

Recreational diving fatalities

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ABSTRACT

The risks of dying during recreational diving are small. The Divers Alert Network (DAN) held a workshop to consider whether the risks could be reduced further. Topics included investigation, surveillance, operational safety and cardiovascular disease. Investigation is essential to determine causes and involves on-scene inquiry, forensic examination of the deceased, and testing of life support equipment, but thorough investigations are unusual. 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 waters 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.

INTRODUCTION

The risk of dying during recreational diving is small, but no activity is completely risk-free, and deaths occasionally occur. Prevention programs might be devised if contributing factors could be identified.

Studies of causes and annual rates of recreational diving fatalities suggested this might be feasible [1,2], and in April 2010 the Divers Alert Network (DAN) convened a workshop to explore the possibilities. Topics discussed included investigation, surveillance and data analysis, training and operations, and cardiovascular disease. The workshop findings are summarized below.

In addition, four cardiovascular papers presented at the workshop are published in this issue of *UHM* for accessibility to diving physicians [16-18,21]. The workshop proceedings [3] and presentation videos are available on the DAN website (www.dan.org) at no cost.

INVESTIGATION

In the United States, the Coast Guard and/or state law enforcement agencies have authority over scuba 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 [4]. Often, agencies are not well coordinated nor do they have the resources or capability for comprehensive investigation.

The ideal investigation would begin immediately with an on-scene inquiry by a trained individual that included equipment inspection, a dive site survey and interviews with witnesses, dive professionals and public safety personnel [5]. Life support equipment should be impounded and preserved at once. A factual written report should summarize the findings with documentation by audio recording, still photography and videography (if needed). Forensic examination of the deceased would identify the COD and contributing medical factors in the context of operational reports.

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 [6]. 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 whether equipment served as 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 [7,8]. An inadequate investigation is a source of distress to the family of the deceased and an impediment to understanding the causes of death. The probability of litigation increases when the events and causes are not discovered. Both United States and European courts are requiring strict adherence to preservation of evidence 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 which 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 [9]. These factors are the basis for countermeasures to improve safety, with regular follow-ups to assess countermeasure effectiveness.

Diving fatality surveillance programs were presented for the United States, Canada and Europe [10]; Australia and the Pacific region [11]; and the United Kingdom (UK) [12]. Annual per capita fatality rates among DAN America (16.4 deaths per 100,000 persons per year) and 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 [10]. 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 [10].

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 [13]. 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 [10], 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, while Cumming *et al.* 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 [12]. 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 [13]. To understand the extent of the recreational diving fatality problem, moreover, estimates of the total population size need updating. Estimates from the 1990s, for example, indicated there were several million U.S. recreational divers [14].

Fundamental problems associated with diving fatalities have not changed significantly in recent history [10-13]. 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 waters. 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 [2].

Operational diving safety

A discussion of diving safety based on operational experience cited many of the risk factors mentioned above [15]. Divers are taught to avoid most of these during training, but many who died seemed not to have acted in accordance with instruction. Why this was so was unclear. Suggested countermeasures included skill refreshers with checkout 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 pre-dive briefings, buddy separation, and dive conditions beyond the diver's training, experience or physical capacity.

Cardiovascular risk assessment

Given that cardiac events are associated with about a quarter of recreational diving fatalities that were investigated [1], current methods for screening appear inadequate to identify divers at risk for sudden cardiovascular death. The most common causes of sudden death in the general population are arrhythmia and acute myocardial infarction [16], usually due to occult cardiovascular disease with little indication of abnormality [17].

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 [18]. 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.

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 dive 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 [19].

The workshop reviewed the RSTC form and suggested revisions to its questions based on the AHA pre-participation questionnaire for competitive athletes [20]. 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 METs (multiples of assumed resting metabolic rate) [21].

The second at-risk group is established older divers who have developed occult cardiovascular disease in the years since initial training. This group may be at greatest risk since there is presently no system for longitudinal health surveillance. A shorter variant of the RSTC form might be appropriate for longitudinal follow-up. Possible follow-up opportunities include before charter boat dive trips and prior to continuing diving education courses.

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