH, Liu CR, Liu CH, et al. The role of carotid arterial intima-media thickness in predicting clinical coronary events. *Ann Intern Med.* 1998; 128:262-269.

Kannel WB, Dawber TR, Kagan A, Revotskie N, Stokes J, 3rd. Factors of risk in the development of coronary heart disease — six year follow-up experience. The Framingham Study. *Ann Intern Med.* 1961; 55:33-50.

Kaul P, Douglas PS. Atherosclerosis imaging: prognostically useful or merely more of what we know? *Circ Cardiovasc Imaging.* 2009; 2:150-160.

Lorenz MW, Markus HS, Bots ML, Rosvall M, Sitzer M. Prediction of clinical cardiovascular events with carotid intima-media thickness: a systematic review and meta-analysis. *Circulation.* 2007; 115:459-467.

Maron BJ. National electrocardiography screening for competitive athletes: feasible in the United States? *Ann Intern Med.* 2010; 152:324-326.

Maron BJ, Doerer JJ, Haas TS, Tierney DM, Mueller FO. Sudden deaths in young competitive athletes: analysis of 1866 deaths in the United States, 1980-2006. *Circulation.* 2009; 119:1085-1092.

Maron BJ, Thompson PD, Puffer JC, McGrew CA, Strong WB, Douglas PS, et al. Cardiovascular preparticipation screening of competitive athletes. A statement for health professionals from the Sudden Death Committee (clinical cardiology) and Congenital Cardiac Defects Committee (cardiovascular disease in the young), American Heart Association. *Circulation.* 1996; 94:850-856.

Maron BJ, Thompson PD, Puffer JC, McGrew CA, Strong WB, Douglas PS, et al. Cardiovascular preparticipation screening of competitive athletes: an addendum to a statement for health professionals from the Sudden Death Committee (Council on Clinical Cardiology) and the Congenital Cardiac Defects Committee (Council on Cardiovascular Disease in the Young), American Heart Association. *Circulation.* 1998; 97:2294.

Maron BJ, Thompson PD, Ackerman MJ, Balady G, Berger S, Cohen D, et al. Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. *Circulation.* 2007; 115:1643-1455.

Medicare.com. Cardiovascular Screening. *http://www.medicare.com/services-and-procedures/cardiovascular-screening.html.* Medx Publishing; 2010 [cited Accessed March 22, 2010]; Available from: *http://www.medicare.com/services-and-procedures/cardiovascular-screening.html.*

Min JK, Lin FY, Gidseg DS, Weinsaft JW, Berman DS, Shaw LJ, et al. Determinants of coronary calcium conversion among patients with a normal coronary calcium scan what is the “warranty period” for remaining normal? *J Am Coll Cardiol.* 2010; 55:1110-1117.

National Cholesterol Education Program. Executive summary of the third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (Adult Treatment Panel III). *JAMA.* 2001; 285:2486-2497.

O’Malley PG, Greenberg BA, Taylor AJ. Cost-effectiveness of using electron beam computed tomography to identify patients at risk for clinical coronary artery disease. *Am Heart J.* 2004; 148:106-113.

Pearson TA, Blair SN, Daniels SR, Eckel RH, Fair JM, Fortmann SP, et al. AHA Guidelines for primary prevention of cardiovascular disease and stroke: 2002 update: consensus panel guide to comprehensive risk reduction for adult patients without coronary or other atherosclerotic vascular diseases. American Heart Association Science Advisory and Coordinating Committee. *Circulation.* 2002; 106:388-391.

Pelliccia A, Zipes DP, Maron BJ. Bethesda Conference #36 and the European Society of Cardiology Consensus Recommendations revisited a comparison of U.S. and European criteria for eligibility and disqualification of competitive athletes with cardiovascular abnormalities. *J Am Coll Cardiol.* 2008; 52:1990-1996.

Redberg RF, Benjamin EJ, Bittner V, Braun LT, Goff DC, Jr., Havas S, et al. ACCF/AHA 2009 performance measures for primary prevention of cardiovascular disease in adults: a report of the American College of Cardiology Foundation/American Heart Association Task Force on performance measures (writing committee to develop performance measures for primary prevention of cardiovascular disease) developed in collaboration with the American Academy of Family Physicians; American Association of Cardiovascular and Pulmonary Rehabilitation; and Preventive Cardiovascular Nurses Association: endorsed by the American College of Preventive Medicine, American College of Sports Medicine, and Society for Women's Health Research. *J Am Coll Cardiol.* 2009; 54:1364-1405.

Sames C, Gorman D, Mitchell SJ, Gamble G. Utility of regular medical examinations of occupational divers. *Intern Med J.* 2009; 39:763-766.

United States Preventive Services Task Force. Screening for coronary heart disease: recommendation statement. *Ann Intern Med.* 2004; 140:569-572.

Wheeler MT, Heidenreich PA, Froelicher VF, Hlatky MA, Ashley EA. Cost-effectiveness of preparticipation screening for prevention of sudden cardiac death in young athletes. *Ann Intern Med.* 2010; 152:276-286.

Wilson JM. The evaluation of the worth of early disease detection. *J R Coll Gen Pract.* 1968; 16 Suppl 2:48-57.

Young LH, Wackers FJ, Chyun DA, Davey JA, Barrett EJ, Taillefer R, et al. Cardiac outcomes after screening for asymptomatic coronary artery disease in patients with type 2 diabetes: the DIAD study: a randomized controlled trial. *JAMA.* 2009; 301:1547-1555.

Medical Screening of Recreational Divers for Cardiovascular Disease: Consensus Discussion at the Divers Alert Network Recreational Diving Fatalities Workshop*

Simon J. Mitchell, M.B. Ch.B., Ph.D, FANZCA
Department of Anesthesiology
University of Auckland
Auckland, New Zealand

Alfred A. Bove, M.D., Ph.D.
Emeritus Professor of Medicine
Cardiology Section
Department of Medicine
Temple University Medical School.
Philadelphia, PA, USA

"The exercise stress test unmasks inducible cardiac ischemia, quantifies exercise capacity and remains the tool of choice for evaluating diver candidates or divers with risk factors for coronary disease."

Cardiac events are responsible for a significant proportion of recreational diving fatalities. It seems inescapable that our current systems for selecting suitable recreational diver candidates and for longitudinal monitoring of diver health are failing to exclude some divers at high risk of cardiac events. Based on review of practice in parallel sporting disciplines and of the relevant literature, a series of recommendations for screening questions, identification of disqualifying conditions and risk factors, and investigation of candidates with risk factors was drafted. Recommendations for ongoing health monitoring in established divers were also generated. These recommendations were promulgated and debated among experts at a dedicated session of the Divers Alert Network Recreatoinal Diving Fatalities Workshop. As a result, we propose a modified list of screening questions for cardiovascular disease that can be incorporated into health questionnaires administered prior to diver training. This list is confluent with the American Heart Association (AHA) preparticipation screen for athletes. The exercise stress test unmasks inducible cardiac ischemia, quantifies exercise capacity and remains the tool of choice for evaluating diver candidates or divers with risk factors for coronary disease. An exercise capacity that allows for sustained exercise at a 6-MET (metabolic equivalent) intensity (possibly representing a peak capacity of 11-12 METs) is an appropriate goal for recreational divers.

Introduction

In 2008, Denoble et al. published a paper titled "Scuba injury death rate among insured DAN members" (Denoble, Pollock et al. 2008). Using data gathered over a seven-year period, they showed that the annual death rate (due to dive accidents) among insured DAN members averaged 16.4 per 100,000 persons. An obvious question is how should this figure be viewed? One interpretation might be that the death rate is relatively low and comparable to that for other active sports that are not considered dangerous. For example, about 13 joggers per 100,000 participants die each year from heart attacks (Thompson et al. 1982). Another interpretation might be that every death is a tragedy and that all practicable steps should be taken to reduce fatalities to as near to zero as possible. In fact, both views have

*This paper originally appeared in the *Undersea and Hyperbaric Medicine Journal* and is reprinted with permission from the Undersea and Hyperbaric Medical Society.

Mitchell S, Bove A. Medical screening of recreational divers for cardiovascular disease: consensus discussion at the Divers Alert Network Fatality Workshop. *Undersea Hyperb Med.* 38(4):289-296; 2011.

merit. Diving can rightfully be lauded as a relatively safe "adventure sport," but nevertheless, if important contributing factors to fatal accidents could be identified, then targeted prevention programs might be instituted.

In the latter regard, a second recent study by the DAN group has presented an opportunity. Denoble et al. (Denoble, Caruso et al. 2008) divided the causative process in 947 fatalities into four sequential components: trigger, disabling agent, disabling injury and cause of death. Although drowning was the preeminent cause of death, the sequential component approach to the analysis identified the more important precursor events. Of note, cardiac incidents constituted 26 percent of disabling injuries. Associations with cardiac incidents included a history of cardiovascular disease and age greater than 40. One implication of these data is that the current systems for medical screening of diver candidates and for health surveillance in established divers are failing to exclude or adequately manage individuals at risk of cardiac events.

All recreational diver training agencies require that a prospective diver undergo some form of medical screening prior to undertaking a diving course. There are two prevalent approaches. In the most widely used system the diver candidate completes a screening questionnaire issued by the training agency. In the absence of any positive responses, the diver may proceed to training. If there are any positive responses the candidate is compelled to see a physician for a "physical examination."

One of the most commonly used screening questionnaires was developed by the Undersea and Hyperbaric Medical Society Diving Committee on behalf of the Recreational Scuba Training Council (RSTC) (RSTC 2010). The second and less commonly used system is for all recreational diver candidates to undergo a "diving physical" with a physician irrespective of the answers elicited by a screening questionnaire. Typically the physician will utilize a pro-forma medical questionnaire (such as the RSTC form) to elicit relevant history, and a physical examination will be conducted. The physician will then make a judgment about whether it is appropriate for the candidate for proceed to diver training. There has been debate over which of these approaches is most appropriate, with limited data supporting both the screening questionnaire approach (Glen et al. 2000; Glen 2004) and an approach requiring all candidates to undergo a medical consultation (Meehan, Bennett 2010).

"[I]t would be possible for someone who learned to dive at 20 years of age to still be diving at 50 years having never undergone any form of intervening health evaluation."

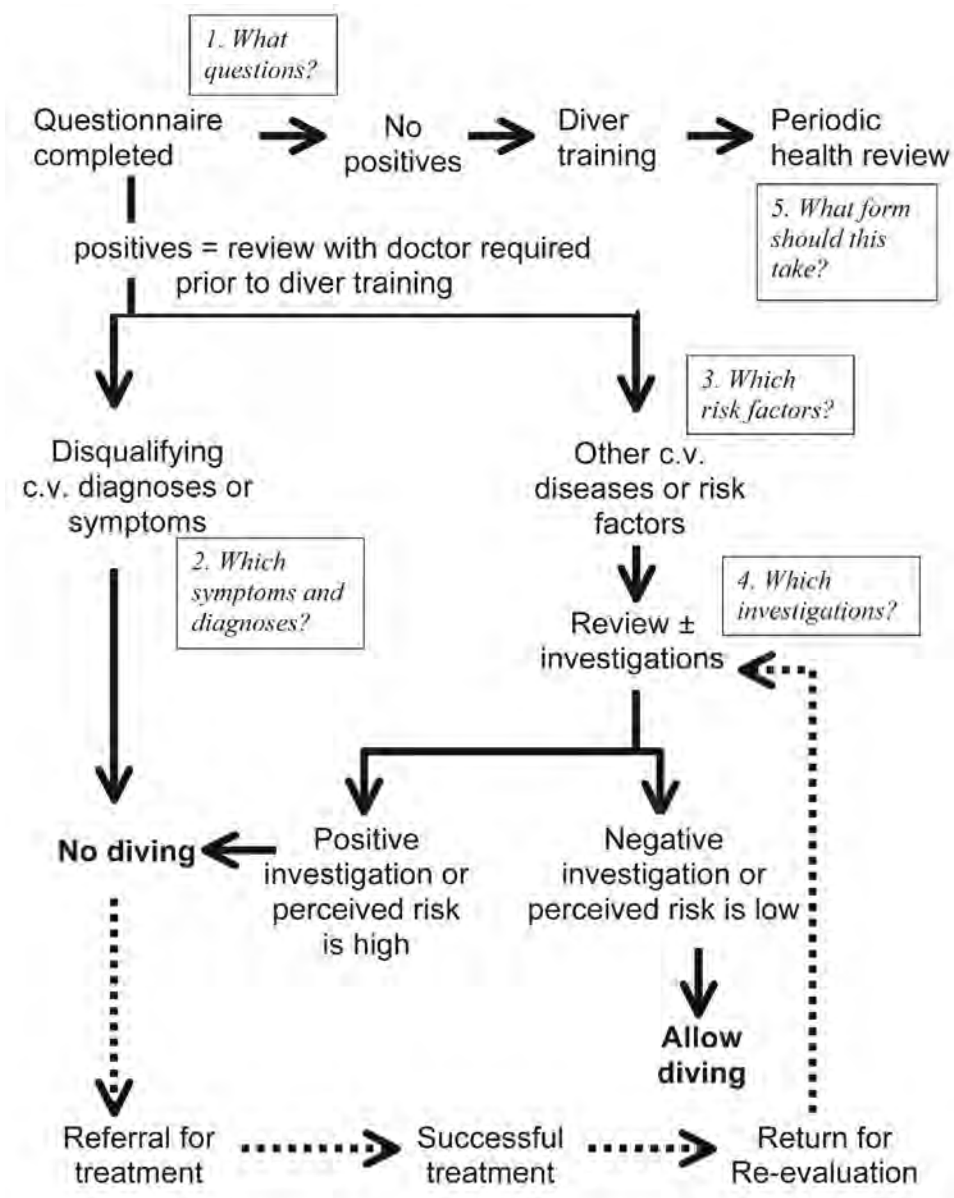
There is no system in place for longitudinal health surveillance of recreational divers. Completion of a screening questionnaire or a medical evaluation by a physician may be required if a diver undertakes continuing diving education courses, but in the absence of such courses it would be possible for someone who learned to dive at 20 years of age to still be diving at 50 years having never undergone any form of intervening health evaluation. This contrasts sharply with the customary requirement for occupational divers to undergo a comprehensive medical evaluation annually; a contrast that is all the more stark when it is considered that occupational divers are arguably a younger, more homogeneous and healthier group.

The discussion session documented here was convened to review the present systems for recreational diver selection and surveillance with specific reference to detection and exclusion of relevant cardiovascular disease. The session followed papers on the implications of various cardiovascular conditions in diving (Bove 2011), the epidemiology of cardiovascular disease (Thompson 2011) and relevant screening methods (Douglas 2011), all of which are published in the present series. For the purposes of setting the agenda we took the position that the screening questionnaire approach described above is the most widely used system and that discussion around optimizing evaluation of diver candidates for cardiovascular disease should start there. Thus, the agenda was built around key steps in selection and longitudinal monitoring of recreational divers beginning with the use of screening questionnaires prior to diver training.

These steps are depicted in Figure 1. The process begins with a diving candidate completing the screening questionnaire. The first point for discussion is whether the current iteration of the RSTC form contains the most appropriate questions for screening cardiovascular disease. If there are no positive responses to the questions the candidate may proceed to diver training. Positive answers to the prediving cardiac screening questions will reveal either existing cardiovascular diagnoses/symptoms that would contraindicate diving or milder disease/risk factors that require further consideration.

"The first point for discussion is whether the current iteration of the RSTC form contains the most appropriate questions for screening cardiovascular disease."

Figure 1: Schema for evaluation of cardiovascular conditions and risk factors in divers



Note: This chart formed an agenda for the discussion session, and discussion took place on each of the numbered points in boxes (see text for elaboration). *c.v. = cardiovascular*

The second point for discussion is the defining of those cardiac diagnoses or associated symptoms that would mandate an automatic decision to disallow diving pending treatment (if possible) and further review. The third point for discussion is the definition of risk factors in an otherwise asymptomatic candidate that would prompt investigation prior to a decision about suitability for diving. The fourth point for discussion is the advice given to physicians with respect to investigating these risk factors. The final point for discussion is recommendations for longitudinal health review in existing divers with particular reference to cardiovascular disease.

WORKSHOP DISCUSSION

Cardiovascular Components of Screening Questionnaire

To provide a starting point for discussion, the authors identified those questions on the current RSTC screening form that were relevant to cardiovascular disease and compared them to those appearing on the AHA preparticipation screening questionnaire for competitive athletes (Maron et al. 2007). Items appearing in the latter and missing from the former are listed in Table 1. We put it to the discussants that these items should be considered for inclusion on the RSTC form.

Table 1: AHA questions omitted from RSTC form

Exertional chest pain / discomfort (appears on RSTC form as "angina")
Excessive exertional and unexplained shortness of breath / fatigue associated with exercise
Prior recognition of a heart murmur
Premature death < 50 years due to heart disease in 1 relative
Disability from heart disease in a close relative < 50 years of age
Do you or a close relative suffer from hypertrophic or dilated cardiomyopathy, long QT syndrome, or other ion channelopathies, Marfan syndrome, or clinically important arrhythmia ?

Note: These items appear on the AHA preparticipation screening questionnaire for competitive athletes and do not appear on the current RSTC prediving screening questionnaire.

"There was no disagreement with the implied concept that some important diagnoses might be missing from the questionnaire in its current form."

There was no disagreement with the implied concept that some important diagnoses might be missing from the questionnaire in its current form. However, there was much discussion around the potential confusion that a more comprehensive list could introduce. Some industry representatives pointed out that diver candidates were encouraged to "tick yes if unsure," and since many would never have heard of some of the diagnoses, they would therefore be "unsure" and be compelled to tick "yes." It therefore was generally agreed that if the items from the AHA list were added to the RSTC questionnaire then the terminology would need maximal simplification, and the criteria for ticking yes would need to be very explicit (such as, "Do you carry the diagnosis of any of …" or "Have you ever been diagnosed with…"). Interpretation of questions phrased in this way would not require understanding of the listed diagnoses.

Some of the individual items on the list were debated. In particular there was concern that benign heart murmurs were prevalent, and that this item would force many candidates into unnecessary medical review. It was agreed that a qualifying statement would be required that excluded murmurs that had been investigated and designated benign. Finally, several commentators expressed the view that some treated cardiovascular conditions (such as hypertension and hypercholesterolemia) probably do not significantly increase risk in diving and should not trigger the requirement for a medical examination. This view was opposed by expert cardiologists present, who pointed out that the adequacy and appropriateness of treatment (of hypertension, for example) could not be evaluated by the questionnaire, and that treated or not, these problems still constituted risk factors for more serious cardiovascular disorders. Based on this discussion, a proposal for a modified list of questions for the recreational diving screening questionnaire is presented in Table 2.

Table 2: Proposed revised screening questions

1. Are you over 45 years of age and can answer yes to one or more of the following:
   _ currently smoke a pipe, cigars, or cigarettes;
   _ you are currently receiving medical care;
   _ you have a family history (in blood relatives) of heart attack or stroke;
   _ you have been diagnosed with either of:
     _ a high cholesterol level or
     _ diabetes mellitus
   even if controlled by diet alone?
2. Have you ever been told you have high blood pressure (or do you take medicine for high blood pressure)?
3. Have you ever had a "heart attack", heart surgery, or blood vessel surgery?
4. Do you experience chest pain / discomfort or excessive / unexplained shortness of breath or fatigue associated with exercise?
5. Do you struggle to perform moderate exercise (example: walk 1 mile in 12 minutes)?
6. To your current knowledge, has a close "blood" relative less than 50 years old suffered disability or premature death due to heart disease?
7. Have you ever been told you have heart valve disease? Tick no if you have a heart murmur that has been described as "insignificant" or "benign."
8. Have you or (to your current knowledge) a close "blood" relative ever been told that you/they suffer from:
   _ a cardiomyopathy;
   _ long QT syndrome;
   _ Marfan's syndrome; or
   _ a heart rhythm problem that limits exercise, causes fainting or needs a pacemaker?
9. Are you presently taking prescription medicines?

Note: If the answer to any of these questions was positive, a review with a doctor, preferably one trained in dive medicine, would be required prior to undertaking diver training.

Cardiovascular Problems That Would Prohibit Diving

The next question considered was which cardiovascular diagnoses or manifestations of cardiac disease would prompt the reviewing physician to make an automatic recommendation not to dive. As a starting point for discussion, the authors proposed a list based on existing elements of the RSTC questionnaire and on items to be added from the AHA athletic sports preparticipation screening questionnaire. This list included:

"The next question considered was which cardiovascular diagnoses or manifestations of cardiac disease would prompt the reviewing physician to make an automatic recommendation not to dive."

- untreated symptomatic coronary disease (history of angina or heart attack)
- cardiomyopathy
- long QT syndrome
- arrhythmias causing impairment of exercise toleranceor consciousness, and a history of poor functional capacity of cardiac origin

For completeness, we added severe valvular lesions, complex congenital heart disease (including cyanotic heart disease and unrepaired atrial septal defect) and the presence of an implantable defibrillator, none of which were directly specified in either questionnaire.

There was some discussion about whether a patent foramen ovale (PFO) should appear on this list. However, there was strong consensus among the experts present that a PFO is not a contraindication to diving. If a diving candidate reported a PFO on their screening questionnaire this would indicate discussion of the implications with a diving physician, but it would not mandate intervention prior to diving. Unfortunately, further discussion in this phase of the workshop was dominated by ongoing debate on the complexity of the terminology associated with some of the added questions. Although this helped develop the wording of questions appearing in Table 2, it did little to inform selection of disqualifying cardiac conditions. It is notable, however, that no particular objections were voiced to the items appearing in Table 3.

Table 3: Proposed automatic initial contraindications

Untreated symptomatic coronary artery disease
Dilated or obstructive cardiomyopathy
Long QT syndrome (or other channelopathies if reported)
Arrhythmias causing impairment of exercise tolerance or consciousness
Poor functional capacity of presumed cardiac origin
Severe cardiac valvular lesions (and lower grade stenotic lesions)
Complex congenital cardiac disease, including cyanotic heart disease and unrepaired atrial septal defect
Presence of an implantable cardiac defibrillator

Note: These are cardiovascular diagnoses or symptoms that would result in an automatic initial recommendation not to dive.

Several qualifying comments are necessary in relation to this list. First, as implied in Figure 1, not all of them represent an absolute dead end in the path to recreational diving. For example, a candidate with coronary artery disease who undergoes an intervention might proceed to diving, providing he/she can subsequently demonstrate good functional capacity without induction of myocardial ischemia. Second, the significance of valvular lesions is highly dependent on the nature of the lesion (stenotic vs. regurgitant) and its severity. Virtually all severe lesions would contraindicate diving, but many patients with milder regurgitant lesions could dive if their functional capacity was adequate. Stenotic lesions are of greater significance and probably contraindicate diving if more than mild. Finally, it is acknowledged that there may be rare cases in which a diagnostic label does not accurately reflect risk in diving (such as a mild "cardiomyopathy"), and in such cases careful evaluation and investigation by an expert might result in diving being allowed.

"It is acknowledged that there may be rare cases in which a diagnostic label does not accurately reflect risk in diving (such as a mild "cardiomyopathy"), and in such cases careful evaluation and investigation by an expert might result in diving being allowed."

Cardiovascular Risk Factors That Would Prompt Investigation

It was generally accepted that any nondisqualifying cardiovascular diagnosis revealed on the questionnaire (that is, diagnoses not listed in Table 3, such as hypertension) would be evaluated "on their own merits" by the reviewing doctor. It was not the aim of this discussion to derive an approach to this. Rather, the intent of this phase of the discussion was to review the spectrum of nonsymptomatic risk factors for cardiac disease that would trigger further investigation either before a diving candidate progressed to diver training or for an established diver presenting for health review. The question put was:

"In the asymptomatic patient with no CV diagnoses, what risk factors for coronary artery or other heart disease identified from the questionnaire should prompt further investigation for inducible cardiac ischemia or other pathology prior to diving?"

The discussants were particularly invited to consider the risk factors that would be identified by positive answers to questions 1, 4, 5, 6, 7 and the family history component of question 8 in Table 2.

There was essentially no debate about the content of the risk factor list. However, there was ongoing discussion about the significance of "prior recognition of a heart murmur," which further informed the wording of question 7 in Table 2. There was consensus among the discussants involved that the wording shown in Table 2 should minimize the possibility of unnecessary investigation of benign murmurs. There was also discussion about how to designate a relative of "hereditary importance," and it was resolved to use the term "blood relative," which should be widely understood.

Investigation of Diver Candidates with Risk Factors for Cardiac Disease

The primary focus of this discussion was on the most appropriate investigation for significant occult coronary artery disease in divers with relevant risk factors as previously defined. The authors proposed a draft statement for discussion, which read:

"Where the risk of ischemic heart disease is intermediate or greater the reviewing physician should assess functional capacity to exclude ischemia and to assure the candidate has an adequate exercise capacity to sustain continuous activity at 6 metabolic equivalents (MET; multiples of assumed resting metabolic rate)."

This statement drew heavily on the discussion following the cardiac session on previous day of the workshop in which the widely cited recommendation for a peak exercise capacity of 13 METs in recreational divers was debated. There was a reasonable consensus among involved discussants that a 13-MET peak capacity might be an unrealistic "standard" for application "across the board," and it therefore carried the risk of being ignored. In support of this notion, Neal Pollock cited a weighted mean peak capacity of 11.9 MET in the 14 published studies on divers that included true aerobic capacity assessment (Pollock 2007). Aerobic capacity data from his own laboratory revealed a mean peak capacity of 12.6 ± 2.7 (7.1-20.3) METs in 103 males and 11.4 ± 2.4 (7.1-17.3) MET in 29 females (Pollock, Natoli 2009).

"It was generally agreed that the metabolic requirement for normal swimming in modest to benign diving conditions was around 4 METs, and a safety margin is gained by having the capacity to sustain a 6-MET exercise intensity."

It was generally agreed that the metabolic requirement for normal swimming in modest to benign diving conditions was around 4 METs, and a safety margin is gained by having the capacity to sustain a 6-MET exercise intensity.

Discussion around this proposal highlighted the dual purpose of the stress test and the associated logic for choosing it over alternative investigations for coronary disease risk described earlier in the meeting (Douglas 2011). Specifically, the stress test is a widely used and well-understood investigation for inducible ischemia, and, in addition, it measures the subject's exercise capacity, which is an important aspect of assessing suitability for diving. The recommendation of a desirable standard for exercise capacity will inevitably be somewhat arbitrary, but there was no disagreement with "continuous activity at 6 METs."

There was no discussion on the specific issue of how this would best be assessed. One obvious option would be to tailor an exercise test specifically to this purpose and require the subject to exercise at 6 METs for 20-30 minutes. Another approach recognizes that the sustainable exercise capacity is usually about 50 percent of peak capacity. This would translate to a peak exercise capacity on stress testing of about 12 METs, which doubles as a desirable target for exclusion of inducible myocardial ischemia (Bove 2011). For the reasons cited above there was little enthusiasm among discussants for designating a 12-MET peak capacity as a required or recommended standard. Nevertheless, if a diver were capable of achieving 12 METs in a stress test without symptoms or relevant electrocardiographic changes, this would be very reassuring in respect of both their risk of significant coronary disease and their exercise capacity. Although the subject of debate in respect of phraseology, it was generally agreed that a higher sustainable capacity could be seen as an "ideal" goal for divers such as divemasters and instructors who participate in activities where a high standard of readiness could be expected and for divers who habitually entered challenging environments.

There was some discussion around how the reviewing physician would define "intermediate" risk in selecting candidates for stress testing, and this was resolved with reference to the Framingham Risk Score (Wilson et al. 1998) as a widely available and easily applied means of risk assessment. Thus, divers found to be at intermediate risk (10-20 percent 10-year cardiovascular event rate) or high risk (above 20 percent 10-year event rate) should have further evaluation of their risk for a cardiovascular event while diving. This section of the session ended with discussion of the need for periodic reevaluation after such investigation. There was no disagreement with the proposal that this is necessary. It was agreed that the nature and periodicity of follow-up should be at the discretion of the reviewing physician.

Longitudinal Health Surveillance of Recreational Divers

The authors identified two potential opportunities for continuing health surveillance in recreational diving: at enrollment for continuing education courses and prior to embarkation on dive charter vessels. The completion of health screening questionnaires often occurs in these situations (particularly continuing education) already. We also identified the need to encourage voluntary reevaluation and identified a number of goals in this regard. Specifically, these were:

- to educate divers on the need to present for review of suitability for diving after any sustained change in health
- to educate divers not to dive and to present for medical review when unwell
- to educate divers to have regular health checks with family physician
- to educate divers to present for review of their cardiovascular status at age 45 for males or 55 for female

There was no debate over most of these recommendations. However, there was considerable discussion over the use of medical screening questionnaires prior to embarkation on charter vessels. Some commentators were adamant that this did not occur and would introduce too many difficulties for dive operators trying to interpret the answers. Others were equally adamant that many charter boats included medical questions in their waiver documentation, and this is known to be true in Queensland, Australia. There was no consensus on the desirability of this practice, but it did become clear that there is no standardized questionnaire for use in this context. It was acknowledged that comprehensive screening questionnaires such as the RSTC form were not suitable for dive charter use and that a shorter and highly discriminatory tool needs to be developed for that situation.

Conclusions

This workshop has brought clarity to some issues relevant to screening recreational diver candidates for diver training. The RSTC health screening questionnaire for candidate selection is less comprehensive in relation to cardiovascular conditions and risk factors for cardiac disease than the athletics preparticipation screening questionnaire designed by the AHA. A redrafted list of questions is proposed (Table 2) that

"The authors identified two potential opportunities for continuing health surveillance in recreational diving: at enrollment for continuing education courses and prior to embarkation on dive charter vessels."

rectifies potential discrepancies in the RSTC form (RSTC 2010) but with careful attention to minimizing ambiguity and unnecessary medical review of candidates.

The exercise stress test remains the intervention of choice for investigating diver candidates with risk factors for ischemic heart disease because it provides additional information about their functional capacity. Recreational diver candidates should be capable of a sustained 6-MET workload, and this could reasonably be deduced from a 12-MET peak exercise capacity on stress testing.

Longitudinal health monitoring of recreational divers is a universally supported goal, and the principles of selection and investigation in relation to cardiac disorders outlined in Figure 1 and discussed earlier in this paper would apply perfectly well to divers undergoing health review.

Reevaluation of health prior to continuing education courses is broadly acceptable and currently practiced. There is less consistency and more controversy around the use of health screening questionnaires prior to dive charter trips. There is a need for a standardized short, highly discriminatory questionnaire that dive charter operators could choose to administer if desired.

"The exercise stress test remains the intervention of choice for investigating diver candidates with risk factors for ischemic heart disease because it provides additional information about their functional capacity."

References

Bove A. The cardiovascular system and diving risk. *Undersea Hyperb Med.* 38(4):261-269; 2011.

Denoble PJ, Caruso JL, Dear G de L, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med* 2008; 35:393-406.

Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA, Vann RD. Scuba injury death rate among insured DAN members. *Diving Hyperbaric Med* 2008; 38:182-188.

Douglas P. Cardiovascular screening in asymptomatic adults: lessons for the diving world. *Undersea Hyperb Med.* 38(4):279-287; 2011.

Glen S, White S, Douglas J. Medical supervision of sport diving in Scotland: reassessing the need for routine medical examinations. *Br J Sports Med* 34:375-8, 2000.

Glen S. Three year follow up of a self certification system for the assessment of fitness to dive in Scotland. *Br J Sports Med* 38:754-7, 2004.

Maron BJ, Thompson PD, Ackerman MJ et al. Recommendations and considerations related preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update. *Circulation* 2007; 115:1643-1655.

Meehan CA, Bennett MH. Medical assessment of fitness to dive — comparing a questionnaire and a medical interview-based approach. *Diving Hyperbaric Med* 2010; 40:119-124.

Pollock NW. Aerobic fitness and underwater diving. *Diving Hyperbaric Med* 2007; 37(3): 118-24.

Pollock NW, Natoli MJ. Aerobic fitness of certified divers volunteering for laboratory diving research studies. *Undersea Hyperb Med* 2009; 36(4):303-4.

Recreational Scuba Training Council Medical Statement. Available at: *http://www.wrstc.com/downloads/10%20%20Medical%20Guidelines.pdf.* Last accessed 12 December 2010.

Thompson PD, Funk EJ, Carleton RA, Sturner WQ. Incidence of death during jogging in Rhode Island from 1975 through 1980. *JAMA* 1982; 247:2535-2538.

Thompson P. The cardiovascular risks of diving. *Undersea Hyperb Med.* 38(4):271-277; 2011.

Wilson PW, D'Agostino RB, Levy D, Belanger AM, Silbershatz H, Kannel WB. Prediction of coronary heart disease using risk factor categories. *Circulation* 1998; 97:1837-1847.

APPENDIX A

Workshop Schedule

Thursday, April 8, 2010

0800 Introduction — Vann

Investigation — How can data collection and reporting be improved?

0805 On-Scene Investigation — Barsky
0850 Equipment Testing — Bozanic
0935 Break
0950 Medical Examiner Activities — Caruso
1040 Legal Issues Panel — Concannon
1200 Lunch

Data Review — What factors are most commonly associated with diving deaths?

1330 Introduction — Vann
1335 Developing and Evaluating Interventions Using Surveillance Data — Marshall and Kucera
1420 DAN America and Europe — Denoble and Marroni
1510 DAN Asia Pacific — Lippmann
1600 BSAC (British Sub Aqua Club) — Cumming
1640 Break
1710 PADI Data — Richardson and Hornsby
1830 Social

Friday, April 9

Role of Training — Might changes to training reduce future fatalities?

0800 Training Panel — Lang
1200 Lunch

Cardiovascular Fitness — What practice guidelines are appropriate?

1330 Statement of the Problem — Mitchell
1405 Cardiovascular Risk in Divers — Bove
1440 Epidemiology of Cardiovascular Disease — Thompson
1520 Screening Options — Douglas
1555 Break
1610 Discussion
1730 End Session

Saturday, April 10

Consensus Discussions

0800 Training and Operations — Lang
0950 Break
1010 Physician Practice Guidelines — Bove and Mitchell
1200 End Session
1230 Lunch

APPENDIX B

Workshop Attendees

Last Name	First Name	Organization
Al-Hinai	Nasser	Royal Navy, Sultanate of Oman
Ange	Mike	*Alert Diver*, reporter
Barsky	Steven	Marine Marketing
Beck	Iain	Duke Center for Hyperbaric Medicine and Environmental Physiology
Bennett	Peter	UHMS
Bird	Nick	DAN America
Boivin	Gordon	USCG
Bove	Alfred	Temple University
Bozanic	Jeffrey	Next Generation Services
Buschmann	Donald	UCSD
Caney	Mark	PADI/EUF
Carney	Brian	SDI/TDI/ERDI
Caruso	James	U.S. Navy
Carver	David	LA Sheriff's Dept.
Christini	Carol	Insurance Management Services, President
Cicchino	Reneé	
Colvard	David	
Concannon	David	DG Concannon, LLC
Cronje	Frans	DAN Southern Africa
Cumming	Brian	BSAC
Dall	Jason	USCG
Davies	Bruce	USCG
Denoble	Petar	DAN America
Devore	Watson	Scuba Schools International
Donegan	Danny	DAN America guest
Douglas	Pamela	Duke Medical Center
Douglas	Eric	DAN America
Ebersole	Douglas	Watson Clinic, LLP
Farkas	Kim	Court reporter
Forbes	Bobby	SULA
Fousek	Patricia	PADI
Freiberger	Jake	Duke Center for Hyperbaric Medicine and Environmental Physiology
Gallagher	Jay	
Graves	Grant	
Guercio	Catriona	
Harper	Shawn	
Haughie	Dwaine	NRPS
Hewitt	Steven	Hewitt & Truszkowski, LLC
Hobbs	Gene	Rubicon/ Duke Hyperbaric Center
Hornsby	Al	PADI
Hruska	Mark	Schwartz & Horwitz, PLC
Huggins	Karl	Catalina Hyperbaric Chamber

Last Name	First Name	Organization
Jaeck	Francois	DAN Europe
Jehle	Carl	USCG
Jenni	Craig	Dive and Marine Consultants
Johnson	Michael	
Kernagis	Dawn	Duke Center for Hyperbaric Medicine and Environmental Physiology
Kison	JoAnn	
Kucera	Kristen	Duke Occupational Medicine
Kurtis	Ken	
Lambertsen	Christian	
Lang	Michael	Smithsonian Institution
Lee	John	DAN America
Lippmann	John	DAN Asia-Pacific
Marroni	Alessandro	DAN Europe
Marshall	Stephen	UNC-Chapel Hill
McCafferty	Marty	DAN America
Mendoza	Pedro	USCG
Mercurio	Scott	USCG
Merrick	Shawn	USCG
Merril	Sam	DAN America
Mitchell	Simon	University of Aukland
Moon	Richard	Duke Center for Hyperbaric Medicine and Environmental Physiology
Moore	Jeanette	DAN America
Moore	Greg	DAN America
Mulford	Wayne	DAN America guest
Murray	John	US Navy
Nord	Dan	DAN America
Norris	John	Aqua Dive
Norsworthy	John	USCG
Ochoa	Edgardo	Intituto Smithsonian de Investigaciones Tropicales
Orr	Dan	DAN America
Orr	Betty	DAN America
Partridge	Bruce	Shearwater
Partridge	Lynn	Shearwater
Pearson	Jim	USCG
Penland	Laurie	
Pilkington	Jon	NRPS
Pollock	Neal	DAN America
Richardson	Drew	PADI
Russomanno	Mark	
Sadler	Richard	
Schopp	Michelle	USCG
Schultz	Gregory	USCG

Last Name	First Name	Organization
Seery	Patty	DAN America
Sherman	Stefan	US Army, Ret
Shields	Raymond	Mayo Clinic
Shreeves	Karl	PADI
Smith	Scott	DAN America
Stanton	Gregg	
Stolp	Bret	Duke Center for Hyperbaric Medicine and Environmental Physiology
Thompson	Paul	Hartford Hospital
Travland	Nicolette	USCG
Vann	Richard	DAN America
Wake	Brian	DAN America guest
Walker	Richard	Duke Center for Hyperbaric Medicine and Environmental Physiology
Watson	James	BSAC
Wilk	Barbara	USCG
Zettwoch	Larry	DAN America guest
Zylka	Colin	
Zylka	Jean	

APPENDIX C

What's Your Dive Safety IQ?

Q. What is the recommended ascent rate for recreational diving?
A. 30–60 feet per minute.

Q. What are four steps to avoid running out of air?
A. (a) Start with a full scuba cylinder, (b) dive with a buddy, (c) monitor cylinder pressure often, (d) dive with a redundant air source

Q. What should you do if you become entangled?
A. Stop, breathe, think. Free yourself with the cutting tool you carry.

Q. What is the best way to prevent entrapment?
A. Avoid overhead environments such as caves or inside wrecks.

Q. How do you achieve neutral buoyancy?
A. With appropriate training, proper weighting and practice

Q. What factors should you consider when choosing a dive site?
A. Dive site conditions, your physical condition, your training and experience

Q. How can you minimize buddy separation?
A. Check your buddy often.

Q. What two common pieces of equipment help control buoyancy?
A. Weights and buoyancy compensator

Q. When should you take a dive refresher?
A. When you feel you need a skills update or haven't dived in about six months

Q. What should you do before diving if your health has changed?
A. See a dive medicine physician

Q. What should you do if you feel sick or anxious before or during a dive?
A. Cancel or end the dive

Q. What is the most important piece of dive equipment?
A. Your brain

APPENDIX D

On-Site Fatality Investigation Checklists

Steven M. Barsky
Marine Marketing & Consulting
2419 E. Harbor Blvd. #149
Ventura, CA 93001 USA

Diving Accident Equipment Inspection

Victim's name: ______________________________

Location of accident: ______________________________

Date of accident: ____________________ Case number: ____________________

Date of gear inspection: ______________________________

Location of gear inspection: ______________________________

Parties present during inspection: ______________________________

Has gear been washed or cleaned? ____________ Was gear tested by police? ____________

COMPLETE SYSTEM

Is cylinder band tight? ____________ Is cylinder band at appropriate height? ____________

Is regulator oriented properly? ______________________________

Is BC inflated? ____________________ Photo taken? ____________________

CYLINDER

Size: ____________________ Manufacturer: ____________________

Serial number: ____________________ Working pressure: ____________________

Date manufactured? ____________________ Color of cylinder: ____________________

Other marks: ______________________________

Hydro test dates: ______________________________

VIP history: ______________________________

____

Pressure in cylinder: ____________________ General condition: ____________________

Boot: ____________________ Photo Taken: ____________________

CYLINDER VALVE

Manufacturer: ____________________ Type of valve: ____________________

O-ring condition: ____________________ Condition of valve: ____________________

Operation of valve: ____________________ Photo taken: ____________________

Number of turns to fully open: ____________ Serial number: ____________________

Other marks: ______________________________

BUOYANCY COMPENSATOR

Manufacturer: ______________________ Model Name: ______________________

Serial Number: ______________________ In-service date: ______________________

Bladder type: ______________________ Condition: ______________________

Size: ______________________ Color: ______________________

Other marks: ______________________

Photo taken: ______________________ Lift capability: ______________________

Corrugated hose attachment: ______________________

Condition of waist belt: ______________________

Condition of chest strap: ______________________

Condition of shoulder straps: ______________________

Condition of cylinder band: ______________________

Contents of right pocket: ______________________

Contents of left pocket: ______________________

Items clipped to BC: ______________________

Strap condition: ______________________

Strap properly threaded? ______________________ Photo tgaken: ______________________

POWER INFLATOR

General condition: ______________________ Manufacturer: ______________________

Number tie-wraps: ______________________ Serial number: ______________________

Other marks: ______________________ Mouthpiece condition: ______________________

Condition of tie-wraps: ______________________

BC FUNCTION TESTS

Does BC hold air? ______________________ Does power inflator function properly? ______________________

Does reg function work? ______________________ Does overpressure relief work? ______________________

Does dump valve work? ______________________

WEIGHTS (If weight integrated)

Total weight: ______________________

Weight distribution: ______________________

Weight release function? ______________________

Notes: ______________________

____

____

REGULATOR

Manufacturer: ______________________ Model: ______________________

In-sevice date: ______________________

FIRST STAGE

Serial number: ______________________ Condition: ______________________

Filter condition: ______________________ Environmental cap? ______________________

Dust cap: ______________________ Color: ______________________

Shop ID marks: ______________________ Photo taken? ______________________

PRIMARY SECOND STAGE

Manufacturer ______________________ Model: ______________________

Serial number: ______________________ Color: ______________________

Shop ID marks: ______________________ Condition: ______________________

Condition mouthpiece lugs? ______________________ Condition tie-wrap? ______________________

Photo taken? ______________________

OCTOPUS SECOND STAGE

Manufacturer ______________________ Model: ______________________

Serial number: ______________________ Color: ______________________

Shop ID marks: ______________________ Condition: ______________________

Condition mouthpiece lugs? ______________________ Condition tie-wrap? ______________________

Photo taken? ______________________

INFLATOR HOSE

For BC? ______________________ Condition: ______________________

For drysuit? ______________________ Condition: ______________________

Photos taken? ______________________

Notes: ______________________

____

____

DIVE COMPUTER

Manufacturer: ______________________ Model number: ______________________

Serial number: ______________________ Color: ______________________

In-service date: ______________________ Condition: ______________________

Shop ID marks: ______________________ Battery condition: ______________________

Service info: ______________________ Photos taken? ______________________

Readings: ____

Dive #	Date	Time of Day	Depth	Bottom Time	Ascent Rate
Dive #1					
Dive #2					
Dive #3					
Dive #4					
Dive #5					
Dive #6					
Dive #7					
Dive #8					
Dive #9					
Dive #10					

Notes: ____

____

INSTRUMENT CONSOLE

Manufacturer: ______________________ Depth gauge: ______________________

Depth gauge model: ______________________ Depth gauge manufacturer: ______________________

Depth gauge serial number: ______________________ Max depth indicator reading: ______________________

Range of depth gauge: ______________________ Does gauge read zero? ______________________

General condition: ______________________ Photo taken? ______________________

Compass? ______________________

SUBMERSIBLE PRESSURE GAUGE

Range ______________________ Manufacturer ______________________

Serial number: ______________________ Does gauge read zero? ______________________

Condition ______________________ Photo taken? ______________________

Slate present: ______________________ Markings on slate: ______________________

Comments: ____

____

DRYSUIT

Manufacturer__________ Model:__________

Size: __________ Color: __________

Serial number:__________ Inflator valve mfg.__________

Condition exhaust: __________ Function inflator: __________

Exhaust valve mfg.__________ Condition exhaust: __________

Function exhaust: __________ Zipper mfg.__________

Hood? __________ Condition zipper: __________

Function of zipper: __________

Type neck seal: __________ Condition neck seal: __________

Type wrist seals:__________ Condition wrist seals: __________

Type boots: __________ Condition of boots:__________

Punctures?__________

Comments: __________

WETSUIT

Manufacturer: __________ Model:__________

Color(s): __________ Style: __________

Thickness: __________ General condition: __________

Jacket zip condition: __________ FJ zipper condition: __________

Beaver tail closure: __________ Closure condition: __________

Size: __________ Hood? __________

Comments__________

WEIGHT BELT

Type of belt:__________ Type of buckle: __________

Number of weights:__________ Type of weights: __________

Color of weights:__________ Weight keepers? __________

Total weight: __________

Clips & accessories?__________

Notes: __________

MASK, FINS AND SNORKEL

Mask mfg. : ______ Model: ______

Color: ______ Condition: ______

Purge valve? ______ Purge valve condition: ______

Strap condition: ______

Snorkel Mfg. ______ Model: ______

Color: ______ Purge valve? ______

Snorkel keeper: ______ Purge valve condition: ______

Fins mfg. ______ Model: ______

Size of fins: ______ Color: ______

General condition: ______ Strap condition: ______

MAINTENANCE RECORDS

Cylinder				
BC				
Power Inflator				
Regulator				
Dive Computer				

APPENDIX E1

Open-Circuit Scuba Equipment Evaluation Forms

Jeffrey E. Bozanic
Next Generation Services
P.O. Box 3448
Huntington Beach, CA 92605-3448 USA

David M. Carver
Emergency Services Detail
Los Angeles County Sheriff's Department
1060 North Eastern Avenue
Los Angeles, CA 90063 USA

Forms in Appendix E:

- Dive computers
- Cylinders
- Valves
- Deco, pony or bailout cylinders
- Buoyancy compensators/alternate air sources
- Regulators
- Wetsuits
- Drysuits
- Watches, bottom timers, SPGs, compasses, depth gauges, capillary gauges, temperature gauges
- Masks
- Snorkels
- Fins
- Camera and video equipment
- Slates
- Goodie bags
- Lift bags
- Reels
- Knives/cutting tools
- Dive lights
- Jon lines
- Spear guns and slings
- Diver propulsion units

DIVE COMPUTER *(Complete one form per computer.)*

Manufacturer: ____ Model: ____

Serial#: ____ Condition: Poor Fair Good Excellent

Battery status: _____________________ Computer set to the correct time? Yes No

Computer status: Working Not working No battery

Location of the computer: Wrist mount Console on HP hose

Attached to BC Attached to hose Mask

Other: ____

Decedent's computer Dive partner's computer

Type of dive computer: Basic air only Basic nitrox Technical gas

Air integrated Dive profile recorder

Downloadable: Yes No

Programmable: Yes No

Program/mode used: Gauge mode Air mode Nitrox mode

Trimix mode Heliox mode Not working

Open circuit Closed circuit

Gas(es) programmed into computer: % O_2 ______ %He ______ In use at time

Gas #_____ %He _____ %O_2 _____ OC/CC Gas #_____ %He _____ %O_2 _____ OC/CC

Gas #_____ %He _____ %O_2 _____ OC/CC Gas #_____ %He _____ %O_2 _____ OC/CC

Gas #_____ %He _____ %O_2 _____ OC/CC Gas #_____ %He _____ %O_2 _____ OC/CC

Gas #_____ %He _____ %O_2 _____ OC/CC Gas #_____ %He _____ %O_2 _____ OC/CC

Gas #_____ %He _____ %O_2 _____ OC/CC Gas #_____ %He _____ %O_2 _____ OC/CC

List the computer's status at the following times:

When first located: On Off Dive Mode Violation Mode SI Mode

At the surface: On Off Dive Mode Violation Mode SI Mode

During evaluation: On Off Dive Mode Violation Mode SI Mode

Does computer automatically go into dive mode when submersed? Yes No

At what depth does computer go into Surface Mode (SI)? ____________________

If the computer information has been recorded, download the information as soon as possible and print hard copies of all relevant profiles and dive details. Maintain a computer file of the data that was downloaded. The computer's manufacturer might need to be contacted to assist in this process. Chamber directors like Karl Huggins have also proven to be a valuable resource when assistance is needed in downloading from older computers. If the computer data cannot be downloaded, take photographs of the different screens showing any relevant information. After all important information has been gathered, the computer should be tested to ensure the computer was/is functioning correctly.

Computer information downloaded? Yes No

Downloaded by: _________________________ Date/time: __________________________

Computer records depth/time every ______ seconds

Computer shows gas consumption rates? Yes No

Depth testing of the computer

Depth	Computer depth	Depth	Computer depth
0 fsw	______ fsw	130 fsw	______ fsw
10 fsw	______ fsw	120 fsw	______ fsw
20 fsw	______ fsw	110 fsw	______ fsw
30 fsw	______ fsw	100 fsw	______ fsw
40 fsw	______ fsw	90 fsw	______ fsw
50 fsw	______ fsw	80 fsw	______ fsw
60 fsw	______ fsw	70 fsw	______ fsw
70 fsw	______ fsw	60 fsw	______ fsw
80 fsw	______ fsw	50 fsw	______ fsw
90 fsw	______ fsw	40 fsw	______ fsw
100 fsw	______ fsw	30 fsw	______ fsw
110 fsw	______ fsw	20 fsw	______ fsw
120 fsw	______ fsw	10 fsw	______ fsw
130 fsw	______ fsw	0 fsw	______ fsw

Complete a copy of this form for each dive computer worn by the decedent. If possible, complete this form for each dive computer worn by the decedent's dive partner, including all downloadable information.

Notes: ____

____

____

____

____

CYLINDER *(Complete one form per cylinder.)*

Manufacturer: ______________________ Model: ______________________

Working pressure: ______________________ Serial #: ______________________

Pressure when recovered: ______________________

Type: Single Sidemount Doubles Bailout Deco Staged Pony

Gas type: Air Nitrox Trimix Heliox O_2 Clean

Cylinder Condition: Poor Fair Good Excellent

Type: Steel HP or LP Aluminum Composite

Size: ______________________ Color: ______________________

Boot: Yes No Cylinder wrap: Yes No

VIP date: ______________________ Where: ______________________

Hydro date: ______________________ Where: ______________________

Initial fill pressure, if known: ______________________

Where the cylinder was last filled: ______________________

Compressor owner and address: ______________________

Current compressor gas analysis on file: Yes No *(Attach copy of analysis.)*

Last compressor filter change: ______________________

Oxygen clean compressor: Yes No

Who last filled the cylinder? ______________________

Date the cylinder was filled: ______________________

Gas labels attached to cylinder: Nitrox Trimix Other: __________

Reported gas mix used: Air Nitrox _______

Heliox/trimix O_2 _______ He _______

Was decedent trained in the use of the gas? Yes No Certification: _______

Was the cylinder analyzed before the dive? Yes No Unknown

Who analyzed the cylinder? ______________________

Investigator analysis

Pressure in cylinder when tested: ______________________

Manufacturer, model and serial# of analyzer: ______________________

Test results of portable analyzer: O_2 _______ He _______

Name of person who tested portable analyzer: ______________________

Date/time analyzer was tested: ______________________

Outside Gas Analysis Information

Cylinder sent for outside analysis: Yes No

Where was cylinder sent: AQMD Lab Private Lab Crime Lab

Name of the lab: ______

Address to the lab: ______

Cylinder given to (name): ______

Date/time cylinder was delivered: ______

Cylinder pressure at delivery: ______

Date/time cylinder was returned: ______

Cylinder pressure when returned: ______

Cylinder analyzed by: ______

Results: Meets Grade E Scuba Air O_2 ______ He______ N_2 ______

Failed for the following reason: ______

In-House Gas Analysis Information

Cylinder gas analyzed by: ______

Where cylinder was analyzed: ______

Date/time of analysis: ______

Cylinder pressure when analyzed: ______

Cylinder pressure when done: ______

Testing analyzer manufacturer: ______ Model: ______ Serial#: ______

Date the analyzer was last tested/calibrated: ______

Gauge manufacturer/model/serial#: ______

Gauge last calibrated: ______

Results: O_2 ______ He______

Visual Inspection Information

VIP conducted by:______________________________________

Company name/address:______________________________________

Date/time VIP was conducted: ______________________________________

Results: Pass Fail Fail Reasons: ______________________________________

Notes: ______________________________________

A complete gas analysis of all cylinders used during diving fatalities should be conducted by an accredited lab to ensure the gas meets scuba standards.

Use calibrated stand-alone gauges for cylinder pressure.

Complete a copy of this form for each cylinder used by the decedent. This includes a partner's cylinder if the decedent used it during the dive or if the partner reported problems that may possibly be related to bad gas in the cylinder.

VALVES *(Complete one form per valve.)*

Manufacturer: ______________________________ Model: ______________________________

Serial#: ______________________________ Condition: Poor Fair Good Excellent

Serial number of the cylinder to which the valve was attached: ______________________________

Type: Yoke O-ring in place: Yes No O-ring condition: P F G E

DIN Yoke insert: Yes No O-ring condition: P F G E

Manifold: Yoke DIN N/A

Was the valve oxygen cleaned? Yes No Unknown

How was regulator attached to the valve? ______________________________

Did O-ring or valve leak during underwater test? Yes No

Position of the valve at time of fatality: ______________________________

Position of the valve at start of testing: ______________________________

Was valve manipulated during rescue/recovery? Yes No Unknown

Number of turns from open to close: ______________________________

Difficulty in turning the valve on or off: Easy Moderate Difficult

Notes: ______________________________

____

____

____

DECO, PONY OR BAILOUT CYLINDER(S) *(Complete one form per cylinder.)*

Manufacturer: ______________________ Model: ______________________

Working pressure: ______________________ Serial #: ______________________

Pressure when recovered: ______________________

Type:	Bailout	Deco	Staged	Spare air	
Gas type:	Air	Nitrox	Trimix	Heliox	O_2 clean
Cylinder condition:	Poor	Fair	Good	Excellent	
Type:	Steel	HP or LP	Aluminum	Composite	

Size: ______________________ Color: ______________________

VIP date: ______________________ Where: ______________________

Hydro date: ______________________ Where: ______________________

How was the cylinder carried? ______________________

How was regulator secured to the cylinder? Band Clip Other: ______________________

Could decedent reach 2nd stage? Yes No Unknown

Could decedent reach valve? Yes No Unknown

Initial fill pressure, if known: ______________________

Where the cylinder was last filled: ______________________

Compressor owner and address: ______________________

Current compressor gas analysis on file? Yes No *(Attach copy of analysis.)*

Last compressor filter change: ______________________

Oxygen clean compressor? Yes No

Who last filled the cylinder? ______________________

Date the cylinder was filled: ______________________

Gas labels attached to cylinder: Nitrox Trimix Other: ________

Reported gas mix used: Air Nitrox ________

Trimix O_2 ________ He ________

Heliox O_2 ________ He ________

Was decedent trained in the use of the gas:? Yes No Certification: ______________________

Was the cylinder analyzed before the dive? Yes No Unknown

Who analyzed the cylinder? ______________________

Investigator Analysis

Manufacturer, model and serial# of analyzer: ______________________________

Pressure in cylinder at time of testing: ______________________________

Test results of portable analyzer: O_2 _______ He _______

Name of person who tested portable analyzer: ______________________________

Date/time analyzer was tested: ______________________________

Outside Gas Analysis Information

Cylinder sent for outside analysis? Yes No

Where was cylinder sent: AQMD Lab Private Lab Crime Lab

Name of the lab: ______________________________

Address to the lab: ______________________________

Cylinder given to (name): ______________________________

Date/time cylinder was delivered: ______________________________

Cylinder pressure at delivery: ______________________________

Date/time cylinder was returned: ______________________________

Cylinder pressure when returned: ______________________________

Cylinder analyzed by: ______________________________

Results: Meets Grade E Scuba Air O_2 _______ He_______ N_2 _______

Failed for the following reason: ______________________________

In-House Gas Analysis Information

Cylinder gas analyzed by: ______________________________

Where cylinder was analyzed: ______________________________

Date/time of analysis: ______________________________

Cylinder pressure when analyzed: ______________________________

Cylinder pressure when done: ______________________________

Testing analyzer manufacturer: ____________ Model: ____________ Serial#: ____________

Date the analyzer was last tested/calibrated: ______________________________

Gauge manufacturer/model/serial#: ______________________________

Gauge last calibrated: ______________________________

Results: O_2 ______ He______

Visual Inspection Information

VIP conducted by:____

Company name/address:____

Date/time VIP was conducted: ____

Results: Pass Fail Fail Reasons: ____

Notes: ____

____

____

____

Complete a copy of this form for each cylinder used by the decedent. This includes a partner's cylinder if the decedent used it during the dive or if the partner reported problems that may possibly be related to bad gas in the cylinder.

BUOYANCY COMPENSATOR

Manufacturer: ______________________________ Model: ______________________________

Serial#: ______________________________ Condition: Poor Fair Good Excellent

Size: XS S M L XL XXL Volume: ____________ Color: ____________

Type: Jacket Style Horse Collar Jacket/Wing

Back Plate: Steel Composite Aluminum Plastic Other: ____________

Wing: Banded Non-Banded

Wing Volume: _______

BC size appropriate for the diver? Yes No

BC attached to cylinder(s) properly? Yes No

Crotch strap? Yes No

Crotch strap interfere with weight ditching? Yes No Unknown

Weight integrated BC? Yes No

Weight integration type: Velcro Snap buckle Ripcord pull Other: ____________________

Weight per integrated pocket: Left: ________ Right: ________

Trim pockets? Yes No

Trim pocket locations: ____

Weight contained in the trim pockets: Left: ________ Right: ________

Integrated weights able to be ditched easily: Yes No

Amount of gas in the BC: ________ cc's

Amount of water in the BC: ________ cc's Fresh Salt

Power inflator attached correctly? Yes No

Does power inflator work correctly? Yes No

Does manual inflation work correctly? Yes No

Location of the dump valves: Upper right Upper left

Lower right Lower left

Do all the dump valves work? Yes No Notes: ______________________________

Does the BC hold air? Yes No Notes: ______________________________

Any leaks detected? Yes No

If yes, where were the leaks? ____

In-water testing of power inflator/dump valves: Worked as designed Did not work as designed

Any type of in-water malfunction? ______________________________

Any diver modifications to the BC or weight system? Yes No

Describe in detail: ______________________________

(Is there anything that prevents weight pockets from being dumped as designed?)

Do the regulator hoses interfere with BC operation? Yes No

Auxiliary gear attached to BC: Knife Light Goodie Bag

Reel Lift Bag Camera

Audible Signal Device Other: ______________________________

Alternate air source connected to the BC

Manufacturer: ____________________ Model: ____________________

Serial #: ____________________ Color: ____________________

Condition: Poor Fair Good Excellent

LP hose connected properly to air source? Yes No

Air source second stage works as designed? Yes No

In-water testing worked as designed? Yes No

Inhalation effort: ____________________ Exhalation effort: ____________________

Cylinder pressure when tested (should match cylinder pressure at time of fatality): ____________________

IP pressure: ____________________ Cracking pressure: ____________________

Magnahelic pressure: ____________________

Notes: ______________________________

____

____

____

REGULATORS *(Complete one form per regulator.)*

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ IP pressure: ______________________

Type: Piston Diaphragm Yoke DIN

Condition of first stage: Poor Fair Good Excellent

Sinter Screen condition: Poor Fair Good Excellent

How many high-pressure ports? ______________ How many low-pressure ports? ______________

How many high-pressure hoses are attached to the first stage? ______________________

HP #1: Brand: ____________ Color: ________ Length: ____ Use: ______________

HP #2: Brand: ____________ Color: ________ Length: ____ Use: ______________

How many low-pressure hoses are attached to the first stage? ______________________

LP #1: Brand: ____________ Color: ________ Length: ____ Use: ______________

LP #2: Brand: ____________ Color: ________ Length: ____ Use: ______________

LP #3: Brand: ____________ Color: ________ Length: ____ Use: ______________

LP #4: Brand: ____________ Color: ________ Length: ____ Use: ______________

LP #5: Brand: ____________ Color: ________ Length: ____ Use: ______________

Was first stage attached correctly to valve? Yes No Unknown

Condition of the O-ring connecting a DIN first stage to the cylinder valve?

Poor Fair Good Excellent Missing

Second Stage of the Regulator

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Condition of 2nd stage: Poor Fair Good Excellent

Condition of the mouthpiece: Poor Fair Good Excellent Missing

Any holes or bite marks noted on the mouthpiece? No Yes Where? ______________

Type of mouth piece: Standard Orthodontic Heat molded

Brand, type, length and color of the hose: ______________________

Position of diver control knob (note if none): ______________________

Position of venture knob (note if none): ______________________

Inhalation effort: ____________ Exhalation effort: ____________ PSI tested: ____________

Cracking pressure: ____________ Magnahelic pressure: ____________ PSI tested: ____________

ANSTI test results: Worked as designed Failed the ANSTI test

Worked underwater as designed? Yes No

Regulator (Alternate 2nd Stage)

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Condition of alternate 2nd stage: Poor Fair Good Excellent

Condition of the mouthpiece: Poor Fair Good Excellent Missing

Any holes or bite marks noted on the mouthpiece: No Yes Where? ______________

Type of mouth piece: Standard Orthodontic Heat molded

Brand, type, length and color of the hose: ______________________

Position of diver control knob (note if none): ______________________

Position of venture knob (note if none): ______________________

How was the decedent wearing the alternate 2nd stage? ______________________

Inhalation effort: ____________ Exhalation effort: ____________ PSI tested: ____________

Cracking pressure: ____________ Magnahelic pressure: ____________ PSI tested: ____________

ANSTI test results: Worked as designed Failed the ANSTI test

Worked underwater as designed? Yes No

Notes: ____

____

____

____

WETSUITS

Manufacturer: ________________________ Model: ________________________

Serial #: ________________________ Color: ________________________

Condition of the suit: Poor Fair Good Excellent Cut off

Wetsuit: Body size: __________ Thickness: ________ mm

Body type: Front zip Side zip Rear zip Hooded vest

Attached hood One piece Two piece

Other: ____

Gloves: Hand size: ________ Thickness: ________ mm Type: __________

Vest: Vest size: ________ Thickness: ________ mm Type: __________

Hood: Head size: ________ Thickness: ________ mm Type: __________

Booties: Boot size: ________ Thickness: ________ mm Type: __________

Lycra suit: Size: ________ Thickness: ________ mm Type: __________

Does the suit have any holes? Yes No Location: ______________

Do the gloves have any holes? Yes No Location: ______________

Does the vest have any holes? Yes No Location: ______________

Does the hood have any holes? Yes No Location: ______________

Do the booties have any holes? Yes No Location: ______________

Does the wetsuit have any damage that is consistent with trauma? Yes No

Was the diver experienced in the wetsuit? Yes No

Was the diver used to diving in cold water? Yes No

Notes: ____

____

____

____

____

DRYSUITS

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Condition of the suit:	Poor	Fair	Good	Excellent	Cut
Condition of the seals:	Poor	Fair	Good	Excellent	Cut
Condition of the zipper:	Poor	Fair	Good	Excellent	Cut
Condition of relief zipper:	Poor	Fair	Good	Excellent	Cut

Drysuit: Body Size: __________ Type: ______________

Body type: Front zip | Side zip | Rear zip | Latex seals

Attached hood | Dry gloves | Attached boots | Neoprene seals

Gloves: Hand size: __________ Thickness: __________ mm Type: ____________

Hood: Head size: __________ Thickness: __________ mm Type: ____________

Pocket locations: ____

Pocket type: Velcro | Zipper | Neoprene

Contents of the pockets: ____

LP hose connected to the drysuit valve? Yes | No | Unknown

Brand and condition of the LP hose: ____

Does the drysuit valve function? Yes | No | Unknown

Location of the exhaust valve on the suit: ____

Does the exhaust valve function properly? ____

Any debris located in the exhaust valve? Yes | No

Did undergarment get stuck in exhaust valve? Yes | No | Unknown

In what position was the exhaust valve dial? ____

Did the drysuit flood? Yes | No | Unknown

Type of insulation worn under the drysuit: ____

Was victim certified or trained in drysuit use? Yes | No

Level of experience in a drysuit: None | Novice (1-10 dives) | Intermediate (11-50 dives) | Experienced (>50 dives)

Notes: ____

____

____

WATCH, BOTTOM TIMER, SPG, COMPASS, DEPTH GAUGE, CAPILLARY GAUGE, TEMPERATURE GAUGE

(Complete one form per instrument.)

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Type of gauge: ______________________

Condition of the gauge: Poor Fair Good Excellent

Is the time correct on timing devices? Yes No

Is temperature correct on all thermometer devices? Yes No

Depth Testing of the Depth Gauge (Descent/Ascent)

Test Gauge Depth	Computer Depth	Test Gauge Depth	Computer Depth
0 fsw	_______ fsw	130 fsw	_______ fsw
10 fsw	_______ fsw	120 fsw	_______ fsw
20 fsw	_______ fsw	110 fsw	_______ fsw
30 fsw	_______ fsw	100 fsw	_______ fsw
40 fsw	_______ fsw	90 fsw	_______ fsw
50 fsw	_______ fsw	80 fsw	_______ fsw
60 fsw	_______ fsw	70 fsw	_______ fsw
70 fsw	_______ fsw	60 fsw	_______ fsw
80 fsw	_______ fsw	50 fsw	_______ fsw
90 fsw	_______ fsw	40 fsw	_______ fsw
100 fsw	_______ fsw	30 fsw	_______ fsw
110 fsw	_______ fsw	20 fsw	_______ fsw
120 fsw	_______ fsw	10 fsw	_______ fsw
130 fsw	_______ fsw	0 fsw	_______ fsw

Testing of the SPG (Pressurization/Depressurization Cycle)

Test Gauge Pressure	SPG Pressure	Test Gauge Pressure	SPG Pressure
0 psi	______ psi	3500 psi	______ psi
500 psi	______ psi	3000 psi	______ psi
1000 psi	______ psi	2500 psi	______ psi
1500 psi	______ psi	2000 psi	______ psi
2000 psi	______ psi	1500 psi	______ psi
2500 psi	______ psi	1000 psi	______ psi
3000 psi	______ psi	500 psi	______ psi
3500 psi	______ psi	0 psi	______ psi

MASKS *(Complete one form per mask.)*

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Data-type mask?	Yes	No			
Condition of the mask:	Poor	Fair	Good	Excellent	Missing
Skirt intact?	Yes	No	Strap intact?	Yes	No
Mask found on decedent?	Yes	No	Mask on face	Mask on forehead	

Did the decedent have any problems equalizing or clearing the mask?	Yes	No	Unknown
Was the mask flooded or partially flooded before fatality occurred?	Yes	No	Unknown
Corrective lenses?	Yes	No	

Decedent's vision without corrective lenses: ______________________

Was decedent wearing contacts during the dive?	Yes	No	Unknown

Magnifying inserts:	Yes	No			
LCD display:	Yes	No	Functioning properly?	Yes	No
Did the mask have a purge valve?	Yes	No	Functioning properly?	Yes	No

Any blood or foreign objects inside the mask?	Yes	No

Detail: ______________________

Data Mask Function Test

Did data mask function properly? Yes No

Notes: ______________________

____

____

____

SNORKELS

Manufacturer: ______________________ Model: __________________________ Color: _________________

Condition of the snorkel:	Poor	Fair	Good	Excellent	Missing
Mouth piece condition:	Poor	Fair	Good	Excellent	Missing
Bite tabs intact?	Yes	No			

Notes: ____

Does the snorkel have a purge valve? Yes No Functioning properly? Yes No

Any blood or foreign objects inside the snorkel? Yes No

Detail: ____

Where was the snorkel attached? Right side Left side

Other (describe): ____

Notes: ____

____

____

____

FINS

Manufacturer: ________________________ Model: _____________________________ Color: ___________________

Condition of the fins:	Poor	Fair	Good	Excellent	Missing	
Fin sizes:	XS	S	M	L	XL	XXL
	Other: ______________					
Type of fins:	Open heel		Full foot			
	Split fins		Freediving fins			
Were the fins found on the decedent?			Yes	No	Unknown	
Type of straps used with the fins:			Straps	Springs		
Did the fin straps have a quick-disconnect feature?			Yes	No		
Were the fin strap quick-disconnects attached?			Yes	No	Unknown	
Did the fins fit the decedent?			Yes	No		

Notes: ____

____

____

____

CAMERA OR VIDEO EQUIPMENT *(Complete one form per camera.)*

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Camera type: Digital Still/video Media type: ______________________

Film Still/movie Film type: ______________________

Lens manufacturer: ______________________ Type: ______________________

Serial #: ______________________ Filter: ______________________

Housing manufacturer: ______________________ Model: ______________________

Serial#: ______________________ Color: ______________________

Lens port type: ______________________

Camera functional? Yes No Housing flooded? Yes No

Decedent's camera? Yes No Partner's camera? Yes No

Strobe #1 manufacturer: ______________________ Model: ______________________

Serial#: ______________________ Color: ______________________

Strobe functional? Yes No Battery flooded? Yes No

Strobe #2 manufacturer: ______________________ Model: ______________________

Serial#: ______________________ Color: ______________________

Strobe functional? Yes No Battery flooded? Yes No

Light manufacturer: ______________________ Model: ______________________

Serial#: ______________________ Color: ______________________

Light functional? Yes No Flooded? Yes No

Type of clip or attachment used to secure equipment to the diver: ______________________

How was equipment connected to the diver? ______________________

Did location of equipment affect incident? Yes No

Did the clip, line or attachment become entangled? Yes No

Was the equipment negative or positively buoyant? Negative Positive

How negative or positively buoyant? ______________________

Did the buoyancy or lack of buoyancy affect incident? ______________________________

How experienced was the decedent with the equipment?______________________________

Name of person who downloaded photographs/video: ______________________________

Date/time photographs/video downloaded: ______________________________

Name/date of person who made duplicate of videotape:______________________________

Download digital photographs and video to at least two different drives or storage devices, and maintain hard copies of all relevant photographs for the case file. If videotape was used in the camera, a duplicate copy of the tape should be made.

Does film or slides need to be developed? Yes No

Name of the lab hired to develop film/slides: ______________________________

Date/time film/slides sent to the lab:______________________________

Date the negatives, prints or slides were received:______________________________

Maintain negatives, copy of prints or slides in the case file.

Notes: ______________________________

____

____

____

SLATE *(Complete one form per slate.)*

Manufacturer: ________________________ Size of slate: ________________________

Type of slate: White board Sketch type Other: ________________________

How slate carried: On arm On leg On BC On console

Clipped to diver/where: ________________________

In a pocket/where: ________________________

Slate attached to lift bag: ________________________

Was pencil attached? Yes No How was pencil attached? ________________________

Did pencil or slate line create entanglement issue? Yes No Unknown

Did the dive plan on the slate match dive profile from the computer? Yes No

What type of deviation from the plan was made? ________________________

Make a photocopy of any slates used by the decedent or dive partner.
Try to get slate translation from partner if slate information is in shorthand.

Transcribe all notes from slate onto this form.

Notes: ________________________

____

____

____

____

____

____

Drawings or sketches from slate:

GOODIE BAG *(Complete one form per bag.)*

Manufacturer: ____________________ Model: ____________________

Size: XS S M L XL Color: ____________________

Type: ____________________ Number of bags: ____________________

Any items attached to the bag? Game measuring devices Other: ____________________

List contents: Empty ____________________

Weight of contents: None ____________________

Did the extra weight or drag cause any issues? Yes No Unknown

How was the bag a carried? ____________________

Did the manner in which the bag was attached cause any issues? Yes No Unknown

Was the bag ditched? Yes No

Who ditched? Victim Partner Rescuer

Was the ditched bag recovered? Yes No

Where and who recovered? ____________________

Notes: ____________________

____

____

____

____

LIFT BAG OR SURFACE MARKER BUOY (SMB) *(Complete one form per lift bag/SMB.)*

Manufacturer: ______________________ Model: ______________________

Type of bag: ______________________ Color: ______________________

Lift bag capacity: ________ pounds Lift bag markings: ______________________

Where was the lift bag carried? ______________________

Was the lift bag used during the dive? Yes No

Why was the lift bag used? Part of Plan Emergency Use Lifting Object

How was the bag inflated? Orally Regulator LP Hose Other ____________

How was the bag deflated? Open bottom Manual dump Other ____________

During testing, any leaks found in lift bag? Yes No Where: ____________

After use, was the bag stowed, found in the water or located on the surface?

Stowed In the Water Found on the surface

Diver experience level with the bag: None Novice Intermediate Experienced

Notes: ______________________

____

____

____

____

REEL *(Complete one form per reel.)*

Manufacturer: ________________________ Model: ________________________

Type of reel: Open Closed Other: ____________ Color: ____________

Type of line: Material ____________ Twisted / Braided Size ________ Color: ________

How much line on the reel? ________________________

Was line marked in increments? Yes No How marked: ____________

Handle type: Standard Goodwin Other: ____________

Where was reel located? In pocket BC D-ring Harness Crotch strap

Weight belt Other: ____________

Did the way in which the reel was carried contribute to the fatality? Yes No Unknown

Was reel used during the dive? Yes No

Why was the reel used during the dive? ________________________

If used, did the reel ever jam or did the line become entangled? ________________________

Type of drag/locking mechanism on reel: ________________________

During testing, any problems noted? No Yes Describe: ____________

Cutting device on reel? Yes No

Diver experience level with reel: None Novice Intermediate Experienced

Notes: ________________________

____

____

____

____

KNIVES OR CUTTING DEVICES *(Complete one form per knife/cutting device.)*

Manufacturer: ______________________ Model: ______________________

Type of tool:	Knife (fixed or folding)		Paramedic shears		
	Line cutters		Other: ______________________		
	No type of tool carried by decedent				
Tool material:	Titanium	Stainless	Non-stainless steel	Other: ______________	
Sheath:	Open	Locking	Other ______________		None

Where was the tool carried?	Calf:	Right	Left	Inner	Outer
	Thigh:	Right	Left	Inner	Outer
	Arm:	Right	Left	Inner	Outer
	Waist:	Right	Left	Front	Side
	Harness:	Right	Left	Front	Side
	Pocket:	Right	Left	Front	Side
	Wetsuit sheath (describe where): ______________________				
	Other: ______________________				

Was the tool in a position it could be used?	Yes	No	Unknown
During testing could tool be removed easily?	Yes	No	
If no, note why the tool could not be removed:	Rust	Sand	Other: ______________
Was tool removed during the dive?	Yes	No	Unknown
Why was tool removed:	Emergency	Non-Emergency	
Was the tool placed back into carrying device?	Yes	No	Unknown

Notes: ____

____

____

____

____

DIVE LIGHTS *(Complete additional forms as needed.)*

Primary Light

Manufacturer: ____________________ Model: ____________________

Serial #: ____________________ Color: ____________________

Battery type: ____________________ Number of batteries: ____________________

Bulb type: Incandescent HID LED Xenon Other: ____________

Light functional? Yes No Flooded? Yes No

How was the light carried or attached to the diver? ____________________

Detached light head (canister light)? Yes No

If yes, describe how light head cable stowed: ____________________

Did light contribute to the accident?: Yes No Unknown

During testing, did light and switch function properly? Yes No Describe: ____________

Second Light

Manufacturer: ____________________ Model: ____________________

Serial #: ____________________ Color: ____________________

Battery type: ____________________ Number of batteries: ____________________

Bulb type: Incandescent HID LED Xenon Other: ____________

Light functional? Yes No Flooded? Yes No

How was the light carried or attached to the diver? ____________________

During testing, did light and switch function properly? Yes No Describe: ____________

Third Light

Manufacturer: ____________________ Model: ____________________

Serial #: ____________________ Color: ____________________

Battery type: ____________________ Number of batteries: ____________________

Bulb type: Incandescent HID LED Xenon Other: ____________

Light functional? Yes No Flooded? Yes No

How was the light carried or attached to the diver? ____________________

During testing, did light and switch function properly? Yes No Describe: ____________

Fourth Light

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Battery type: ______________________ Number of batteries: ______________________

Bulb type: Incandescent HID LED Xenon Other: ______________

Light functional? Yes No Flooded? Yes No

How was the light carried or attached to the diver? ______________________

During testing, did light and switch function properly? Yes No Describe: ______________

Fifth Light

Manufacturer: ______________________ Model: ______________________

Serial #: ______________________ Color: ______________________

Battery type: ______________________ Number of batteries: ______________________

Bulb type: Incandescent HID LED Xenon Other: ______________

Light functional? Yes No Flooded? Yes No

How was the light carried or attached to the diver? ______________________

During testing, did light and switch function properly? Yes No Describe: ______________

Notes: ____

____

____

____

____

JON LINE *(Complete one form per jon line.)*

Manufacturer: ______________________ Model: ______________________

Type: ________________ Length: ________________ Color: ____________

Where was the line carried?	Waist:	Right	Left	Front	Side
	Harness:	Right	Left	Front	Side
	Pocket:	Right	Left	Front	Side
	Other (describe): ______________________				
Was the jon line in a position it could be used?		Yes	No	Unknown	
During testing could the line be removed easily?		Yes	No		
If no, note why the jon line could not be removed:		Rust	Sand	Other: ____________	
Was jon line removed during the dive?		Yes	No	Unknown	
Why was jon line removed?		Non-emergency		Emergency	
Was the jon line placed back into carrying device?		Yes	No	Unknown	

Jon line length: ____________ feet / inches

What type of clip was attached to the diver's side of the jon line? ______________________

What type of clip was attached to the nondiver end of the jon line? ______________________

If deployed, did the jon line become entangled?	Yes	No	Unknown
Did the jon line contribute to the fatality?	Yes	No	Unknown

Notes: ____

____

____

____

____

SPEAR GUN AND SLINGS *(Complete one form per spear gun.)*

Manufacturer: ________________________ Model: ________________________

Type: Pneumatic Banded Pole spear Hawaiian sling Other: ____________

Length of gun: ________________________ Color: ________________________

How many bands? 1 2 3 4

Material made from: Wood Metal Other: ________________________

Does the gun have an attached reel? Yes No Unknown

Does the gun have an attached buoyancy device? Yes No Unknown

How much line is on the reel? ____________ feet

Is there a "safety" on the gun? Yes No

If yes, does it function properly? Yes No Describe: ____________

Buoyancy of gun: Negative Positive Buoyant force: ________ lbs

Was the gun used during the dive? Yes No Unknown

Was the use of the gun a factor in the incident? Yes No Unknown

Was the gun attached to the diver? Yes No Unknown

How was the gun attached to the diver? ________________________

Did the gun contribute to the fatality? Yes No Unknown

Was any game attached to the diver? Yes No Unknown

If yes, describe types, number, sizes, and how attached: ________________________

____

Notes: ____

____

____

____

DIVER PROPULSION VEHICLES (DPV)

Manufacturer: ______________________ Model: ______________________

Type: ______________________ Color: ______________________

DPV activation mechanism: ______________________

Was the diver trained to use the unit? Yes No Unknown

How experienced was the diver with the unit? Novice Intermediate Experienced

How was the unit attached to the diver? ______________________

Number of divers using the DPV at the time of the incident: ______________________

Number of divers with DPVs in dive team: ______________________

Was the diver using the unit when the incident occurred? Yes No Unknown

Was the DPV functional at time of the incident? Yes No Unknown

Was the unit negatively or positively buoyant? Negative Positive

How negative or positively buoyant was the unit? __________ pounds

Trim weights added to DPV? Yes No Unknown __________ pounds

DPV flooded? Yes No Unknown

Any modifications made to DPV? ______________________

Did the DPV contribute to the accident? Yes No Unknown

Note test results below.

Notes: ______________________

____

____

____

____

APPENDIX E2

Rebreather Evaluation Protocol

Jeffrey E. Bozanic
Next Generation Services
P.O. Box 3448
Huntington Beach, CA 92605-3448 USA

David M. Carver
Emergency Services Detail
Los Angeles County Sheriff's Department
1060 North Eastern Avenue
Los Angeles, CA 90063 USA

Consigned by: ____________________ Title: ______________________ Date: ____________________

Address: ____

Case # _____________________________ Decedent: _______________________________________

Step 1: Inventory (Photograph all components) Inspection date: ___________________________

CCR Manufacturer: ________________ Model: _________________________ Serial #: ______________

CCR Computer No. 1 Serial #: _____________________ No. 2 Serial #: _____________________________

Description of exterior condition: ____

Attachments and ancillary equipment *(NOTE: Begin noting this data now, but continue to add to it during later inspection steps as access to items becomes available.)*:

1: __________________________ Condition: ________________________ S/N: _________________

2: __________________________ Condition: ________________________ S/N: _________________

3: __________________________ Condition: ________________________ S/N: _________________

4: __________________________ Condition: ________________________ S/N: _________________

5: __________________________ Condition: ________________________ S/N: _________________

6: __________________________ Condition: ________________________ S/N: _________________

7: __________________________ Condition: ________________________ S/N: _________________

8: __________________________ Condition: ________________________ S/N: _________________

9: __________________________ Condition: ________________________ S/N: _________________

10: _________________________ Condition: ________________________ S/N: _________________

11: _________________________ Condition: ________________________ S/N: _________________

12: _________________________ Condition: ________________________ S/N: _________________

13: _________________________ Condition: ________________________ S/N: _________________

Component Testing (Videotape all steps.)

Step 2: Counterlung Gas Sampling

Using a syringe or other sampling device, collect and analyze gas samples from existing volumes within the rebreather BEFORE disassembly or gas additions are made.

Location	Oxygen	Helium	CO_2	H_2O
Inhalation counterlung				
Exhalation counterlung				
Inhalation hose				
Exhalation hose				
Canister				
Other (note location)				

Step 3: Functionality Testing

Positive Pressure Test

Before any disassembly or modification is done to the unit, use the diluent cylinder (or a replacement gas supply, if the diluent cylinder is empty or low on gas) to perform a positive pressure test of the breathing loop. Pay particular attention to any connections and seals, looking for leaks of any type. Snoop may be necessary to complete this evaluation.

Results:

❑ No leaks observed.

❑ Minor leaks observed at ____

❑ Major leaks observed at ____

Cylinders

Diluent: Valve operational __________ cylinder hydro_________ VIP __________

S/N: _________________ Contents: gas type__________% gas pressure _________ psi / bar

Oxygen: Valve operational __________ cylinder hydro_________ VIP __________

S/N: _________________ Contents: gas type__________% gas pressure _________ psi / bar

Bail-out: Valve operational __________ cylinder hydro_________ VIP __________

S/N: _________________ Contents: gas type__________% gas pressure _________ psi / bar

Bail-out: Valve operational __________ cylinder hydro_________ VIP __________

S/N: _________________ Contents: gas type__________% gas pressure _________ psi / bar

Water Containment

Check each part of the system for water volumes contained. Use a measuring device to determine volume. Note if units measured are ounces or milliliters.

Results:

❑ No significant water volume observed in breathing loop

❑ Water volume found in the following places and quantities:

Mouthpiece/DSV: ____________oz / ml

Canister: ___________________ oz / ml

Water trap: __________________oz / ml

Computer/handset #1: _________oz / ml

Computer/handset #2: _________oz / ml

Inhalation hose: ____________oz / ml

Exhalation hose: ____________oz / ml

Inhalation C/L: _____________oz / ml

Exhalation C/L: _____________oz / ml

Other (list): _________________oz / ml

Sensors

Note sensor conditions both prior to and after cleaning and drying. Pay particular attention to wiring and sensor faces. Note corrosion, discoloration, moisture, debris on sensor faces, etc.

Sensor	Wire condition	Sensor face
1		
2		
3		
4		

Before cleaning:

Sensor	Manufacturer	S/N	Date Code	0.21 PO_2 (Mv)	1.0 PO_2 (Mv)	2.0 PO_2 (Mv)	3.0 PO_2 (Mv)
1							
2							
3							
4							

After cleaning and drying:

Sensor	Manufacturer	S/N	Date Code	0.21 PO_2 (Mv)	1.0 PO_2 (Mv)	2.0 PO_2 (Mv)	3.0 PO_2 (Mv)
1							
2							
3							
4							

CCR Displays

Primary: calibration: ______________________________

Battery level: ______________________ Menu scrolls: ______________________

Secondary: calibration: ______________________________

Battery level: ______________________ Menu scrolls: ______________________

HUD: Lights: ______________________ Vibrating? (Y/N) ______________________

Alarms: ______________________________

CCR Batteries

Battery	Visual condition (discolor, corrosion, etc.)	Flooded (Y/N)	Manufacturer	Date code	Voltage (no load)	Voltage (under load)
1						
2						
3						

General Interior Inspection

Note any unusual conditions of the CCR interior. Pay particular attention to any residue, foreign materials or alterations made to the system.

Notes: ______________________________

____

____

Dive Computer(s)

NOTE: Download data to PC as soon as possible!

Brand: ______________________ Model: ______________________

Configuration for: ______________________________

Dives logged: ______________________ (see attached download)

Battery level: ______________________ Menu scrolls: ______________________

Brand: ______________________ Model: ______________________

Configuration for: ______________________________

Dives logged: ______________________ (see attached download)

Battery level: ______________________ Menu scrolls: ______________________

Brand: ____________________ Model: ____________________

Configuration for: ____________________

Dives logged: ____________________ (see attached download)

Battery level: ____________________ Menu scrolls: ____________________

Valve Tests

ADV: Brand: ____________________ Model: ____________________

S/N: ____________________ Inflation test: ____________________

OPV: Brand: ____________________ Model: ____________________

S/N: ____________________ Inflation/deflation test: ____________________

Man O_2: Brand: ____________________ Model: ____________________

S/N: ____________________ Inflation test: ____________________

Man dil: Brand: ____________________ Model: ____________________

S/N: ____________________ Inflation test: ____________________

DSV: Brand: ____________________ Model: ____________________

S/N: ____________________ Mushroom test: ____________________

Dil Reg: Brand: ____________________ Model: ____________________

S/N: ______________ IP pressure ______________ Test: ______________

O_2 Reg: Brand: ____________________ Model: ____________________

S/N: ______________ IP pressure ______________ Test: ______________

Inline hose isolation valve: Brand: ______________ Position: ____________________

S/N: ______________ Location: ______________ Test: ______________

Inline hose isolation valve: Brand: ______________ Position: ____________________

S/N: ______________ Location: ______________ Test: ______________

Buoyancy Control Devices

Brand: ____________________ Model: ____________________

S/N: ____________________ Inflation test: ____________________

Harness Devices: Brand: ____________________ Model: ____________________

S/N: ____________________ Condition test: ____________________

Crotch strap? (Y/N): ______________ Chest straps (Y/N): ______________ Scooter ring (Y/N): __________

Note any straps, harness clips or counterlung clips not fastened correctly. Pay particular attention to lower clips on counterlungs that might not be fastened. Also look for any breathing hoses or IP hoses that are misrouted.

Notes: ______________________________

____

____

____

Absorbent Condition

Retain absorbent, even if wet, for later analysis of carbonates vs. hydroxides content.

Manufacturer: ____________ Grade: ____________ Type: ____________

When filled: ____________ By whom: ____________

How: ____________ Flooded? (Y/N) ____________

Channeling prevention O-rings or gaskets noted: ____________

____

Regulator Testing

Alternate sir source combined with BC:

Manufacturer: ____________ Model: ____________ S/N: ____________

Function test: ______________________________

Cracking pressure: ____________ Free flow? (Y/N/Int): ____________

Predive/dive lever selection: ____________ Adjustment knob status: ____________

Notes: ______________________________

Other alternate air source attached to onboard diluent cylinder:

Manufacturer: ____________ Model: ____________ S/N: ____________

Function test: ______________________________

Cracking pressure: ____________ Free flow? (Y/N/Int): ____________

Predive/dive lever selection: ____________ Adjustment knob status: ____________

Notes: ______________________________

Bailout regulator 1

Manufacturer: ______________________ Model: __________________________________ S/N: ______________________

Function test: ____

Cracking pressure: ____________________________________ Free flow? (Y/N/Int): ______________________________

Predive/dive lever selection: ____________________________ Adjustment knob status: ____________________________

Notes: ____

Bailout regulator 2

Manufacturer: ______________________ Model: __________________________________ S/N: ______________________

Function test: ____

Cracking pressure: ____________________________________ Free flow? (Y/N/Int): ______________________________

Predive/dive lever selection: ____________________________ Adjustment knob status: ____________________________

Notes: ____

Weighting System

Note amounts and locations of all weights carried by the diver. Note units used.

Weight belt: _____________________ lbs / Kg Quick release (Y / N)

Integrated, left pocket: _____________________ lbs / Kg Quick release (Y / N)

Integrated, right pocket: _____________________ lbs / Kg Quick release (Y / N)

Integrated, in CCR housing: _____________________ lbs / Kg Quick release (Y / N)

Integrated, top of CCR: _____________________ lbs / Kg Quick release (Y / N)

Integrated, on backplate: _____________________ lbs / Kg Quick release (Y / N)

Other: ___________ lbs / Kg Quick release (Y / N) Location: ____________________________________

Other: ___________ lbs / Kg Quick release (Y / N) Location: ____________________________________

Other: ___________ lbs / Kg Quick release (Y / N) Location: ____________________________________

Weight estimate: ❏ Reasonable amount ❏ Obviously overweighted ❏ Obviously underweighted

Step 4: Post Disassembly Testing

After the complete disassembly and component testing is completed, then the following steps should be completed using appropriate manufacturer's predive and postdive checklists:

❏ Unit cleaned, disinfected and dried

❏ Unit reassembled using new sensors and batteries, charged gas cylinders, etc.

❏ Functional tests of calibration, handset/computer function, etc.

❏ Functional tests of other electronic components

❏ Functional tests of gas addition and controls

❏ Unit cleaned, disassembled and stored

Step 5: Unit-Specific Testing

Refer to unit-specific guidelines for other items to inspect or consider during testing.

Inspection Equipment Needs (Inventory)

Oxygen analyzer

Helium analyzer

Voltmeter

IP gauge

SPG

Rebreather manual

Oxygen cylinder

Diluent cylinder

Special tools for CCR

Set of replacement sensors for CCR

Replacement batteries for CCR

Bags for absorbent

Measuring cups

Pressure chamber to test sensors

Disinfectant and application device

Predive and postdive checklists for CCR

Regulator test bench

Calipers

Magnifying glass

Camera with macro lens

Media sticks for camera

Video camera with macro

Tapes for video camera

Standard tools (slotted and Phillips screwdrivers, hex wrenches, needlenose pliers, slip joint pliers, adjustable wrenches, box-end wrenches, nut drivers, knife, etc.)

Flashlight (for inspections)

Snoop (soapy water in spray bottle)

UV light

Scale

Preparation

Instrument Calibration

Oxygen gas analysis: model:______________________________ Calibration date: ____________________________________

Helium gas analysis: model: ______________________________ Calibration date: ____________________________________

Sensor analysis: model:__________________________________ Calibration date: ____________________________________

Voltmeter: model:______________________________________ Calibration date: ____________________________________

Pressure analysis: model: ________________________________ Calibration date: ____________________________________

APPENDIX F

Autopsy Protocol for Recreational Scuba Diving Fatalities

James Caruso
Regional Armed Forces Medical Examiner
Navy Recruiting Command
5722 Integrity Drive
Millington, TN 38054 USA

Since most pathologists and autopsy technicians rarely perform an autopsy on someone who died while scuba diving, few medical examiners' offices will have significant experience in performing appropriate postmortem examinations. The following is a guideline that can be followed with the understanding that some of the recommended procedures will be impractical and may only take place in a facility with significant laboratory resources available.

History

This is absolutely the most important part of the evaluation of a recreational diving fatality. Ideally, one should obtain significant past medical history with a special focus on cardiovascular disease, seizure disorder, diabetes, asthma and chronic obstructive pulmonary disease. Medications taken on a regular basis as well as on the day of the dive should be recorded, and information regarding how the diver felt prior to the dive should be obtained. Any history of drug or alcohol use must also be noted.

The dive history is extremely important. If possible, the investigator should find out the diver's experience and certification level. The most important part of the history will be the specific events related to the dive itself. The dive profile (depth, bottom time) is an essential piece of information, and if the diver was not diving alone, eyewitness accounts will be invaluable. With the near-universal use of dive computers, the computer used by the deceased diver should be interrogated, and if it has a download function all recent dives should be reviewed. Not only will the last dive or dive series be invaluable to the investigation, much can be learned about the diver by looking at previous dives made, including frequency, depth, ascent habits and with certain computers even breathing gas usage. Written dive logs are also a valuable source of information related to the diver's experience level and dive habits.

Questions to be asked include:

- When did the diver begin to have a problem (predive, descent, bottom, ascent, postdive)?
- Did the diver ascend rapidly (a factor in air embolism and pulmonary barotrauma)?
- Was there a history of entrapment, entanglement or trauma?
- If resuscitation was attempted, what was done, and how did the diver respond?

External Examination and Preparation

A thorough external examination including documentation of signs of trauma or animal bites or envenomation should be carried out. Palpate the area between the clavicles and the angles of the jaw for evidence of subcutaneous emphysema. X-rays of the head, neck, thorax and abdomen should be taken to look for free air. Postmortem CT imaging can be obtained as an alternative.

Modify the initial incision over the chest to make a "tent" or "pocket" out of the soft tissue (an "I" shaped incision) and fill this area with water. A large bore needle can be inserted into the second intercostal spaces on each side; if desired, any escaping air can be captured in an inverted, water-filled, graduated cylinder for measurement and analysis. As the breastplate is removed, note any gas escaping from vessels. An alternative test for pneumothorax consists of teasing through the intercostal muscles with a scalpel and observing the relationship between the visceral and parietal pleura as each pleural cavity is entered. If the two pleural layers are still adjacent until the pleural cavity is breached, there is no evidence of a pneumothorax. If a pneumothorax had occurred during the final dive, the lung would already be at least partially deflated and not up against the parietal pleura.

The pericardial sac can be filled with water and the chambers of the heart may be incised with a scalpel to look for any intracardiac gas. As was possible for the pleural cavities, escaping gas may be captured and analyzed, but most medical examiner offices do not have the resources for such endeavors. After the mediastinum, heart and great vessels have been examined under water for the presence of gas, the water may be evacuated and a standard autopsy may be performed.

Carefully examine the lungs for bullae, emphysematous blebs and hemorrhage.

Note any interatrial or interventricular septal defects. Carefully check for evidence of cardiovascular disease and any changes that would compromise cardiac function.

Toxicology: Obtain blood, urine, vitreous, bile, liver and stomach contents. Not all specimens need to be run, but at least look for drugs or abuse. If an electrolyte abnormality is suspected or if the decedent is a diabetic, the vitreous fluid may prove useful for analysis.

Prior to opening the skull, tie off all the vessels in the neck to prevent artifactual air from entering the intracranial vessels. Tie the vessels at the base of the brain once the skull is opened. Disregard bubbles in the superficial veins or venous sinuses. Examine the meningeal vessels and the superficial cortical vessels for the presence of gas. Carefully examine the Circle of Willis and middle cerebral arteries for bubbles.

Have an expert evaluate the dive gear. Are the cylinders empty? If not, the gas should be analyzed for purity (a little carbon monoxide goes a long way at depth). All gear should be in good working order with accurate functioning gauges.

Possible Findings

Air embolism: Intra-arterial and intra-arteriolar air bubbles in the brain and meningeal vessels, petechial hemorrhages in gray and white matter, evidence of COPD or pulmonary barotrauma (pneumothorax, pneumomediastinum, subcutaneous emphysema), signs of acute right heart failure, pneumopericardium, air in coronary and retinal arteries

Decompression sickness: Lesions in the white matter in the middle third of the spinal cord including stasis infarction, if there is a patent foramen ovale (or other potential right to left heart shunt) a paradoxical air embolism can occur due to significant venous bubbles entering the arterial circulation

Venomous stings or bites: A bite or sting on any part of the body, unexplained edema on any part of the body, evidence of anaphylaxis or other severe allergic reaction

Drowning: While drowning essentially remains a diagnosis of exclusion, there are some anatomic findings that are observed with considerable frequency. The lungs usually appear hyperinflated and can even meet at the midline when the anterior chest wall is removed. Lungs are typically heavy and edematous, and pleural effusions may be present. A moderate amount of water and even some plant material may be present, not only in the airway but also in the esophagus and stomach. Dilatation of the right ventricle of the heart is commonly observed as is engorgement of the large central veins. Fluid is also often found in the sphenoid sinus.

Carbon monoxide poisoning: Deaths due to carbon monoxide poisoning are rare in recreational diving, but they do occur. Autopsy findings are similar to carbon-monoxide-related deaths in other settings, with the classic finding of a cherry red color to the organs and blood. A carboxy-hemoglobin measurement should be obtained as routine toxicology in all diving-related deaths to exclude the contribution of contaminated breathing gas.

Interpretation

The presence of gas in any organ or vessel observed at the autopsy of someone who breathed compressed gas just prior to death is not conclusive evidence of decompression sickness or air embolism. During a dive, especially one of considerable depth or bottom time, inert gas dissolves in the tissues, and the gas will come out of solution when the body returns to atmospheric pressure. This, combined with postmortem gas production, will produce bubbles in tissue and vessels. The phenomenon has caused many experienced pathologists to erroneously conclude that a death occurred due to decompression sickness or air embolism.

Intravascular bubbles present predominantly in arteries and observed during an autopsy performed soon after the death occurred is suspicious for air embolism. The dive history will help support or refute this theory.

Gas present only in the left ventricle or if analysis shows the gas in the left ventricle has a higher oxygen content than that present on the right side would also be supportive for the occurrence of an air embolism.

Intravascular gas from decomposition or off-gasing from the dive would contain little oxygen and be made up of mostly nitrogen and carbon dioxide.

Deeper, longer dives can cause decompression sickness and significant intravascular (mostly venous) gas. Decompression sickness is rarely fatal and more commonly causes significant morbidity (illness and injury) in severe cases. Rapid ascents and pulmonary barotrauma are associated with air embolism.

APPENDIX G

Personal Assessment of Cardiovascular Risk for Diving

Alfred A. Bove, M.D., Ph.D.
Emeritus Professor of Medicine
Cardiology Section
Temple University School of Medicine
Philadelphia, Pa. USA

Heart attack risk is affected by a number of factors that may go undetected for many years until the attack occurs. These factors in general do not cause symptoms, are cumulative over time and ultimately result in blood vessel disease that leads to a heart attack that may occur while diving.

Known factors that increase risk for heart attack include:

1. Elevated blood pressure

2. Elevated cholesterol

3. Cigarette smoking

4. Diabetes

In addition, males are at higher risk than females until about age 60 when heart attack risk for females increases, and heart attack risk is increased with age due to the cumulative nature of the blood vessel damage that occurs over time. Therefore two other factors that need to be considered are:

5. Age

6. Male gender

Research has shown that these six factors when combined into a risk score can be used to estimate heart attack risk and guide efforts to lower the risk. The score is called the Framingham risk score, and calculators can be found at numerous locations on the Internet. To determine your risk score you need your blood pressure, cholesterol level, including total, LDL and HDL cholesterol. You will also be asked for your age and gender and whether you are diabetic.

The calculation provides the 10-year risk for heart attack presented as a percent. If your risk score is less than 10 percent (or 1 percent/year — that is less than one in a hundred chance of having a heart attack in a year), you are considered a low risk. Intermediate risk is 10 percent or greater and less than 20 percent, and high risk is more than 20 percent (or 2 percent/year). If your Framingham risk score is more than 10 percent, you should be evaluated medically to be sure you are safe for diving.

You should periodically check your heart attack risk. This means you should have a blood pressure check and tests for cholesterol and diabetes. Other factors that are not included in the Framingham risk score but are thought to increase your heart attack risk include history of a heart attack before age 50 in a close family member, poor physical conditioning, lack of exercise, and obesity.

For safe diving, you should avoid obesity, exercise enough to maintain good physical condition, keep your blood pressure and cholesterol normal, and get a check for diabetes. All of these factors can be modified by attention to your lifestyle and will keep your heart attack risk low even if your family history is not favorable.