Dr David Sawatzky

Any personal enquiries can be sent to sportdiving@motpub.com.au

CARBON DIOXIDE – A SILENT KILLER (PART 2)

In the last column I reviewed the physiology of CO_2 and explained why every diver on virtually every dive has some elevation of the partial pressure of CO_2 (pCO_2) in their bodies during the dive. I also explained how a tight weight belt, wetsuit, drysuit, buoyancy compensator, cummerbund, tank straps, etc. as well as depth and a poorly functioning regulator, can all increase the work of breathing and result in an elevated pCO_2. I also explained how stress/panic can result in elevated pCO_2.

Why are rebreather divers even more likely to suffer from CO_2 accumulation than OC divers? All of the factors mentioned so far apply if the diver is diving open circuit or if they are using a rebreather, however there are several additional ways in which pCO_2 can be elevated when diving a rebreather. When diving a rebreather some or all of the exhaled gas is inhaled on future breaths. In a well designed and fully functional rebreather, the CO_2 in the exhaled gas is removed and the oxygen (O_2) that was absorbed by the body replaced before the gas is re-inhaled. However, there are several ways this can go wrong.

The mouthpiece on the breathing loop contains dead space just like a normal scuba regulator. This dead space is usually comparable in volume to a scuba regulator. However, the mouthpiece on a rebreather also contains two one-way valves to force the exhaled gas to go around the loop to be 'reconditioned' before it is inhaled. If either of these valves is malfunctioning, some of the exhaled gas (containing CO_2) will be inhaled on the next breath.

The exhaled gas is passed through a container full of a chemical that absorbs CO_2. There are many ways in which this process can malfunction. The chemical can be defective and not absorb CO_2 as well as it should. Although it is possible for the chemical to be faulty from the factory, the diver is far more likely to be the cause of the problem.

If the chemical is left exposed to the air (it comes from the factory in sealed containers) it will absorb CO_2 from the air until it is saturated and thus not be able to absorb any more CO_2.

The chemical typically comes in granules of two sizes. Grade 8-12 has smaller granules than grade 4-8. Smaller granules result in more surface area and a greater ability to absorb CO_2. In many rebreathers if the scrubber is filled with 8-12 absorbent it should last for three hours, while if 4-8 absorbent is used diving should be limited to only two hours. Many divers dive longer than these recommended times in an attempt to save a few dollars by using less absorbent, and several have paid for their 'thriftiness' with their lives.

The absorbent has to be 'packed' correctly in the container. If it is not packed correctly, gas will pass through only one part of the absorbent, quickly saturating it and then CO_2 will pass through the container without being absorbed. If the container is not 'full' or if the absorbent has been partially used, removed, and then replaced in the container, the same process can occur.

If the diver is breathing very quickly (for whatever reason), their exhaled gas will pass through the absorbent very rapidly and (especially if the absorbent is partially used) the gas may not be in contact with the absorbent long enough for all of the CO_2 to be absorbed, resulting in some CO_2 getting through the container and being re-inhaled by the diver.

Temperature has an affect on the ability of the absorbent to take up CO_2 and in cold water the process is less efficient. Therefore, in cold water the absorbent should be changed more frequently.

The work of breathing on a rebreather is almost always greater than the work of breathing on a scuba regulator. If the breathing loop on a rebreather is partially obstructed due to water getting into the loop (a relatively common occurrence), the work of breathing can increase dramatically and as a result the pCO_2 in the body will rise rapidly.

Finally, divers who are diving a rebreather are often diving deeper than open circuit divers and hence have a higher work of breathing due to gas density (one of the primary reasons to use a rebreather is because they use dramatically less gas at depth compared to open circuit). In addition, divers using a rebreather are typically older and less fit than open circuit divers (rebreathers can be very expensive both to buy and to dive). At a given level of effort, an older and less fit person will generate more CO_2 than a younger and fitter person.

From the preceding discussion it should be clear that CO_2 accumulation is a real problem in open circuit divers and potentially a significant factor in the death of many rebreather divers.

What are the Signs and Symptoms of CO_2 Toxicity? On the surface, the first sign of rising pCO_2 in the blood is usually an increase in the rate and depth of breathing (this makes sense as pCO_2 is used to control respiration). However, oxygen (O_2) also influences respiration and when diving a rebreather the diver is typically breathing a gas with 6.5 times more O_2 than in air on the surface (rebreathers typically maintain a pO_2 of 1.3 ata). This dramatically elevated pO_2 partially counteracts the stimulus to breath caused by the elevated pCO_2 and the diver may NOT have a noticeable increase in ventilation.

When diving a rebreather, always be aware of potential CO_2 problems.

Carbon dioxide controls the circulation to the brain. As the pCO_2 increases, the blood flow to the brain increases. This often results in a headache. Open circuit divers who attempt to extend their dive time by consciously reducing the amount they breathe will usually suffer a post-dive, CO_2 induced headache. The headache is often throbbing and at the front of the head (muscle tension headaches are usually at the back of the head and constant).

Carbon dioxide depresses the central nervous system (like alcohol and nitrogen narcosis) and therefore the signs and symptoms can be similar. The diver can experience dizziness, nausea, confusion, disorientation, restlessness and loss of consciousness. These symptoms can lead to panic or a sense of impending doom.

Not too long after I started diving closed circuit rebreathers, I was on a diving expedition and I had pretty well used up the allotted time on the CO_2 absorbent in by rebreather. I was told the next dive would be short and shallow (max depth 20m) so I decided to do one more dive before I changed the absorbent. When I got to the wreck I followed the bottom down to the top of a cliff at 30m. I love cliffs so I swam over the edge and dropped down. When I reached a depth of approximately 50m, I realized something was seriously wrong. The level of narcosis I was experiencing should not have happened until I was MUCH deeper. I immediately identified the problem as elevated CO_2, ascended to 15m and finished an enjoyable dive swimming slowly around the wreck (fortunately, no post-dive headache).

The major problem with elevated pCO_2 in rebreathers is that the diver often does not notice ANYTHING unusual before they loose consciousness. In one experiment, divers were placed in a pool wearing rebreathers that did NOT contain any absorbent. They were asked to swim against a wall in shallow water until they noticed the first sign or symptom of elevated CO_2 and then stand up and go off the rebreather. Many of them continued swimming until they lost consciousness with no awareness that anything was wrong.

How Should A Diver Respond to Elevated CO_2? If you have another gas supply, switch to it immediately. If not, stop moving, relax, breathe slowly and deeply, and ascend. On a rebreather you can also add fresh gas to the breathing loop or switch to a semi-closed mode of operation. On all dives, it is important to be efficient and try to avoid excessive exercise. You should always ensure your gear fits and works well. On deep dives some elevation of CO_2 is inevitable so even more precautions are required. Only use regulators with a low work of breathing, and minimize narcosis as well as work of breathing by using helium to replace some or all of the nitrogen.

When diving a rebreather, always be aware of potential CO_2 problems. Maintain your gear religiously and don't try to save a few dollars by diving for too long before you change your CO_2 absorbent!

Carbon dioxide can be a silent killer in both open circuit and rebreather diving. Hopefully you now know enough to reduce the likelihood of encountering this problem, to recognize it immediately when it does occur, and know how to respond to it appropriately.

■

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!