LOSS OF CONSCIOUSNESS IN DIVERS

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Key words

Diving industry, equipment, occupational diving, physiology, recreational diving, unconsciousness.

Abstract

Loss of consciousness while a diver is in the water is potentially a pre-morbid condition as it can rapidly progress to drowning. There are many causes of loss of consciousness and in this brief review only the main ones are dealt with. In attempting to determine the cause, consideration should be given to the type of breathing equipment being used and the phase of the dive in which loss of consciousness occurred. In addition to the diving-related causes of loss of consciousness, it should be remembered that divers are vulnerable to trauma and the medical conditions to which the general population is susceptible.

Introduction

In this presentation, I am not going to discuss the management of an unconscious diver. I am going to assume that care has been taken to manage the diver's airway, breathing and circulation, a primary survey has been conducted and the emergency services have been contacted. Instead, I will focus on determining the cause of the loss of consciousness (LOC) and, in doing so, point out that it can be a demanding task.

If a history is available from a diving partner, dive supervisor or other witness, it is important to determine at what point in the dive the loss of consciousness occurred and whether or not there were any prodromal symptoms or signs.

Take note of what equipment the diver was using, what the purpose of the dive was and the surface and underwater conditions. Does the diver have any relevant past medical history? How experienced is the diver?

The more information that is obtained, the more likely it is that the cause will be determined. Although I will focus on diving-related causes of LOC, it should be remembered that divers are vulnerable to the medical conditions that cause LOC in the general population, in particular cerebrovascular accidents and myocardial infarction can and do happen when people take to the water.

In the following sections I will discuss the importance of the underwater breathing apparatus (UBA) being used, the phase of the dive and the environmental conditions that are relevant to LOC. After that I will briefly discuss each of the main diving-related causes of loss of consciousness.

Breathing apparatus used by the diver

There are advantages and disadvantages in the use of most types of breathing apparatus. For example, one of the earliest and longest used rigs, the surface-supplied, free-flow hard-hat has intrinsic flaws.[1] Adequate levels of air flow to early designs of helmet generated noise levels that impeded communication and, with repeated use, caused hearing loss in the diver. A level of air flow that resulted in acceptable noise levels was inadequate to control the level of CO_2 in the helmet and hypercapnia was a problem, particularly when the diver was working hard. To some extent, these problems have persisted with subsequent designs. Every set has potential problems that may result in LOC. Users of scuba sets rely on it being charged with clean air, divers with constant PO_2 re-breathers rely on the accuracy of their oxygen sensors and the integrity of their battery and CO_2 scrubber. Should any of these fail, LOC is a possible consequence. Table 1 shows various types of diving rig and their propensity for generating the conditions that can result in LOC.[2]

Phase of dive

Knowing when the diver lost consciousness provides a powerful clue as to the likely cause. For example, it is impossible for decompression illness (DCI) to cause LOC during the descent or bottom phases of a dive. Equally, nitrogen narcosis will not cause LOC early in the descent or late in the ascent phases of a dive. Table 2 lists the causes of LOC by phase of a dive. Since these are, in some cases, dependent on the equipment being used, I have annotated this accordingly.

Causes of loss of consciousness

HYPOXIA

Diving is normally a hyperoxic process and so scuba diving with air should not result in hypoxia unless the regulator fails completely or the diver runs out of air. Both situations can result in asphyxia although, in the latter situation, there is usually enough air in the cylinder to get the diver to the surface. If a closed circuit rig is used, hypoxia can occur if there is a failure of the oxygen sensors or the injector circuit. Most modern sets have a display to alert the diver to a low oxygen situation and a manual override can be used to restore the partial pressure of oxygen. Depending on the design of the rig, a battery flood may disable some of the safety features making hypoxia more likely. Although hypoxia on the bottom is possible, it becomes more likely during ascent when the partial pressure of oxygen in the counterlung is falling. In semi-closed sets, failure of the injectors may also cause hypoxia on the bottom. As with closed circuit sets, it is on ascent that hypoxia may become a problem, especially if the diver is working hard.

Military divers using a 100% oxygen closed-circuit rebreather may experience so-called "dilution" hypoxia. Unless the set is purged properly, the counterlung may gradually come to contain an excessive amount of nitrogen originating from the lungs and body tissues as the diver "off gases" into the set. As with other closed circuit sets, this problem is most likely to become manifest during ascent.

The scuba diver with regulator failure will experience both hypoxia and hypercapnia and the symptoms of the latter will predominate. The onset of pure hypoxia can be subtle and go unnoticed by the diver until he or she is in potentially serious trouble. The symptoms include: impaired judgement, disorientation in time and space, euphoria, excitement and headache. Dyspnoea, which is such a marked consequence of hypercapnia, is a late symptom in hypoxia and may not be noticed before the diver experiences loss of consciousness.

CNS OXYGEN TOXICITY

This is never a problem with normal air diving. It can become so when mixed gases or pure oxygen are used. With the increasing popularity of mixed gas diving among the sport diving community, oxygen toxicity is becoming a significant hazard. The likelihood of CNS oxygen toxicity increases with the partial pressure of oxygen breathed and the duration of exposure, usually a P_iO_2 of about 2 ATA or higher is needed.[3] There are considerable variations in sensitivity to oxygen toxicity between individuals and within an individual from day to day.[4,5] Furthermore, factors such as immersion in thermoneurtal, hot or cold water, exercise, and hypercapnia exacerbate the toxicity of oxygen on the brain.[6-9] Thus, while there are ways of predicting the effect of hyperbaric oxygen on the lung by using, for example, the unit of pulmonary toxic dose (UPTD), this is not possible for the effect of oxygen on the brain.

Even when very high partial pressures of oxygen are breathed there is a latent interval of a few minutes before the onset of CNS oxygen toxicity. Equally, oxygen toxicity may be expressed for a few minutes after the partial pressure of oxygen is reduced. This is the so-called "off effect".[8] The most dangerous aspect of CNS oxygen toxicity, from a diver's perspective, is that it can be expressed as a grand mal seizure without warning. Solo divers, and particularly those who are using a mouthpiece rather than a full face

TABLE 1

CAUSES OF LOSS OF CONSCIOUSNESS IN DIVERS USING VARIOUS DIVING SETS

UBA	Gas	Hypoxia	CNS O_2 Toxicity	Hypercapnia	Nitrogen Narcosis	Contaminated Gas	DCI
Demand scuba	(air)	0	0	+	+	+	+
	(N_2-O_2)*	0	+	+	+	+	+
Surface-supplied demand helmet	(air)	0	0	0	++	++	+
	(N_2-O_2)*	0	++	0	+	+	++
	(He-O_2)†	0	++	0	0	0	++
Free-flow helmet	(air)	+	0	+++	++	++	++
Closed scuba	(100% O_2)	+	+++	++	0	0	0
Semi-closed scuba	(N_2-O_2)*	++	++	++	+	0	+
	(He-O_2)†	++	++	++	0	0	++
Constant PO_2 scuba	(N_2-O_2)§	+++	+	++	++	0	++
	(He-O_2)§	+++	+	++	0	0	++

NOTES

*32.5% O_2 (to 40 msw) †16% O_2 (to 90 msw) § pO_2 0.7-1.4 ATA

0 = improbable + = possible ++ = probable +++ = very probable

Adapted from Flynn ET. Medical supervision of diving operations. In *Diving Medicine 3rd Ed.* Bove AA Ed. Philadelphia: WB Saunders, 1997; 323.

mask, run a high risk of losing their gas supply irretrievably either during or following the clonic phase of the seizure. Fortunately, there may be warning signs of impending CNS oxygen toxicity as shown in Table 3.[10] Mixed gas divers who experience any of the listed symptoms while at depth should take action to reduce their P_iO_2 by switching breathing mix or reducing their depth.

HYPERCAPNIA

Hypercapnia is not only potentially hazardous itself, it also potentiates the effects of nitrogen narcosis and oxygen toxicity. In the diving environment, a certain degree of hypercapnia is common and may arise because of the qualities of the UBA being used (increased breathing

TABLE 2

CAUSES OF LOSS OF CONSCIOUSNESS IN DIVERS BY PHASE OF THE DIVE

	PRE-DIVE	DESCENT	BOTTOM	ASCENT	POST-DIVE
Hypoxia	May occur using semi-closed set with hypoxic mix	Unlikely	Possible using closed set or ‘out of air’	Most likely time using closed or semi-closed set	Should not happen de novo
CNS oxygen toxicity	Impossible	Possible	Possible	Unlikely but may occur *	Unlikely but may occur*
Hypercapnia	Should not happen de novo	Possible scrubber failure using closed or semi-closed set	Most likely time Faulty scuba regulator Using hard hat Scrubber failure using closed or semi-closed set	Unlikely PCO_2 will fall during ascent	Should not happen de novo
Carbon monoxide	Should not happen de novo	Unlikely	Possible	Most likely time	Unlikely
Nitrogen narcosis	Impossible	Possible air and nitrox mixes only	Most likely time air and nitrox mixes only	Unlikely	Impossible
DCI	Impossible	Impossible	Impossible	Possible using any UBA	Most likely time
Near drowning	Impossible	Possible	Possible	Possible	Possible delayed onset of symptoms/signs
Trauma	Possible	Possible	Possible	Possible	Possible
Hypothermia	Should not happen in temperate or warmer climates	Unlikely	Possible	Possible	Should not happen in temperate or warmer climates

NOTES
* = “off phenomenon”

resistance and/or dead space), the effect of depth (increased breathing gas density), the diver himself (skip breathing and/or the suppression of ventilatory drive by a high P_iO_2) or, in those using rebreathers, failure of the CO_2 scrubber.

Inadequate ventilation of hard hats was a common cause of hypercapnia in older designs. Hard work greatly increases the risk of hypercapnia.

As with oxygen toxicity, there is great inter-individual variability in susceptibility to CO_2.[11] In most people, the onset of CO_2 toxicity is heralded by dyspnoea, anxiety and headache. This may progress to include disorientation, mental impairment loss of consciousness and convulsions. In those who are tolerant of hypercapnia, the first sign may be loss of consciousness or a grand mal seizure.

CONTAMINATED GAS

A poorly maintained compressor, or one that is sited with its intake down wind of its own exhaust or another source of pollution is a potential cause of divers breathing contaminated gas underwater. This may occur in those who charge their cylinders from the contaminated source or who receive a surface supply from it. Another potential source of pollution is solvents used to clean diving apparatus if this is done improperly. Although these sources can introduce a number of different hydrocarbons into a diver's breathing gas, it is carbon monoxide that is the most important contaminant. This is a problem with compressed air rather than mixed gas diving. Commercial mixed gases are usually made up from pure sources.

Carbon monoxide is a metabolic poison competing with oxygen for binding sites on haemoglobin and other haem-containing proteins for which it has a far higher affinity. During descent, the partial pressures of both CO and O_2 increase and, even in the presence of quite severe contamination, the diver may be unaware of this because, with increasing depth, more oxygen can be carried in plasma. Thus it is during decompression, as the partial pressure of oxygen falls, that symptoms most commonly become manifest. The symptoms include nausea, headache, visual disturbance, weakness, disorientation, convulsions and, eventually, loss of consciousness. Measurement of the carboxyhaemoglobin level will confirm the diagnosis, but the recorded level is a poor index of the severity of poisoning.[12]

TABLE 3

SYMPTOMS AND SIGNS OF CNS OXYGEN TOXICITY

Facial pallor
Sweating
Bradycardia
Choking sensation
Sleepiness
Depression
Euphoria
Apprehension
Changes of behaviour
- Fidgeting
- Disinterest
- Clumsiness

Visual symptoms
- Loss of acuity
- Dazzle
- Lateral movement
- Decrease of intensity
- Constricted visual field

Acoustic symptoms
- Music
- Bell ringing
- Knocking

Unpleasant olfactory sensations
Unpleasant gustatory sensations
Respiratory changes
- Panting
- Grunting
- Hiccoughs
- Inspiratory predominance
- Diaphragmatic spasms

Severe nausea
Spasmodic vomiting
Vertigo
Fibrillation of lips
Twitching of lips
Twitching of the cheek and nose
Palpitations
Epigastric tensions
Syncope
Convulsions

From: Clark JM. Oxygen toxicity. In *The Physiology and Medicine of Diving. 4th Edition*. Bennett PB and Elliott DH. Eds. London: WB Saunders Co., 1993; 135.

NITROGEN NARCOSIS

Nitrogen narcosis becomes noticeable in most divers breathing air at a depth of about 30 m. The effect is very similar to intoxication with alcohol, with a similar impact on performance. The decree of intoxication is progressive with depth such that below 70 m it is severely incapacitating. As with alcohol, the effect can be ameliorated with regular exposure and some people appear to be more tolerant of the effect than others. A rapid descent generates a greater narcotic effect than a slow one and the effect is rapidly reversed by surfacing. There is no hangover. Nitrogen narcosis does not normally result directly in loss of consciousness. It is more likely to occur because the narcosed diver does something that they normally would not. This includes loss of buoyancy control followed by an uncontrolled ascent and failure to keep track of time or tank contents so that they run out of air. Loss of consciousness may follow as a result of near drowning or DCI that had its origins in narcosis.

DECOMPRESSION ILLNESS

Loss of consciousness can arise from classical arterial gas embolism, cerebral decompression sickness or from severe cardiopulmonary involvement. The latter is very rare and results in LOC late and, if untreated, as a pre-terminal event. More commonly, loss of consciousness is an early sign of DCI. The natural history is for spontaneous recovery rather than progression.[13]

TRAUMA

Head injury is a hazard for divers who surface rapidly under a boat or pontoon. The other main traumatic cause of LOC is a laceration or puncture wound with sufficient bleeding to cause shock. Although such injuries can be caused by large fish, this is rare and it is worth remembering that man is the most dangerous animal in the water and on it. Unshrouded propellers can cause extensive injury.

HYPOTHERMIA

I spoke at some length on hypothermia at the 1997 SPUMS meeting in the Bay of Islands.[14] By definition, a diver has to be severely hypothermic to lose consciousness which means a core temperature of 27°C or below. Moderate hypothermia (core temperature 31-28°C) can result in a semi-conscious state and cause the victim to drown.

NEAR-DROWNING

I will not discuss near drowning in any detail because it will be covered later in the meeting.

I will just observe that in addition to being a potent cause of LOC in its own right, it can also be the outcome of any of problems discussed above that cause loss of consciousness.

The undersea environment is hostile to man and potentially lethal to one who is unconscious. While the cause of death in many divers who are retrieved from the water is deemed to have been drowning, there is often a reason why this happened.

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