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OXYGEN AND DIVING – ANOXIA AND HYPOXIA

In the last column we reviewed the basic physics and physiology of oxygen (O2) from a diver's perspective. In this column we are going to cover the problems divers can encounter when there is 'no' or 'not enough' O2 in the air that they are breathing. 'Anoxia' is the complete lack of O2 while in 'hypoxia' there is some O2 but not as much as the diver needs.

Anoxia / Hypoxia While Diving
When diving we are typically breathing air, and therefore oxygen, at increased pressure. Therefore, how can we suffer a 'lack' of oxygen?

In open circuit diving, hypoxia can only happen when we breathe from a tank that contains less than 21% oxygen. This can happen if the tank has some water inside and is left sit for weeks or months. The water causes oxidation and this process consumes the oxygen in the tank. In steel tanks this process produces rust. Rust flakes away from the underlying steel, exposing it to the water. The process continues until the O2 or the water is gone. Steel tanks left with water inside them for weeks/months can have ZERO O2 left in the gas. The tanks also become weak and can burst (explode).

In aluminum tanks this process produces aluminum oxide. Aluminum oxide coats the inside of the tank and prevents the underlying aluminum from oxidizing. As a result, water inside aluminum tanks is much less of a problem than in steel tanks. In spite of this, I prefer steel tanks to aluminum tanks because of a large number of other reasons, but you must keep the inside of steel tanks dry!

The two most common ways to get water inside a tank is to fill it from a malfunctioning compressor (a dive compressor has a water trap to remove most of the water from the air) or to breathe from it until it is completely empty. If the tank is empty and the diver descends even a short distance, water will be pulled into the tank through the regulator. If you ever breathe a tank completely empty, the inside needs to be inspected before the tank is filled. There are several other ways a diver can have anoxic or hypoxic gas in a tank. You can mistakenly fill the tank with the wrong gas (e.g. argon instead of air). You can intentionally fill a tank with argon (for suit inflation) and then breathe from it by mistake. You can intentionally fill a tank with hypoxic Trimix to reduce the risk of O2 toxicity for diving very deep. Some rebreathers use one tank of pure inert gas for diluent and another tank of pure O2. I know one diver who put two tanks of pure nitrogen into his rebreather. He passed out when he started to breathe from the set but was rescued and revived. I had previously identified this problem to the manufacturer but had been told it would never happen! The rebreather was redesigned ☺.

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When diving a rebreather there are several other ways the concentration of O2 in the breathing mixture can decline, including solenoid failure closed, O2 tank turned off, O2 tank empty, O2 tank containing something other than O2 (like air), electronic failure, rebreather not turned on, etc.

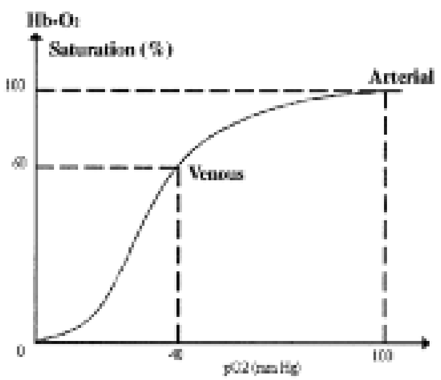
The seriousness of the hypoxia will be determined by the percentage O2 being breathed and the resulting pO2 as determined by the depth of the diver.

In general we have no signs or symptoms of hypoxia even at maximum exercise until the pO2 is less than 0.16 atmospheres (atm). At rest we are usually asymptomatic until the pO2 is less than 0.12 atm. Therefore, an open circuit diver should not breathe a mixture of less than 16% O2 on the surface. This is one of the reasons a travel gas is required on deep Trimix dives to get the diver from the surface to a depth where the Trimix has a pO2 of at least 0.16 atm.

Physiologically a special situation exists when the diver breathes a pure inert gas. Many tech divers use argon for suit inflation and some rebreathers use pure inert gas as the diluent. If a person breathes a pure inert gas the pO2 in the lungs becomes extremely low after a couple of breaths. The blood returning from the body to the lungs normally has a pO2 of around 40 mm Hg and contains almost 60% of the O2 it can carry. If the lungs contain almost no O2, the O2 in the blood moves into the lungs. When this blood is pumped out to the tissues it REMOVES O2 from the tissues. Therefore, when a person breathes a pure inert gas they lose consciousness after a few breaths and after a minute or so they become virtually impossible to revive (they die).

For this reason many people (including the author) believe that pure inert gases should NEVER be used in diving. Argon used for drysuit inflation provides only a trivial reduction in heat loss from the body (2 to 3%). Therefore, instead of using argon you should purchase better drysuit underwear and inflate your suit with air or nitrox. Helium is an excellent conductor of heat and Trimix/Heliox should NEVER be used to inflate your drysuit!

Acute Hypoxia
As we reduce the pO2 in inspired gas, the pO2 in the alveoli and therefore the arterial blood will fall. Hemoglobin (Hb) is very effective in scavenging O2 from the gas in the lungs, even when the pO2 is less than normal. The Hb/O2 dissociation curve shows that if the pO2 in blood falls 40% or 40 mm Hg (100 to 60 mm Hg), Hb saturation will fall



from 97% to 85% (12%). In this part of the curve a large fall in pO2 causes a small fall in Hb saturation. Therefore, a virtually normal amount of O2 will be delivered to the tissues even though the inspired pO2 is significantly less than normal.

If the pO2 in blood falls another 40% or 40 mm Hg (60 to 20 mm Hg), Hb saturation will fall from 85% to 25% (60%). In this part of the curve a small change in pO2 results in a large change in Hb saturation. This feature is critically important to the normal functioning of the body and results in large amounts of O2 being off loaded in the tissues. However, it also means that a falling pO2 will result in no symptoms initially and then a rapid loss of consciousness. The FIRST symptom of hypoxia is often loss of consciousness.

The brain is totally dependent on O2 to function. Most other tissues in the body have alternative biochemical pathways that do not involve O2 to generate small amounts of energy. These pathways are very inefficient, and generate waste products that ultimately limit the ability of the cells to function. However, they do allow the cells to function for a while when not enough O2 is available. The brain does not have this capability. In addition, it does not have the O2 stores that muscle contains (no myoglobin and very little CP). The end result is that brain cells stop working very quickly when inadequate O2 is being delivered. Most of the signs and symptoms of hypoxia are related to brain cells not working properly.

Signs and Symptoms of Hypoxia
Loss of consciousness is often the first sign of hypoxia, especially if the fall in pO2 is rapid. Other signs and symptoms include poor performance, lack of coordination, euphoria, over confidence, apathy, fatigue, headache, and blurred vision. Hyperventilation is usually NOT present if the pCO2 is normal. Defective memory and impaired judgment are common. These often cause the diver to respond inappropriately to an emergency, and to ignore other signs and symptoms of hypoxia. Therefore, loss of consciousness is very common in hypoxic divers.

A further problem is that many of the signs and symptoms of hypoxia are the same as those of narcosis and elevated pCO2. In addition, these three problems are additive. For example, if the pCO2 is slightly elevated (scrubber on a rebreather is starting to break through or the diver is working hard) and the pN2 a little high (diving a bit deep on air or Nitrox), the resulting mental impairment will be far worse than expected from either problem alone. If the pO2 is also a bit low, the diver will be in very serious trouble.

Conclusion
The bottom line is that if a diver is exposed to hypoxia, the most common outcome is loss of consciousness and death. For an open circuit diver, the most common cause of hypoxia is breathing from a tank that does not contain enough oxygen. Therefore, you must keep water out of your tanks and always know exactly what you are breathing.

If you dive a rebreather, you must be extremely vigilant to ensure you always have sufficient O2 in the breathing loop (check your pO2 every one to four minutes). I have been an expert witness in several legal cases where rebreather divers almost certainly died from hypoxia. Most commonly the electronics or the O2 bottle was turned off. The O2 in the breathing loop will keep you conscious for several minutes on the surface and if you dive the O2 added to the loop in the diluent and the increased pressure will keep you conscious for 10 to 20 minutes (longer the deeper you go), even with the set or the O2 bottle turned off. Always know your pO2! ■

DAVID SAWATZKY, S.C., C.D., B.Med.Sc., M.D., M.Sc., is a diving medical specialist who was on contract at Defence Research and Development Toronto from 1998 to 2005. Previously he was the Canadian Forces Staff Officer in Hyperbaric Medicine at DCIEM (1986-1993) and later the Senior Medical Officer at Garrison Support Unit Toronto (1993-1998). He's written a monthly column on diving medicine in Canada's *Diver* Magazine since 1993, has been on the Board of Advisors for the International Association of Nitrox and Technical Divers (IANTD) since 2000, and is an active cave, trimix and closed circuit rebreather diver/instructor/instructor trainer. David's first love is cave diving exploration and he's been exploring and surveying underwater passages in Canada since 1985. David was responsible for the exploration and mapping of almost 11 kilometres of underwater passages in the Ottawa River Cave System. In 1995, he executed the first successful rescue of a missing trained cave diver. David received the Canadian Star of Courage for this rescue which took place in the chilly Canadian waters of Tobermory, Ontario. He still dives as much as possible, but admits his six year old son Lukas, five year old daughter Emeline and wife (Dr Debbie Pestell) are currently higher priorities than diving!