PROGRAM OBJECTIVES:

Understand the physics and physiology specific to the underwater environment. Interpret circumstances surrounding a death of a person using recreational diving equipment.

Apply a few specialized techniques while performing an autopsy on someone who died while performing a recreational dive. Interpret the findings of the postmortem examination in the context of the circumstances surrounding the death.

Discuss the epidemiology of diving related accidents.

Recognize resources available when faced with performing an autopsy on someone who died while using recreational diving equipment.

FACULTY:

James L. Caruso, MD
Chief Deputy Medical Examiner
Office of the Armed Forces Medical Examiner
Rockville, MD

Associate Consulting Professor
Anesthesiology and Pathology
Duke University Medical Center
Durham, NC
As a service to the medical profession and to the general public, the American Society for Clinical Pathology organizes educational workshops to provide a forum for qualified specialists to express their views on topics affecting medical research and practice. It should be recognized that the individual speakers and authors are expected to express their individual opinions and evaluations and, in doing so, to draw upon their professional experience. Accordingly, the comments, opinions and evaluations expressed by the faculty are not edited or reviewed by ASCP. The individual faculty retain the sole responsibility for the validity of any opinions, evaluations or conclusions which they may express, and their statement should be evaluated accordingly. Specifically, ASCP does not authorize any workshop faculty to express any such personal opinion or evaluation as the act or position of ASCP.

All teleconference participants receive an electronic handout which can consist of an annotated slide key, corresponding to the speaker's slide presentation, or a slide image handout, or other relevant reading/reference material. This handout is simply to reference the slides and to aid in taking notes during the lecture or reviewing the slides after the program. On occasion, supplemental material may be submitted by the speaker, and may be seen in the handout as well.

In accordance with ACCME guidelines, any individual in a position to influence and/or control the content of this ASCP CME activity has disclosed all relevant financial relationships within the past 12 months with commercial interests that provide products and/or services related to the content of this CME activity.

The individuals below have disclosed the following financial relationships with commercial interests:

James L. Caruso, MD

The materials for this program have been reviewed by our ASCP Teleconferences Planning Committee to ensure that no conflict of interest exists in this presentation.

Note: The majority of the slide images in this presentation were prepared using the SurePath® slide preparation technique.

Copyright © 2006 by American Society for Clinical Pathology
All Rights Reserved. Printed in the United States of America.

The electronic handout material provided by ASCP to each registered site is designed to be printed out and duplicated for the number of people attending the real-time teleconference. ASCP grants full permission to copy the handout material for each participant in attendance. Except as stated above, no part of this publication may be reproduced or transmitted in any form or by any means - electronic, mechanical, photocopying, recording, or otherwise used as a part of any audiovisual presentation, without the prior written permission of the publisher.
**Program Title: The Pathologist’s Approach to SCUBA Diving Deaths**

<table>
<thead>
<tr>
<th>Slide 0:</th>
<th>ASCP Logo slide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide 1:</td>
<td>ASCP Notice of Faculty Disclosure</td>
</tr>
<tr>
<td>Slides 2-3:</td>
<td>The Pathologist’s Approach to SCUBA Diving Deaths</td>
</tr>
<tr>
<td></td>
<td>James L. Caruso, M.D</td>
</tr>
<tr>
<td></td>
<td>Armed Forces Medical Examiner-Pacific</td>
</tr>
<tr>
<td></td>
<td>U.S. Naval Hospital, Okinawa, Japan</td>
</tr>
<tr>
<td></td>
<td>Photo Slide</td>
</tr>
<tr>
<td>Slide 4:</td>
<td>Program Objectives</td>
</tr>
<tr>
<td>Slides 5-6:</td>
<td>History of Diving - Man likely first entered the water to obtain food and recover lost tools. Breath-hold diving was followed by using hollow reeds to increase the time a diver could spend beneath the surface. Eventually man descended in creative containers with a connection to the surface for air. It took the invention of mechanical pumps to bring success to these early surface supplied divers.</td>
</tr>
<tr>
<td></td>
<td>Recreational Diving – In the United States recreational diving is not governed by strict regulations or laws. Most dive shops will ask for a certification card to fill, sell, or rent compressed air cylinders to divers, but nothing prevents someone from borrowing equipment. There are no government standards for dive training or strict physical qualifications to participate in recreational diving. Several national and international organizations have established guidelines for dive training and safe diving. The Undersea and Hyperbaric Medical Society (UHMS) provides recommendations concerning medical fitness to dive issues.</td>
</tr>
<tr>
<td></td>
<td>Introduction - Recreational diving using SCUBA is actually a fairly safe and forgiving endeavor. With successful completion of any recognized initial open-water certification course, the individual should be able to participate safely in routine dives to depths up to 60 feet under conditions of reasonable visibility and only a mild current. As the novice diver gains experience in the water, he/she will usually seek additional training opportunities and perform more challenging types of dives (e.g., deep, wreck, cave/cavern dives). Recreational diving is a somewhat forgiving past-time by virtue of the fact that a diver may make several errors in calculation or judgment during a dive and often have no negative impact on the dive. This is not the case in more difficult, technical types of dives where one mistake may be the difference</td>
</tr>
</tbody>
</table>
between life and death. For this reason, technical divers often carry redundant back-up systems that are unnecessary and impractical for standard recreational types of dives.

**Equipment** - Diving using SCUBA (Self-Contained Underwater Breathing Apparatus) is relatively recent technology, developed by Jacques Cousteau and others in the years surrounding World War II. Standard equipment includes a regulator, buoyancy compensator, weight belt, fins, mask, snorkel, thermal protection such as a wetsuit, air tank, and depth/pressure gauges. The list of optional equipment is endless. The regulator consists of two stages connected by a hose. The first stage decreases the pressure of the air in the tank from the standard 3000 pounds-per-square-inch (psi) to a more manageable pressure for the second stage. The second stage acts as a demand valve, delivering air or other gas in response to inhalation efforts by the diver. The most common system is known as open-circuit, where exhaled gas is simply dumped into the surrounding water in the form of bubbles. More complex breathing apparatus, such as closed-circuit and semi closed-circuit systems, are available and are becoming increasingly popular with the recreational diving community. The tank is usually an aluminum cylinder, though in the past steel tanks were more common. The breathing gas is most commonly air but mixtures of oxygen and helium, oxygen and nitrogen, or even all three gases may be used. The diver typically wears a buoyancy compensator, though some people dive without one. This device is a vest containing an inflatable bladder designed to counter negative buoyancy while below the surface as well as keep the diver on the surface before and after excursions to depth. Most often the buoyancy compensator vest serves as the point of attachment for the tank. Some of the more recently designed models employ weights that are integrated into the vest and can be dropped with the pull of a cord. The masks and fins come in various styles and colors to complement individual tastes. Certain fin styles are better suited for increased propulsion power in the water; other styles are designed with comfort in mind. A snorkel is somewhat optional, but extremely useful during the time spent on the surface when breathing through the regulator would decrease the amount of air available for the dive. While gauges that indicate depth and how much breathing gas remains are considered essential equipment, most divers also use a dive computer to guide their dive. Some computers are very basic and provide only minimal information on the dive; others are more elaborate and monitor each breathing cycle via a connection to the regulator. Other equipment that may be used during the dive includes motorized propulsion devices, a wide array of photographic gear, and accessories designed to collect game (such as a spear gun). More specialized types of diving, such as entering wrecks or caves, require additional gear. Most recently rebreather devices have become more popular with the general public. Once the domain of Special Forces divers, these highly technical rigs are no longer cost prohibitive.

**Slides 7-8:** Why Investigate? Recreational diving fatalities frequently involve young to middle-aged individuals resulting in the loss of many years of productive life, and are nearly all litigated in the court system. Men are more likely than women to be victims but this gender disparity continues to shrink. Diving fatalities also usually attract great press interest and, most recently, generate abundant attention on the Internet. It is extremely important to the family of the deceased, to the other individuals involved with the dive, and to recreational diving as a whole that the fatal mishap be thoroughly investigated to the extent possible. An accurate report of the events leading up to the fatality and the cause of death, as far as it can be determined, should be generated for every fatal diving mishap.
### Slide 9: Drowning in SCUBA

The leading cause of death in diving related mishaps is drowning, but that conclusion provides little in the way of “lessons learned” for the dive community and it does not provide closure for the family. To appropriately and thoroughly investigate a diving related death, at least a basic understanding of diving physiology is required. However, the average practicing pathologist will see far more drowning deaths than diving related deaths. It is important to understand the basic concepts involved in a drowning death and what to look for at autopsy.

### Slides 10-16: Drowning Pathophysiology and Autopsy Findings

**Definition and Background**
Drowning, when all is said and done, is death by asphyxiation. Many detailed theories about the exact pathophysiology of drowning have been elaborated during the past 100 years, but the end result in drowning is death secondary to hypoxemia due to asphyxiation by immersion in a liquid.

**Epidemiology**
- Drowning is a leading cause of accidental death in the United States, especially in the pediatric age group.
- Nearly 9000 drowning deaths occur in the United States each year (third most common cause of accidental death) with an estimated 80,000 near drownings
- Over 50% of adult drowning victims have alcohol as a contributing factor
- Most common victim is male, age 10-19; male:female = 10:1; 90% accidental/10% suicide
- Boating accidents account for 17% of accidental drownings
- Half of all drowning deaths occur May-August; 2/3 occur in fresh water

Not surprisingly, drowning is the leading cause of death in fatal scuba diving mishaps. Of the approximately 90 recreational scuba diving fatalities that involve U.S. citizens each year, drowning accounts for at least half. With this in mind, any medical examiner or forensic investigator should be familiar with the pathophysiology of drowning. The most common single factor leading to drowning in scuba diving fatalities is running out of air at depth or while in a cave or wreck. Drowning is also seen in breath-hold divers where the possibility of shallow-water blackout exists. Other factors that can contribute to drowning include hypothermia, contaminated air (especially carbon monoxide), and trauma. Drowning secondary to an air embolism is also a common scenario in a fatal diving mishap.

**Key Points**
1. Drowning is a diagnosis of exclusion; prior to arriving at this conclusion, one must rule out other causes of death (e.g. trauma, natural disease processes, drug overdose, disposal of a homicide victim in water, etc.). Therefore, a complete autopsy including toxicology is always indicated.
2. A drowning death is death by asphyxiation with subsequent hypoxemia and cerebral anoxia. The amount of water inhaled is variable. Most forensic references usually propose that in 10-15% of cases, laryngeal spasm can result in a “dry drowning”. More recently, the existence of “dry drowning” has been disputed. Opponents of the concept state that there is likely an
alternative cause of death (e.g., cardiac) in what were formally categorized as “dry drownings”.

3. Absorption of significant amounts of water, which can especially occur in cases of freshwater drowning, was once thought to cause serious electrolyte abnormalities and potential fatal dysrhythmias. This is no longer felt to be the case as it is likely that a healthy heart and kidneys would compensate for the modest increase in volume, and electrolyte abnormalities do not seem to play a large role; near drowning victims do not usually exhibit extreme electrolyte abnormalities on initial presentation.

4. The “break point” is defined as the time when an individual can no longer voluntarily breath-hold. This occurs in response to blood levels of CO2 and O2. The person will breathe regardless of his or her immersion status and if submerged, continued inhalation of water will occur.

5. The type of water aspirated, fresh or saltwater, usually has little bearing on survival. Freshwater drowning usually results in larger amounts of fluid absorbed and more damage to pulmonary surfactant. This may become clinically important if the victim survives. Saltwater drowning usually results in greater pulmonary edema, pleural effusions, and hemoconcentration.

6. Near drowning is defined as resuscitation of a submersion victim with subsequent survival of at least 24 hours regardless of whether or not death occurs after this period.

7. No definitive diagnosis of drowning can be made based on autopsy findings alone. The circumstances, autopsy findings, and toxicology results are combined in order to arrive at the cause of death. Nonspecific autopsy findings in drowning deaths may include fluid in the airways, large and bulky lungs filled with fluid, pulmonary edema, water in the stomach, right ventricular dilatation, cerebral edema, fluid in the cranial sinuses, and hemorrhage in the petrous or mastoid bones.

8. External findings that may occur prior to or after death include “washerwoman palms” (wrinkled skin), “gooseflesh” (cutis anserina), and predation from animals living in the water.

9. Because the drowning victim usually struggles, rigor mortis sets in earlier and rapid cooling slows the decomposition process. Immersion leaches blood from wounds so deciding an antemortem vs. a postmortem wound may be difficult. Animal bites may have occurred prior to or after death.

10. Various chemical tests, especially electrolyte studies, have been proposed to aid in the diagnosis of drowning or in determining freshwater vs. saltwater drowning. None has proved consistently useful and most are of no value. Evaluations centered around diatoms are controversial at best.

**Drowning Pathophysiology**

Regardless of the circumstances leading to the drowning, the primary effect on the body is hypoxemia. Typically, the victim struggles and consciously holds his breath. Eventually a breakpoint is reached and the victim must inhale, resulting in aspiration of water. Regardless of the amount of fluid aspirated, hypoxemia occurs.

The typical drowning victim aspirates a moderate amount of water, which results in an altered ability of the alveoli to exchange gas. There is always great controversy over the differences between a freshwater drowning victim and someone who drowns in saltwater. If the victim dies before any rescue or resuscitation efforts can be attempted, then the death is pretty much purely
one of asphyxiation. If the victim survives for any period of time, then there are differences in
the chain of events that lead to the final pathway of death due to hypoxemia. In saltwater
aspiration, the hypertonicity causes fluid to be drawn into the alveolar spaces resulting in an
inability to ventilate and ultimately hypoxemia. In freshwater drowning, pulmonary surfactant is
damaged which increases the surface tension in the alveoli and causes them to collapse. Again,
the end result is hypoxemia.

A complication of drowning when aspiration occurs is that the victim also usually swallows
enough water to cause gastric distention, further hampering ventilation. The decreased alveolar
ventilation and resultant hypoxemia quickly create a setting of increasing blood levels of carbon
dioxide (thus H+) and lactic acid (a combined respiratory and metabolic acidosis). For many
years the most accepted theory on the pathophysiology of drowning was that large serum
electrolyte changes occurred due to large fluid shifts created when the victim aspirated water.
The extent of the electrolyte changes were thought to be somewhat dependent on whether salt or
freshwater was aspirated. This theory was founded on a very detailed study using dogs forced to
aspirate fluids with various concentrations of electrolytes. Repeated evaluation of human
drowning and near-drowning victims has never shown significant electrolyte changes to occur
and theory has fallen out of favor with physiologists during the past few decades. Mild changes
in serum sodium and chloride levels have been observed and serum potassium remains virtually
unchanged. The quantity of aspirated water is not usually significant enough to produce any
clinically significant changes in serum electrolytes.

The Autopsy
In a suspected drowning a thorough external examination is essential. Abrasions on the
forehead, forearms, and knees are common if the body has been dragged by the surf. It may be
extremely difficult to differentiate between antemortem and postmortem wounds in a body that
has been immersed for any length of time. A complete autopsy looking for evidence of natural
disease processes and documenting some of the changes typically associated with drowning (see
above) should be performed. Complete toxicological studies are essential. As noted above, a
definitive diagnosis of drowning cannot be made based on autopsy findings alone. The
pathologist must take into account the circumstances surrounding the death, the autopsy
findings, and toxicology results.

Slides 17-20: Diving Physiology
Basic Diving Physiology: The vast majority of diving-related injuries are due to effects of
pressure, the effects of inert gas, mechanical trauma, or insufficient breathing gas. Occasional
injuries and fatalities are due to hazardous marine life and problems such as oxygen toxicity. Of
course, natural disease plays a role in many diving fatalities, especially as the diving population
ages and older adults take up diving. In order to properly investigate a diving related fatality, a
basic understanding of diving physiology is invaluable.

Pressure - The most important concepts to understand are how pressure changes occur at depth
and the effects increased ambient pressure has on body. These changes are governed by Boyle’s
Law, which is derived from the Ideal Gas Law. Boyle’s Law describes the inverse relationship
between pressure and volume. As pressure decreases, volume increases and the opposite is also true. The ambient pressure at sea level is one atmosphere (equals 760 mm Hg; 14.7 psi). As a diver descends to depth, the ambient pressure increases by an additional atmosphere every 33 feet. For example, a diver at a depth of 100 FSW (feet of seawater) is experiencing an ambient pressure of slightly greater than 4 atmospheres (one atmosphere on the surface and one more for each 33 feet of depth). As dictated by Boyle’s Law a balloon inflated on the surface and brought down to 100 FSW will shrink to one-fourth of its original volume. The greatest pressure changes occur closer to the surface. If that same balloon is filled while at a depth of 33 FSW, the volume will double (as the pressure decreases from two atmospheres to one) when the balloon is brought to the surface. Gases behave according to partial pressure, which is the product of the percentage of a gas in a mixture and the ambient atmospheric pressure. For example, the partial pressure of oxygen at the surface is .21 atmospheres (1 atmosphere x 21 percent) but at 33 feet below the surface of the ocean that partial pressure doubles to .42 atmospheres.

**Barotrauma** - Any enclosed or functionally enclosed space can be affected by pressure changes and therefore sustain barotrauma. The most severe form of barotrauma involves the lungs (see below). Less catastrophic but more common injuries due to the effects of pressure include barotrauma to the middle ear, inner ear, sinuses, and teeth.

**Inert gas** - In diving terminology an inert gas is defined as basically any gas except oxygen. In diving it is often the nitrogen contained in air but divers can use mixtures containing helium and oxygen, enriched air (higher oxygen content), or pure oxygen. Nitrogen has an intoxicating effect at high partial pressures which most divers can feel when they descend (breathing air) below 100-130 feet. Divers going too deep will become progressively disoriented with increasing depth. Substituting helium for nitrogen can prevent nitrogen narcosis. Both nitrogen and helium progressively dissolve in tissues when breathed at hyperbaric (higher than sea level) partial pressures. This is also depth-dependent and a diver must limit the exposure at deeper depths as well as ascend slowly, often stopping at shallower depths in order to “off-gas”. If the diver’s tissues become supersaturated with inert gas, as he or she ascends the gas may bubble out of solution, which can lead to venous bubbles causing decreased tissue perfusion. This can potentially lead to decompression sickness (caisson disease) with classic symptoms of joint pain or neurological deficits (and various atypical presentations). The venous bubbles can arterialize in divers with a patent foramen ovale who shunt the bubbles to the left side (paradoxical embolism).

---

**Pulmonary Barotrauma and Air Embolism**

Boyle’s Law provides the physiologic explanation for pulmonary barotrauma, also known as extra-alveolar air syndrome. If the diver inhales compressed gas at depth and then ascends without exhaling, the result will be over-expansion of the lungs. Pulmonary over-expansion can lead to any or all of the four types of pulmonary barotrauma: mediastinal emphysema; subcutaneous emphysema; pneumothorax; and arterial gas embolism. The intimate association of small blood vessels with the alveoli in the lungs allows for the entrance of gas into the pulmonary circulation as a result of a pulmonary over-expansion injury. This intravascular gas returns to the heart via the pulmonary veins where it will be distributed systemically. The symptoms of an air embolism in typical cases mimic a cerebrovascular accident. The classic presentation is that of a diver becoming incapacitated immediately upon
As noted previously, inert gas and most often nitrogen accumulates in tissue as a function of time and depth of the dive. Long, deep dives tend to saturate tissue with dissolved gas and if the diver does not eliminate some of that gas before ascending to the surface, decompression sickness may result. There are elaborate dive tables and now dive computers that keep track of theoretical amounts of dissolved gas in the body during the dive. Usually, but not always, if a diver abides by these restrictions the risk of decompression sickness is minimal. Exceeding these time and depth limits increases the chances of suffering decompression sickness. As the diver ascends ambient pressure decreases and the dissolved gas comes out of solution and forms bubbles. These bubbles, unlike in an air embolism, are on the venous side of the circulation and cause problems by impairing flow in capillary beds around joints and in the central nervous system, specifically the spinal cord. Symptoms of decompression sickness usually do not begin until the diver has been on the surface for minutes to even hours, except for catastrophic cases. They include the classic joint pains of “the bends”, neurological impairment that may manifest as numbness, tingling, or even paralysis, or a characteristic marbling rash of the skin. Decompression sickness is almost never fatal, though it may cause significant morbidity. Less than one-percent of all diving fatalities are due to decompression sickness and the ones that occur usually involve long hospital stays with complications. Treatment includes recompression in a hyperbaric chamber.

Nitrogen, helium, hydrogen, and argon all have this effect but nitrogen is the most common inert gas encountered in diving and its effects are best described. The narcotic effect is a function of time and usually is imperceptible at depths shallower than 100 feet (if the breathing gas is air). As the diver descends further, cognitive function and situational awareness become increasingly impaired. Ascending minimizes this problem. There are many stories about divers going very deep on air and becoming impaired enough to hallucinate, even trying to pass their regulators to the fish for example. Extreme depths (greater than 300 feet) would be expected to result in loss of consciousness. For that reason, air is not used for very deep dives.

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, the latter of 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. Most often it is just a simple absence of situational awareness and a lack of attention to detail. Divers are taught to return to the surface with no less than 500 psi of breathing gas remaining in the tank. A classic scenario is an out of air episode at depth, followed by a panicked, rapid ascent, resulting in an air embolism on the surface and a subsequent drowning due to the diver being incapacitated from the air embolism.

Oxygen at high partial pressures can be dangerous, even acutely. This is rarely a problem if the diver breathes air since the diver would have to go to extreme depths to reach the point where
central nervous system oxygen toxicity would occur. Technical divers may employ high oxygen containing mixes for decompression stops. High partial pressures of oxygen can cause seizures, which would be catastrophic at depth. Several fatalities have occurred due to a diver breathing the incorrect mixture (e.g., a mix meant for decompression closer to the surface while on the bottom).

### Slide 28: Natural Disease

As you might 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. Diving often takes place in remote areas or at least far from advanced emergency medical care. Suffering a seizure at depth or having a myocardial infarction while diving off a remote island would have increased morbidity and mortality compared to the same events taking place on land in a large metropolitan area.

- Medical problems that result in a decreased level of consciousness or unconsciousness are contraindications to diving as are those that impair judgment or rational thinking (e.g., seizure disorder, major psychiatric illness).
- The other category of medical problems that would put an individual at higher risk of injury during diving includes those that are exacerbated or have serious sequelae due to Boyle’s Law (e.g., emphysema or asthma due to potential air trapping and therefore a higher risk for pulmonary barotrauma).
- There is no upper age limit for recreational diving, but a person continuing to dive or desiring to participate in initial dive training after age 40 should be scrutinized a little more closely for medical problems.

### Slides 29-30: 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. What is often seen at autopsy is postmortem predation on a body by a shark. A recent highly publicized death due to a stingray barb is a very rare occurrence. There are very few places on the body where that barb would cause a severe injury and unfortunately in that case the barb went into the worst possible anatomic location.

### Slide 31: Miscellaneous

- **Mechanical trauma** - There are always a few deaths every year due to a diver being hit by the boat propeller or other forms of mechanical trauma. The popularity of personal watercraft in recent years has caused a few fatalities where divers have been struck by these vessels.
- **Toxicology** – each year there are a small number diving related deaths where toxicologic studies are very relevant. A few cases of fatal carbon monoxide poisoning occurring during a dive have been reported. I have seen postmortem toxicology reports showing illicit drugs such as cocaine and THC present as well as numerous cases where highly sedating prescription medications have been present at significant concentrations.
- **Non-natural, non-accident** – I know of at least one reported case of a homicide during a recreational dive and I personally reviewed another that was at least suspicious. Suicides during a dive trip are infrequent but I have reviewed a couple and there was one a few decades ago that
even involved discharging a firearm below the surface of the water.

**Slide 32:** Drowning in SCUBA

This slide just reiterates the central pathway drowning often occupies in recreational diving deaths and how the various contributing factors contribute to this outcome.

**Slides 33-37:** Diving Autopsy

**Protocol for the Autopsy:**

Standard toxicologic studies are recommended. Obtaining a carboxyhemoglobin level on aortic or IVC blood should be considered for every diving fatality to exclude the possibility of contaminated breathing gas.

**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 examiners’ offices will have significant experience in performing appropriate postmortem examinations. The following is a guideline which 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 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.
- 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 (they are taught never to do so), eyewitness accounts will be invaluable. 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 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 and intravascular gas.

**INTERNAL EXAMINATION**

**Protocol for the Autopsy:** Various techniques can be used to demonstrate the presence or absence of a pneumothorax. Modify the initial incision over the chest to make a “tent” 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 bilaterally; if desired, any escaping air can be captured in an inverted, water filled, graduated cylinder for measurement and analysis. Alternatively, the intercostal muscles can be carefully dissected away to visualize the visceral pleura falling away from the parietal pleura if pneumothorax is absent. As the breastplate is removed, note any gas escaping from vessels. The pericardial sac can be filled with water, with insertion of a needle or scalpel into each ventricle to document intracardiac gas. In certain academic settings any gas escaping from the pleural cavities or heart may be captured and analyzed though this is not particularly practical in a busy ME Office. After the mediastinum, heart, and great vessels have been examined for the presence of air, the water may be evacuated and a standard autopsy may be performed.

- Carefully examine the lungs for bullae, emphysematous blebs, and hemorrhage.
- Note any inter-atrial or inter-ventricular 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 of abuse. If an electrolyte abnormality is suspected or if the decedent is a diabetic, the vitreous may prove useful.
- Prior to opening the skull, tie off all of 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 scull 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.

**EQUIPMENT**

- Have an expert evaluate the dive gear. Are the tanks empty? If not, the gas should 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.

**INTERPRETATION**

- The presence of gas in any organ or vessel after a scuba diving death is not 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 postmortem 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 the 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 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 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.

<table>
<thead>
<tr>
<th>Slide 38-39: Investigation, Equipment, and Computers</th>
</tr>
</thead>
</table>
| As mentioned above, the dive equipment should absolutely be examined by an expert and not by the dive shop that rented it out. Gas left in the tank should be analyzed for purity and all gauges and regulators need to be tested for proper function. If a dive computer is present it should be interrogated (most have a downloadable memory) to not only look at the most recent dives (including presumably the fatal incident) but also diving patterns and habits (always makes rapid ascents, pushes the limits, etc.)  
- It is extremely important to the family of the deceased, to the other individuals involved with the dive, and to recreational diving as a whole that the fatal mishap be thoroughly investigated to the extent possible. An accurate report of the events leading up to the fatality and the cause of death, as far as it can be determined, should be generated for every fatal diving mishap. Individuals tasked with these investigations should seek out knowledgeable experts in the field for appropriate consultation. In many cases, physicians in the local area who render medical care to divers will be in the best position to provide insight into the event for the investigating authorities.  
- A thorough investigation of a dive fatality includes an accurate history, detailed witness accounts of the incident, the findings of a thorough postmortem examination including toxicology studies, and the evaluation of the equipment used in the dive. |

<table>
<thead>
<tr>
<th>Slides 40-43: WHERE AND HOW DO DIVERS DIE?</th>
</tr>
</thead>
</table>
| - There are approximately 90 diving-related fatalities that occur in the U.S. or that involve U.S. citizens diving abroad each year. Twenty to thirty years ago the annual number was actually higher. Divers were less likely to have formal training and the equipment was less reliable. Fatalities are more common in areas where diving is more frequent, but the popularity of SCUBA diving has resulted in a diving fatality being reported in nearly every part of the United States.  
- A thorough investigation usually reveals a critical error in judgment or a violation of recommended safe diving procedures.  
- Drowning is the most common cause of death, with various events leading up to the drowning including running out of air, entrapment, air embolism, cardiac dysrhythmia, and trauma.  
- Cardiovascular disease is the most common natural disease process associated with a diving fatality. In many cases the decedent has been asymptomatic and sudden death is the first
manifestation of CVD. In other instances, the diver participated in the sport with known health problems and placed himself/herself and the dive buddy at risk. In divers over the age of 35, cardiovascular disease was second only to drowning as the primary cause of death; in many of those drownings, CVD also played a role.

- Other health problems that often figure into a fatal diving mishap include chronic obstructive pulmonary disease, depression, and physical disabilities. Obesity and poor exercise tolerance are also frequently the case. Every year there are a few fatalities in which toxicology reveals that alcohol or some other impairing substance had a role in the outcome of the dive.

- Other factors that figure into a fatal diving mishap include inexperience, diving beyond one’s capabilities, and separation from the diving buddy. Novice divers (those with less than 20 lifetime dives) are over-represented in the diving fatality database-nearly one in every five fatalities is a novice diver. Divers in their initial open-water certification course are also over-represented (5-15% of fatalities each year). Fatalities that occur during initial training are especially alarming, since the diver is presumably under instruction and with a group of divers during this phase.

- Certain types of more challenging dives (specialty dives) require extra training and sometimes special equipment. These activities include cave penetration, wreck penetration, very deep dives, diving under ice, and diving with gases other than air. Many of the fatalities that occur during these specialty dives involve divers who did not receive formal training in the specific type of diving activity.

- Divers are taught to dive with a buddy and keep at least visual contact with their buddy. Buddy separation is a very common theme in fatal diving mishaps. Unfortunately, this complicates the investigative process since the terminal or near terminal event goes unwitnessed.

- It goes without saying that the vast majority of diving fatalities occur in locations where there is the greatest number of dives performed. In the last 5 years, Florida has had nearly double the number of diving fatalities than the next state on the list, California. Washington, Hawaii, and Massachusetts round out the top five. Not all fatalities occur in the ocean or in large bodies of water for that matter. A significant number of fatalities occur in states not thought to be “great diving locations”. In the last several years, there have been numerous fatalities in Wisconsin, Pennsylvania, and Michigan. Many initial dive-training classes are held in quarries, a location that accounts for a significant number of fatalities. A diving fatality can occur in any state. In the locations where this is a rare event, the forensic investigator and medical examiner may wish to get assistance with interpretation of the findings of the investigation and autopsy.

- There is a very small subset of fatalities each year where the diver did everything correctly and the outcome of the dive was beyond his/her control. Following standard no-decompression tables and conservative ascent rates do not guarantee that the dive will go smoothly. Decompression sickness does occur in dives where tables were used correctly and a history of a rapid ascent or breath-holding is not the case in all gas embolism mishaps. Trauma, such as being struck by the boat or the boat’s propeller, can also be part of the dive fatality scenario (these cases often involve diver error as well, e.g., no dive flag used).

Slide 44-47: Cardiovascular Disease and Diving – Case #1
I reviewed all U.S diving deaths 1990-1999 (n = 877) for which I had enough data to evaluate, 130 (14.8%) were attributed to cardiovascular disease. Common findings in these cases included severe atherosclerosis of the coronary arteries, hypertrophy of the left ventricle of the
heart, and evidence of acute and/or recent myocardial infarction. There was a significant jump in the ASCVD related diving deaths in males over the age of 40. Divers with a significant cardiovascular history or individuals wishing to begin diving after the age of 40 should receive medical clearance and an exercise stress test would be a prudent idea. Another case that comes to mind is a diver who had a massive hypertension-related CVA immediately upon surfacing from an uneventful dive. His presentation was identical to an air embolism case and he was initially transferred to a facility with a recompression chamber. Just because the individual is diving doesn’t mean that the diving history figured into the cause of death.

**Slide 48-52: Cave Diving and Paradoxical Embolism - Case #2**

Cave diving was once thought to be only for an eclectic fringe subset of divers but it has become somewhat more mainstream. At one time the cave diving deaths that I saw involved primarily basic open-water trained divers with no formal cave diving training who decided that going into a cave would be a great idea. More recently I am seeing trained cave divers also lose their lives with a little more frequency. Entering an underwater cave system requires advanced navigational skills, the use of lines, redundant backup equipment in case the primary breathing apparatus, light, etc. fail, and formal training and certification.

This particular case is interesting not because it was a cave diving death but because it demonstrates the phenomenon of paradoxical embolism. The diver made a dive that would cause gas to accumulate in tissue at a significant concentration. The ascent was uneventful and she did well during the initial post-dive period. Those facts argue against an air embolism. However her presentation is also not typical for decompression sickness. The sudden collapse is more typical of an air embolism. The “paradox” was explained at the autopsy where a patent foramen ovale was noted. This intra-atrial communication is present in 25-30% of individuals but often only provides a right to left shunt with straining or valsalva. Climbing the hill while carrying heavy equipment provides the perfect explanation to how those bubbles went from right to left in terms of circulation.

**Slides 53-58: Technical Diving – Case #3**

Like cave diving, technical diving is becoming more mainstream in the diving community. Standard open-water diving usually involves air as the breathing gas, with some individuals using enriched air (contains more than 21% oxygen), or Nitrox. Technical diving involves using other gas mixes, often with changing from one gas to another during the course of the dive. Specialized equipment may be used to dive very deep, penetrate a wreck, dive under ice, or stay down for extended periods of time. Once solely the domain of the military and scientific divers, civilian divers now have access to rebreather devices which circulate exhaled air through the rig and remove carbon dioxide while adding breathable gas back to the loop.

This case demonstrates a very common phenomenon that I hope to discourage among the teleconference participants. The pathologist who performed the autopsy let the intravascular and intracardiac gas take precedence over the dive history. In order to suffer an air embolism, the diver must ascend and the ascent must involve a significant pressure change. Going from 160 to 130 feet is really not much of a pressure change and with the seizure occurring at 130 feet this was not likely an air embolism. The gas present at autopsy is explained by the long, deep dive where tissues became saturated with inert gas. An autopsy performed after any delay but especially after a day or two would have artifacts that must be taken into account in the final determination. The photos demonstrate the complexity and bulkiness of technical diving gear.
They also show some unwise habits, primarily that of color coding the regulators so you know which one to use at a given depth. Below the surface most bright colors turn to shades of blue-green. As described previously a gas mixture containing a high percentage of oxygen can be very dangerous when breathed at significant depths.

**Slides 59-62:**

**Carbon Monoxide Poisoning – Case #4**

**CO Poisoning in Diving Deaths**

There are few cases of carbon monoxide diving deaths documented. In my review of over 800 diving related deaths I found only five, but I also noted that postmortem testing for CO exposure was rarely performed in diving related deaths. Therefore we are likely missing some cases of carbon monoxide poisoning among the diving related deaths. With contaminated gas sources the physiologic effects of CO exposure would be enhanced due to increased partial pressure. In this particular case the faulty compressor was producing CO when leaking oil dripped onto a hot surface. This would occur with either an electric or gasoline driven compressor. The typical way for carbon monoxide to be introduced into breathing gas is through the air intake. Some less than reputable dive shops have their air intake near locations where cars or trucks may be left running. This is more common in lesser developed countries but those are the types of places where diving occurs.

CO competes with oxygen to bind to hemoglobin and it has 250 times the affinity for hemoglobin that oxygen has; other heme proteins affected as well. Hemoglobin becomes saturated with CO and oxygen delivery is impaired; additionally, the hemoglobin-oxygen dissociation curve is displaced to the left such that the O2 that is bound to hemoglobin does not dissociate easily and delivery of O2 to tissues is significantly impaired. There is also recent evidence that CO acts directly on a cellular level (cytochromes, electron transport chain) mediating numerous deleterious effects

- Half life of carbon monoxide in the body:
  - 5 hours, 20 minutes breathing room air
  - 1 hour, 20 minutes breathing 100% oxygen
  - 23 minutes breathing hyperbaric oxygen (2 atmospheres)

- Postmortem carboxyhemoglobin levels in blood and body fluids fairly accurately reflect those present at the time of death; decomposition changes the level minimally. Accidental deaths due to CO poisoning can be mistaken for heart disease (as it was in this case initially).

**Slides 63-64:**

**Review and Summary**

**References**


Special thanks to Dr. Michael Bell, Chief Medical Examiner of West Palm Beach, Florida for allowing the use of slides 11, 12, 13, and 31.