The Investigation of SCUBA Diving Fatalities

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Diving using compressed air, or a similar breathing gas, and self-contained underwater breathing apparatus equipment (SCUBA) is a popular pastime throughout the world. Recreational diving fatalities include most types of diving for personal pleasure and without remuneration. This also includes diving for personal game collection such as spearfishing and abalone and lobster collecting. Fortunately, fatalities related to recreational diving are infrequent. In the United States there is an average of 90 recreational diving fatalities each year [1]. These deaths, however, are often catastrophic events that involve young individuals and in the majority of cases are totally preventable. They are also frequently litigated. It is extremely important to thoroughly investigate recreational diving fatalities and use the case reports as lessons learned with the hope of reducing the number of diving-related deaths in the future. That is exactly the role played by the Divers Alert Network (DAN).

175.1 Military and Commercial Diving Fatalities

These were once dangerous environments with frequent accidents, many of which were fatal. However, fatal accidents have become a very rare occurrence in both the military and commercial diving setting. The rare accidents that do occur are often due to equipment malfunctions or unsafe work practices. This is very different from what is seen in recreational diving deaths [2].

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175.2 Basic Diving Physiology

In order to be able to interpret the circumstances surrounding a fatal diving incident, a basic understanding of diving physiology is required [3]. The vast majority of diving-related injuries are due to effects of pressure, the effects of inert gas, mechanical trauma or insufficient breathing gas. Chap. 166 provides an overview of the most important items of diving physiology. Occasional injuries and fatalities are due to hazardous marine life and problems such as oxygen toxicity or impurities in the breathing gas [4]. Of course, natural disease plays a role in many diving fatalities, especially as the diving population ages and older adults take up diving.

175.2.1 Mechanical Trauma

There are a few deaths every year due to a diver being hit by a boat propeller or other forms of mechanical trauma. In some cases, the source of the injury is the boat that the diver is using as a platform. Sometimes the accident is due to reckless boaters who speed through the dive site without regard for the welfare of those who are in the water. In other instances, the diver failed to use a marker buoy or dive flag to warn boaters of his or her location.

175.2.2 Insufficient Breathing Gas

It may seem unconscionable for a diver to run out of air, but it unfortunately is an all-too-common occurrence. The result can include drowning or a rapid ascent, which can cause pulmonary barotrauma or air embolism. Entrapment or entanglement in a cave, wreck or kelp can result in a diver running out of air and subsequently drowning.

175.2.3 Hazardous Marine Life

This is rarely a cause of mortality but more commonly causes morbidity. Envenomation, bites, stings and simple wounds can result from contact with various sea creatures. Sharks rarely attack divers while on the bottom. More likely shark targets include free divers and surfers who spend considerable time on the surface or moving up and down in the water column.

175.2.4 Oxygen Toxicity

This is rarely a problem if the diver breathes air since the diver would have to go to depths above 40 m where CNS oxygen toxicity would occur. High partial pressures of oxygen can cause seizures, which would be catastrophic at depth. Using breathing mixes that contain a high percentage of oxygen is increasing in popularity, and several recent fatalities related to seizures at depth have occurred.

175.2.5 Natural Disease

As one would expect, cardiovascular disease is the most common natural cause of death implicated in a fatal diving incident. Some divers have undiagnosed health problems, while others dive with known health problems that may put them at increased risk for morbidity and mortality [5]. Diving often takes place in remote areas or at least far from advanced emergency medical care. Suffering a seizure at depth or having myocardial ischaemia or infarction while diving off a remote island would have increased mortality compared to the same events taking place on land in a large metropolitan area.

175.2.6 What Kills SCUBA Divers?

A thorough investigation usually reveals a critical error in judgement, the diver going beyond his or her level of training and experience, or a violation of generally accepted safe diving procedures. In other words, the root cause is most commonly diver error [6]. As noted previously, cardiovascular disease is the most common natural disease process associated with a recreational diving fatality [5].

Drowning is the most common cause of death with various events leading up to the drowning including running out of air at depth, entrapment, air embolism, cardiac dysrhythmia and trauma. However, to simply sign a case out as a death due to drowning may not be accurate and certainly does very little to prevent future similar incidents. It also offers little closure for the family. It is absolutely essential to determine, to the extent possible, the events leading up to the drowning and any significant contributing factors.

Recent work has introduced new terminology into the investigation of diving-related deaths. An attempt has been made to place diving-related fatalities into a sequential cascade of four events [7]. It is hoped that the identification of triggers, disabling agents, disabling injuries and cause of death for cases contained in the DAN diving fatality database will result in a better understanding of the root cause and contributing circumstances.

- Triggers are felt to be the initial incident or problem that sets a string of events in motion
- The disabling agent is often the initial response to the trigger
- The disabling injury is often the physiological response to the disabling agent

The cause of death is the culmination of preceding events such as the trigger and disabling agent, and therefore looking at a cause of death, particularly when it is drowning, does not come close to explaining why a diver died.

A recent query of the diving fatality database that is kept by the Divers Alert Network (DAN) revealed information on 841 diving fatalities for the period

1997–2006 [8–11]. The cause of death for over half of these cases was drowning, followed by cardiac events and air embolism. Insufficient air (20 %), cardiac-related health problems (15 %) and air embolism (10 %) were determined to be the most common primary contributing factors to the fatal outcome. The cases included 695 males and 146 females, with a median age of 47 years. Over 50 % of the fatalities involved divers who reported pleasure or sightseeing as a dive activity, but students comprised a significant portion of the deaths.

The majority of fatal diving mishaps involve either an insufficient air scenario or a cardiac-related health problem. The logical conclusion is that efforts to decrease diving-related deaths would be best focused on avoiding out-of-air situations and emphasise diving within training and experience levels. Additionally, improved diver awareness of cardiovascular health should be part of any effort to decrease diving fatalities.

Other important observations on recreation diving fatalities from the DAN database include the following:

- Nearly half of all fatalities involved a diver who had made 20 or fewer lifetime dives.
- Buddy separation occurred in 40 % of diving-related deaths, and solo divers made up at least 14 % of the fatalities.
- Barely a third of divers who died while engaged in more challenging types of diving, such as cave diving and wreck penetration, possessed documented training specific to that type of diving.

175.3 Autopsy Protocol for Recreational SCUBA Diving Fatalities

Since most pathologists and autopsy technicians rarely perform an autopsy on someone who died while SCUBA diving, few medical examiner offices will have significant experience in performing appropriate post-mortem examinations on cases like this. 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 (see also Table 175.1). In all cases, expert consultation should be obtained if there are any questions regarding diving procedure, autopsy findings or equipment [12–14].

A thorough investigation of the events surrounding the fatality, including eyewitness accounts, the scene investigation, and a professional evaluation of the equipment, are essential.

Table 175.1 Basic investigations

Review past history, clinical history and resuscitation efforts
Scene investigation and circumstances of the death, evidence
External exam and evidence of injury, X-rays, special attention to head and neck
Autopsy to include thorough cardiovascular, respiratory, musculoskeletal and brain exam
Sinuses and middle ear exam
Toxicology

A complete autopsy with standard toxicology for drugs of abuse and therapeutic medications, as well as a carboxyhaemoglobin level, should be performed in every diving-related fatality. A short post-mortem interval is desirable to minimise artefacts.

175.4 History

The medical history is without doubt the most important part of the evaluation of a recreational diving fatality. Ideally, one should obtain significant past medical history with a focus especially 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.

A key component of the investigation is getting a detailed dive history. If possible, the investigator should find out the experience and certification level of the diver. The most important part of the history will be the specific events related to the dive itself. The dive profile, depth and bottom time are essential pieces of information, and of information, and if the diver was not diving alone, eyewitness accounts will be invaluable. Questions to be asked include:

- When did the diver begin to have a problem: pre-dive, descent, bottom, ascent and post-dive?
- Did the diver ascend rapidly?
- Did the diver panic?
- Was there a history of entrapment, entanglement or trauma?
- If resuscitation was attempted, what was done and how did the diver respond?
- What were the weather and water conditions at the time of the mishap?

175.5 External Examination and Preparation

A thorough external examination including signs of trauma, animal bites or envenomation should be carried out. The area between the clavicles and the angles of the jaw is palpated for evidence of subcutaneous emphysema. Radiographic imaging studies of the head, neck, thorax and abdomen should be taken to look for free air.

The initial incision over the chest is modified to make a tent out of the soft tissue with a T-shaped incision and fill this area with water. A large bore needle can be inserted into the second intercostal space bilaterally. If desired, any escaping air can be captured in an inverted, water-filled, graduated cylinder for measurement and analysis. This is a very difficult procedure and unlikely to be undertaken in most medical examiner offices. The oxygen content of the captured gas may give some clues to its origin. As the breastplate is removed, note any gas escaping from vessels.

A needle, or scalpel, should only be inserted in the right and left ventricles after the pericardial sack is filled with water. This allows to capture any gas coming from the heart. After the mediastinum, heart and great vessels have been examined underwater for the presence of air, the water may be evacuated and a standard autopsy may be performed. The lungs are carefully examined for bullae, emphysematous blebs and haemorrhage.

Any inter-atrial or interventricular septal should be noted, particularly if there is a patent foramen ovale. Carefully check for evidence of cardiovascular disease and any changes that would compromise cardiac function.

Blood, urine, vitreous, bile, liver, kidney and stomach contents are obtained for toxicological analysis. Not all specimens need to be run, but at least look for drugs of abuse. If an electrolyte abnormality is suspected or if the decedent is a diabetic, the analysis of the vitreous fluid for electrolytes and glucose may prove useful.

Prior to opening the skull, all vessels in the neck are tied off to prevent artefact air from entering the intracranial vessels. The skull may be opened prior to the examination of the chest. The vessels at the base of the brain are tied off once the skull is opened. Disregard bubbles in the superficial veins or venous sinuses. The meningeal vessels and the superficial cortical vessels are examined for the presence of gas. Also the circle of Willis and middle cerebral arteries are carefully examined for bubbles.

Have an expert evaluate the dive gear. Are the tanks empty? If not, the gas should be analysed for purity because little carbon monoxide goes a long way at depth. All gear should be in good working order with accurate functioning gauges.

175.6 Possible Findings

Air Embolism

Intra-arterial and intra-arteriolar air bubbles in the brain and meningeal vessels, petechial haemorrhages in grey 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

Findings may include 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 oedema on any part of the body, evidence of anaphylaxis or other severe allergic reaction. A serum tryptase level may prove useful in these cases.

175.7 Interpretation

The presence of gas in any organ or vessel after a SCUBA diving death is not the conclusive evidence of decompression sickness or air embolism. During a long dive inert gas dissolves in the tissues, and the gas will come out of solution when the body returns to atmospheric pressure. This, combined with post-mortem gas production, will produce bubbles in tissue and vessels. This has caused many experienced pathologists to erroneously conclude that a death occurred due to decompression sickness or air embolism. Intravascular bubbles, especially if present predominantly in arteries, found during an autopsy performed soon after death occurred is highly 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 that the gas in the left ventricle has a higher oxygen content than that present on the right side, would lead the pathologist to correctly conclude that an air embolism probably has occurred.

Intravascular gas from decomposition or off-gassing from the dive would have 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. Rapid ascents and pulmonary barotrauma are associated with air embolism.

175.8 Some Case Descriptions Where the Investigation and Autopsy Made a Difference

Case 1

A 52-year-old male was in good health except for hypertension that was controlled with a single medication. After an uneventful dive, the man returned to the boat but collapsed on the deck within minutes of completing the dive. The autopsy showed a massive intracerebral haemorrhage. The history would make an air embolism a likely diagnosis, and the autopsy was the key part of the investigation to distinguish between an accidental and a natural manner of death. The fact that he was diving prior to the CVA was pure coincidence.

Case 2

A 38-year-old male made a short dive to a fairly shallow depth and collapsed shortly after returning to the boat. The story is similar to case 1, except a key piece of evidence was the dive computer. The computer showed a bottom time of 7 min and a maximum depth of 34 ft (11 m). It also had an ascent rate display that was in the dangerously rapid ascent area. The autopsy showed intravascular bubbles in the cerebral arteries. The case was correctly interpreted as an air embolism.

Case 3

A 26-year-old navy diver was using a 100 % oxygen rebreather rig and was noted to have a seizure in the water. He was pulled from the water but could not be resuscitated. The presumption was that the diver suffered an oxygen-induced seizure due to the type of diving he was doing. However, a full autopsy disclosed the presence of a high-grade malignant brain tumour that already was causing cerebral oedema. The contribution of the diving environment, including the oxygen being used as a breathing gas, is uncertain. The diver had no significant medical history and had not complained of any recent health problems.

Case 4

A very experienced technical diver was using multiple breathing gas mixes during a long and deep dive profile. After ascending from 160 ft (48 m) to 120 ft (36 m), the diver suffered a witnessed seizure and drowned. The autopsy disclosed abundant intravascular gas, and the medical examiner incorrectly determined the cause of death to be an air embolism. Further investigation into the dive profile and an examination of the equipment revealed that the diver had mistakenly used a high oxygen containing decompression mix instead of the bottom and travel mixes he should have been breathing at 120 ft (36 m). The correct interpretation of the circumstances is that the diver drowned due to a seizure because of central nervous system oxygen toxicity, while breathing from the wrong regulator at depth [15].

Case 5

A 45-year-old man became separated from his dive buddy and was found unconscious on the bottom. The cause of death was presumed to be a cardiac event, but a complete autopsy with appropriate toxicology was performed. Coincidentally, another diver on the boat became ill during the dive and aborted the dive due to an equipment problem. The dead diver had an extremely high carboxyhaemoglobin level, and a full investigation disclosed several contaminated tanks, all from the same dive shop.

Case 6
A 52-year-old man was a novice diver who had been having chest pains for a few days prior to his dive. He made the dive anyway and became separated from his dive buddy. The diver was found on the bottom unconscious and could not be resuscitated. The autopsy disclosed severe coronary atherosclerosis and a ruptured plaque in the left anterior descending coronary artery.

Case 7
A 19-year-old man was diving off a party boat in a large group but without a designated dive buddy. One of the boat crew remembers giving the diver a small bag prior to his departure from the surface. All of the other divers returned to the boat, but the missing diver was not found despite an extensive search. Days later the body of the diver was recovered by fishermen. X-rays and a complete autopsy revealed the cause of death, which was a single gunshot wound to the head. This case represents a rare suicide while diving. Additional investigation revealed that the diver had recently dropped out of school, had a dispute with his parents and purchased a handgun at a pawnshop.

175.9 Drowning

To many in the healthcare field, particularly in forensic medicine, the term drowning is applied to any individual who was known to enter the water alive and subsequently was found in the water without signs of life [16, 17]. The reason for this is that some believe that drowning is a diagnosis of exclusion, and certainly anyone who is immersed in a liquid is at risk for drowning. While drowning is for the most part a diagnosis of exclusion, a thorough medicolegal investigation is required in each case of drowning. Nowhere is this truer than in recreational diving deaths. Some divers die of other conditions while in the water.

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