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Medical issues in rebreather diving

Petar J Denoble, MD., D.Sc.
Vice President, Research
Divers Alert Network

Use of closed circuit breathing apparatus by recreational divers has become a driving force in advancing rebreather technology.[1] High technology combined with the casual settings of recreational diving may have some unwanted consequences.[2] While the complexity of the human-machine interface requires highly professional users, recreational divers are generally enthusiastic amateurs.[3] CCR enables exploration into extreme environments that normally require users of exceptional athletic abilities, while the typical recreational user tends to be middle aged with an average level of fitness. The complexity of the technology and the challenges of the environment require robust logistical support and organization, while recreational CCR diving is performed by individual divers or a loosely structured group of divers. The average age and fitness level of CCR divers and the extreme environments explored presents conditions for significant medical issues to arise from chronic medical conditions in CCR diving. We will cover today only some of the most common.

A rebreather is a type of breathing apparatus in which breathing gas circulates in a closed loop and it is colloquially called a closed circuit rebreather (CCR).[4] Carbon dioxide (CO_2) from the exhaled gas is removed by chemical absorption and consumed oxygen is replenished as needed from the oxygen cylinder. The compression of gas during descent is compensated by adding diluent gas which can be air, nitrox, heliox or trimix. In an electronic rebreather (eCCR), oxygen is continuously monitored via oxygen sensors by an on-board computer and the pre-set partial pressure is maintained automatically by adding needed gas through electronic solenoid valves. The advantages of CCR, and especially of eCCR are gas economy, oxygen enhanced decompression and silent operation. Major advancements in functionality and safety of use have been achieved through improved components and redundant systems like oxygen sensors, onboard computers and warning systems.[5] There are at least a dozen viable models and some 10,000 nonprofessional users worldwide.

CCR diving is associated with hazards, some related to the complexity of the machine and others to human exposure to extreme environments. Many problems originate from failures in human-machine interactions.[2] When eCCR fails to maintain breathable gas, the user may be affected by hypoxia, hyperoxia or carbon dioxide intoxication. Other possible injuries include chemical injuries, asphyxia and decompression sickness resulting from an emergency ascent to the surface.[6] Poor maintenance increases the likelihood of failures.[7]

With the increased use of CCR starting in last decade of twentieth century, there was a surge in the annual number of fatalities.[8, 9] The leading cause of accidents seems to be a breach of standard operating procedures either in the pre-dive, dive or post-dive stage. This results in injuries related to inadequate gas composition (hypoxia, hyperoxia or hypercarbia) more often than in any other type of diving.

The unconscious diver may die of asphyxia if he stays on the loop or drown if he drops the mouthpiece. Prevention of hypoxia includes the use of pre-dive checklists, controlled ascent, and prevention of drowning includes mouth-piece protection or full-face mask and buddy assistance.

Seizures due to oxygen toxicity may occur after a brief exposure to PO_2 greater than 1.3ATA.[10] Cold, exercise, increased CO_2 and some drugs may enhance the occurrence of seizures. Rescuing a diver with seizures is difficult but some successful rescues have been reported.[11] Proper maintenance and calibration of the oxygen sensor system are the best prevention. The use of a full-face mask or mouthpiece retainers may help prevent drowning.

Carbon dioxide may become a problem in connection with scrubbing failure, inadequate CCR design or relative overexertion. In cold environments, the capacity for CO_2 removal may be diminished. Even with optimal design and proper gas mixture, breathing capacity in extreme environments is limited due to the increased gas density and exertion may result with incapacitation due to the inability to washout metabolic CO_2.[8, 12]

Decompression sickness in CCR diving is rare, but if diver must ascend rapidly from a deep and long dive by completely omitting decompression Severe Decompression

Accident (SDA) may occur. In most cases, symptoms occur immediately and are very severe. The leading problem is cardiopulmonary arrest due to the massive presence of gas in the circulation.[13] If that is resolved by prompt medical intervention, the brain swelling and intracranial pressure must be handled next before recompression may be effective.[14] Prevention of SDA includes meticulous predive preparations and extensive support throughout the water column and at the surface.

The long training path, the free time needed and the significant cost associated with CCR diving all contribute to the typical CCR diver being middle aged or older, while CCR diving is conducted in environments that impose more stress on divers body than in typical open circuit recreational diving. Thus, chronic medical conditions may cause more problems in CCR diving.

The recent international conference Rebreather Forum 3.0 (RF3), after a thorough review of available data, current practice and problems came up with a set of recommendations for enhancements in technology but above all, it stressed the importance of fostering the "Culture of Safety" in order to minimize human errors and mitigate the risks of severe outcomes.[1]

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