Oxygen Toxcity Management in the Field

by Kathy Weydig and Joel Silverstein

This cautionary tale about a central nervous system oxygen convulsion was presented after dinner at the Technical Diving Conference organized by DAN Jan. 18-19, 2008, in Durham, N.C. Events such as these are very rare, and it is even more unusual for a video camera to capture the whole experience. It really brings it home: Yes, oxygen toxicity is real, and it pays to be informed. Best of all, the event had a safe outcome.

— Richard D. Vann, Ph.D., Vice President of DAN Research

Technical diving expeditions require extensive planning. Despite the best of plans, accidents can happen when you least expect them. How you deal with them is critical to the outcome.

In 2004, the National Oceanic and Atmospheric Administration granted us a civilian research permit to visit the USS *Monitor. (See sidebar.)* NOAA had stopped issuing permits in 1997 and began work with the U.S. Navy to salvage certain parts of the ship. Between 1998 and 2002, divers removed the propeller shaft, engine and the gun turret.

Our visit would be the first civilian visit in more than seven years. The USS *Monitor* rests at a depth of 235 feet (72 meters) 18 miles (29 km) out from Cape Hatteras, N.C. At that depth, our divers would be using mixed gases to document the changes to the site since they had removed major portions of the *Monitor*. We were also gathering decompression data for new mixed-gas dive computers for Cochran Undersea Technology.

The incident

Two days into the second week of our project, a rare incident occurred: A team member convulsed as a result of oxygen toxicity. One of our photographers, a 51-year-old man with five years of technical experience and more than 30 years of overall diving experience, suffered an underwater convulsion caused by oxygen toxicity. His dive was to last no more than 20 minutes with a "run time" of 60 minutes. (Run time is the total time spent underwater in reference to a decompression dive. In this case, the diver spent 20 minutes at depth and 40 minutes on decompression stops.) He was properly equipped with twin tanks filled with 17/40 trimix and decompression cylinders of 50 percent nitrox and 100 percent oxygen, standard mixes at these depths.

After 14 minutes on the bottom, the diver began his ascent to 70 feet (21 meters), where he was to make his gas switch to the nitrox mix of 50 percent oxygen-enriched air. While managing a large camera without a tether, he made the gas switch to 100 percent oxygen instead. This put his partial pressure of oxygen level, or PO_2, at 3.12 atmospheres absolute, more than twice the maximum oxygen level for a diver. (Note: The U.S. Navy is currently using 1.3 ATA as the limit in its closed-circuit rebreathers, while limits of 1.4-1.6 are more commonly selected by civilian divers. *See Oxygen Toxicity sidebar.*)

While making his ascent, the photographer continued breathing the oxygen for the next nine minutes. At 38 feet (12 meters), he encountered another diver who was completing decompression. At this point, he began experiencing a full-blown convulsion. The diver grabbed the injured diver and the anchor line.

Diving the *Monitor*

The USS *Monitor* is a Civil War-era ironclad ship, made famous by the first-ever naval battle of ironclad warships. Commissioned by the U.S. Navy, the *Monitor* clashed with the Confederate States Navy ironclad CSS *Virginia* (often referred to as the *Merrimac*; it was built from the remains of the USS *Merrimack*) in the Battle of Hampton Roads on March 9, 1862. The four-hour battle ended in a strategic victory for the *Monitor*, as the *Virginia/Merrimac* failed to break the Union blockade of Hampton Roads, Va. Because of their construction, neither ship experienced significant damage.

Later that year, the *Monitor* sank in heavy seas off the N.C. coast near Cape Hatteras. The ship's heavy gun turret and low freeboard (i.e., the distance from the waterline to the upper deck) made it less than seaworthy in rough waters.

The *Monitor* was rediscovered in 1973 at a depth of 235 feet (72 meters). The National Oceanic and Atmospheric Administration designated the wreck site as the United States' first marine sanctuary. The *Monitor* Sanctuary is the only national marine sanctuary created to protect a cultural, rather than a natural, resource.

Scuba divers made their first dives to the *Monitor* in 1991.

Unable to interrupt his own decompression, the diver held the injured diver while the convulsion continued. As the diver's entire body shook, the decompressing diver managed to deploy a marker buoy to get some attention. Two divers had just entered the water and got the injured diver to the surface. On the boat, we heard a yell for help.

To the rescue

Immediately, we went into rescue mode. Swimmers rolled into the water to get the injured man up and on the deck, where we stripped him of all gear. The injured man had a weak pulse and was experiencing labored breathing; clear froth came from his nose and mouth.

We began first aid and oxygen administration while the captain radioed the U.S. Coast Guard; he issued a mayday call and requested a helicopter. We worked on the injured diver for almost 30 minutes, when, without any notice, he regained consciousness and sat up.

Still there were other divers we needed to get out of the water before we could move the boat. Once everyone was on board, we completed the airlift.

The helicopter flew to Virginia Beach, where the injured man underwent hyperbaric treatment. He remained overnight under observation and was released the next day. The diver made a full recovery,

Oxygen Toxicity

Although oxygen is required for human life, it can have toxic effects when breathed at above-normal pressures. The target organs affected are the lung and the central nervous system. Oxygen toxicity involving the lungs, called pulmonary oxygen toxicity, results from many hours of exposure, usually encountered only during recompression treatments or during long decompression using enriched oxygen breathing.

Recreational divers can encounter oxygen toxicity involving the brain (termed CNS oxygen toxicity). The diver using regular scuba equipment at reasonable depths will not encounter this problem, but gas density and heavy exertion can cause carbon dioxide retention that makes divers more sensitive to oxygen. The current maximum oxygen partial pressure recommended for recreational diving is 1.4 to 1.6 ATA.

Air will have an oxygen partial pressure of 1.4 and 1.6 ATA at 188 and 220 fsw (61 and 72 msw), respectively. Divers using modified gas mixtures with concentrations of oxygen higher than air are at risk at much shallower depths.

A 32 percent enriched-air nitrox mix will have an oxygen partial pressure of 1.4 and 1.6 ATA at 111 and 132 fsw (36 and 43 msw), respectively. A 36 percent nitrox mix will have an oxygen partial pressure of 1.4 and 1.6 ATA at 95 and 114 fsw (31 and 37 msw), respectively. A diver breathing pure oxygen can have convulsions at depths as shallow as 20 fsw (6 msw).

Signs & Symptoms

- Nausea
- Dizziness
- Abnormal vision
- Confusion
- Convulsion
- Ringing ears
- Facial twitching

Convulsions or seizures due to oxygen are not harmful *per se*, if the diver can be prevented from injury while thrashing about or from drowning. An oxygen convulsion may occur without warning.

Prevention

Avoid deep diving, and do not use breathing gases with oxygen concentrations inappropriately high for the depth. Oxygen partial pressures high enough to cause symptoms are unlikely when diving on air within recommended recreational depth/time limits; most likely they will be encountered when breathing elevated oxygen mixtures or when using rebreathers.

A maximum oxygen partial pressure of 1.4 ATA has been recommended for open-circuit scuba using nitrogen-oxygen breathing gas mixtures. For scuba divers who adhere to the 1.4 ATA oxygen limit, an oxygen convulsion is unlikely.

Oxygen partial pressures as high as 1.6 ATA following the NOAA depth/time limits have been used by some, but it is usually recommended that these higher partial pressures be reserved for situations in which the diver is largely at rest, such as during decompression stops.

For extended diving exposures using rebreathers, the U.S. Navy has a 1.3 ATA limit oxygen partial pressure. Special training is required before diving nitrox or using rebreathers. This should include methods of minimizing the possibility of oxygen toxicity.

If symptoms occur, reduce the oxygen partial pressure immediately by ascending or switching to a breathing gas with a lower oxygen partial pressure. Do not assume that an oxygen convulsion will not occur until the diver has been on a reduced oxygen level for at least five minutes.

Treatment

Early symptoms should be treated by surfacing, if possible. Management of an underwater seizure is difficult, and the victim's life is clearly at risk. Like learning CPR, practicing the proper handling of an oxygen convulsion helps you maintain this vital skill.

Once the convulsion subsides, if the mouthpiece is secure (or if the diver is wearing a full face mask) and the diver is still in the water and breathing, then leave everything in place until you can get the diver out of the water. Once on the surface, if the diver is not breathing, remove the mouthpiece and begin rescue breathing, clearing the airway, as required.

While the injured diver is in the water, the main goal is to prevent drowning. After the seizure ends, ensure that the diver's airway is open. Once out of the water, be on the lookout for foreign bodies in the airway. During a convulsion, it is possible to bite off parts of the mouthpiece, which can find their way into the trachea. In these cases the diver will begin coughing upon returning to consciousness, or the diver may try to breathe but not get any air into the lungs. Here you need to institute the standard procedures taught in CPR classes to remove a foreign body.

Source: Dear GdeL, Pollock NW, (with Moon RE, Uguccioni DM, Myers J, Douglas E). DAN *Dive and Travel Medical Guide*, 4th ed. Divers Alert Network: Durham, NC, 2006; 90 pp.

For more information on oxygen toxicity — what it is, how it occurs, how to prevent it and what to do in case of oxtox — see www.DiversAlertNetwork.org/medical/articles/article.asp?articleid=35.

and within a few months he returned to diving. Our own dive operations resumed the next day.

caption

A good outcome

The outcome of this accident was positive, but it could have quickly become a fatality. Fortunately, we had a management plan and personnel in place to handle the situation and the support of the Coast Guard; as a result, we airlifted the injured diver expeditiously to an appropriate medical center.

After the incident, we revised our diving protocols. All divers now conduct a visual gas confirmation check of ascending and descending divers, and a dive partner or safety diver confirms all gas switches. In addition, camera tethers are now mandatory.

Good planning entails preventive measures

Technical diving operations require a support crew not only to run the diving operations but also to manage unexpected accidents. While oxygen toxicity cases rarely develop, this incident showed what can happen.

Since 2004 we have completed four research expeditions on the USS *Monitor*, conducting 146 dives. This totaled 169 hours of dive time without further incident. We plan to be back on the *Monitor* again in June.

About the Authors:

Capt. Kathy Weydig is president of Scuba Training and Technology Inc., a diving equipment and technology company in Arizona. She is co-founder and past president of the Women Divers Hall of Fame and is a member of the DAN Board of Directors.

Joel Silverstein is chief operating officer of Scuba Training and Technology Inc. and its subsidiary Tech Diving Limited, a technical diving equipment company. Since the early 1990s, he has been at the forefront of technical diving training and expeditions.

DAN Technical Diving Conference Receives Rave Reviews

Reactions to the 2008 Technical Diving Conference, which DAN® hosted Jan. 18-19, have been consistent and enthusiastic, praising the dynamic discussions and workshop contents.

More than 165 persons attended the two-day conference in Durham, N.C.; it consisted of four half-day workshops addressing physiology, decompression, rebreathers and training, with discussions targeting operational and medical aspects of technical diving. Participants came from across the United States and from the following countries: Finland, the United Kingdom, Canada, American Samoa, Australia, New Zealand and Grand Cayman.

Richard D. Vann, Ph.D., event organizer and vice president of DAN Research, said the conference objectives were to establish communications among technical divers, diving physicians and diving scientists, to provide objective information concerning what is known and unknown, and to establish the need for data collection and quantitative analysis to answer unresolved questions.

"Attendees were enthusiastic," Vann said. "They found the breadth of the information exciting, and they took advantage of opportunities to meet members of the technical diving community who they had not known."

Simon Mitchell, M.D., one of four workshop chairman and a fellow in anesthesia at the Auckland City Hospital in Auckland, New Zealand, said he had never experienced anything like it. "It is the first time technical divers have had the opportunity to interact with experts in the field of dive medicine and dive physiology," Mitchell said. "They have had many of their unanswerable questions answered by experts you trust."

captions

Dan Orr, DAN president and CEO, called the event a starting point. "Whether discussing deep stops, oxygen toxicity, thermal issues or other such topics, where do we go from here?" Orr said. "Given its position in the dive industry, DAN should be the focus and provide a forum to bring together parties for the exchange of information on technical issues."

For more details, visit the DAN website at www.DiversAlertNetwork.org. Online information will include audio, Powerpoint slides and videos regarding the conference. DAN will also publish proceedings of the conference.