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## DEEP WATER BLACKOUT

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### Key Words

Accidents, carbon dioxide, deep diving, nitrogen narcosis, oxygen, unconsciousness.

This review is the first of several to assess some of the physiological hazards and associated risks of what has been termed "advanced recreational diving." This includes nitrox diving, extreme air diving, technical diving and the use of rebreathers. It is instructive to look first at the interactions of carbon dioxide and hyperbaric oxygen in "shallow water blackout" as an introduction to the potentially more complex synergisms that may occur in the presence of nitrogen narcosis, as in "deep water blackout". Shallow water blackout remains a hazard for those, such as movie cameramen, who use closed-circuit oxygen breathing apparatus. Deep water blackout, as described, is however associated not with oxy-nitrogen rebreathers, but with the use of open-circuit compressed air breathing apparatus.

Loss of consciousness underwater is a serious event, particularly for a diver wearing a half-mask and using a mouthpiece, because the most likely outcome is drowning. Of the many causes of impaired consciousness at depth, the concept of deep water blackout is distinct from the more obvious possibilities such as carbon monoxide poisoning and myocardial infarction. Deep water blackout is part of an ill-defined and fortunately rare group of incidents which are best titled "loss of consciousness of unknown aetiology" and this phenomenon appears to be a hazard for only those compressed air divers who swim deeper than the limits recommended by most recreational training agencies.

In essence, the circumstantial evidence is that under certain conditions the swimming diver on open-circuit compressed air can lapse into unconsciousness at depths below 50 m (165 ft) without a primary cause being obvious. The importance of these considerations relates to the risks that are undertaken by the so-called "Extreme Air" divers. "How deep do you dive?" is a siren call to the novice. In 1990 Gillam achieved the depth of 452 feet

(133 m) with compressed air scuba (attaining, as he did so, a PO<sub>2</sub> of 2.9 bar) and, since then, Marion has reached 513 feet (156 m). A number of those wishing to take an even deeper place in a book of diving records have died at depth, maybe deeper than the holders, maybe not. Perhaps these records and deaths are merely a reflection of wide biological variation but the well-informed deep diver needs to be aware that there are a number of relatively unquantifiable risks and also needs to know that, to get a world record recognised, the diver must make it back to the surface.

Within this general category of underwater loss of consciousness falls another longstanding concept, that of the shallow water blackout. Historically the term is firmly associated with the use of closed circuit breathing apparatus using 100% oxygen. It is important to put aside the subsequent adoption of this term for hypoxic incidents associated with prolonged breath-hold diving. Shallow water blackout was first investigated more than 50 years ago and was well described by Donald.<sup>1</sup>

### Shallow water blackout

A number of unexplained cases of impairment or loss of consciousness were reported some 55 years ago<sup>1,2</sup> among those swimming with pure oxygen rebreathers at depths less than 25 feet (7.5 m, 1.8 bar PO<sub>2</sub>). There were no convulsions or other signs or symptoms of oxygen toxicity and recovery was rapid, once out of the water. Confusion and disorientation were common, headache, nausea and respiratory distress less so. Barlow and McIntosh<sup>3</sup> were able to exclude as causes of this the effects of pulmonary overpressure while immersed and also "dilution hypoxia". Dilution hypoxia, a problem unique to rebreathers, is a situation which occurs when the available oxygen in the counter lung is consumed leaving the diver to breathe only some of the nitrogen which has been excreted from the tissues into the counter lung. This hazard of hypoxia is "silent" because of the absence of any CO<sub>2</sub> build-up, as would usually be associated with hypoxia, because the CO<sub>2</sub> is constantly removed by the scrubber in the circuit. The risk of fatal hypoxia in these circumstances is minimised by a meticulous two minute "nitrogen wash-out" procedure of breathing oxygen and then emptying the breathing bag before descent.

The effects of high concentrations of carbon dioxide in the absence of oxygen lack were examined<sup>3</sup> and showed impairment or loss of consciousness when exercising hard on pure oxygen breathed through 800 ml external dead space. As a result of these and other studies, the CO<sub>2</sub> scrubber was improved and the number of incidents diminished. Nevertheless unexpected impairment or loss of consciousness was still encountered and, besides the specific circumstances of hyperoxia and hypercarbia, Donald looked towards a synergism between oxygen poisoning, CO<sub>2</sub>

intoxication and hypoxia due to procedural errors, as being among other causes.<sup>1</sup>

### Carbon dioxide retainers

Some divers might be more susceptible to underwater incidents of impaired consciousness because they do not hyperventilate in response to CO<sub>2</sub>. The existence of a proportion of "CO<sub>2</sub> retainers" among a population of regular naval divers was proposed by Lanphier.<sup>4</sup> Such persons appear to have acquired CO<sub>2</sub> hyporeactivity and, once acquired, it is not temporary but appears to persist. This aspect of underwater respiratory physiology has been reviewed recently by Lanphier and Camporesi.<sup>5</sup>

### Nitrogen

Although the intoxicating effects of breathing compressed air at depth had been noted for some years it was not until 100 years later that this effect was attributed to the specific narcotic action of a raised partial pressure of nitrogen.<sup>6</sup> The manifestations of nitrogen narcosis are proportionate to the partial pressure of the inspired nitrogen and, subject to individual variability, begin to be noticed during descent from around 30 m (4 bar). Nevertheless, mental impairment due to nitrogen certainly occurs at less than 3 bar and effects have been reported at 2 bar.<sup>8</sup> Narcosis increases to the extent that early reports described a "semi-loss of consciousness" on air at depths as great as 350 ft (105 m, 11.6 bar). The signs and symptoms are similar to those of alcoholic intoxication and there may be an impairment of a diver's ability to recognise and cope with a diving emergency when it occurs. Down to some 50 m (6 bar) the individual may find only that concentration is difficult and that there may be a slightly impaired degree of neuromuscular co-ordination. Before codes of safe diving practice advised against compressed-air diving deeper than some 50 m, experience demonstrated that only very few divers could accomplish useful work at depths greater than 90 m (10 bar). Although compressed air has been breathed at depths as great as 600 ft (180 m, 19 bar) in submarine escape procedures, the duration of this exposure was deliberately kept short and thus was within the latent period of onset of narcosis. One of the deepest recorded experience is that of Goodman<sup>8</sup> who describes the glassy appearance of the diver's eyes at 462 ft (144 m; 15 bar) as suggesting those of the "firmly plastered drinker" and adds that after some 45 seconds the simple task of assembling pegs had deteriorated to mere fumbling. "Bending forward ever more closely over his 'precious' pegboard, with intermittent bursts of inappropriate laughter and hearty, self-satisfied chuckling, the subject has, after 90 seconds of air breathing, effectively retreated into a private world."

The mechanism of narcosis is the same as that of the gaseous anaesthetics and that of alcohol intoxication. The individual passes through similar stages in each, from excitation to sleep. The biophysical basis for narcosis is well reviewed elsewhere.<sup>9</sup> Of interest in the practical situation is the interaction and possible potentiation at depth of narcosis by the effects of the individual respiratory gases, oxygen and carbon dioxide.

### Oxygen

The pulmonary and neurological features of oxygen toxicity are reasonably well known but the behaviour of oxygen as an "inert" (i.e. narcotic) gas has received less attention. The greater the depth of the oxygen exposure the greater its relevance.

In 1970 a 15-minute oxy-helium bounce dive in a bell with an air atmosphere to 400 feet (120 m) was done by 2 divers. On completion, they were hoisted in the bell for in-water stops until they reached 180 feet (55 m) where the stop duration was long enough to shut the bottom door. At this stop there was a switch on BIBS (built in breathing system) from 10/90 oxy-helium to 20/80 prior to transfer-under-pressure to the deck chamber. A medical officer was watching the video monitor of the bell interior during the transfer and within a few minutes of the gas switch was alerted by a "squark" noise from one diver. First one and then the other was seen to lapse, over a period of several seconds, into unconsciousness. There was no fit, they each just slowly slid down the side of the bell to the floor. This was not a foreseen emergency and, even when locked on to the deck chamber, they were still inaccessible. It seemed a long time before the first began to recover. In fact it was the one who had been seen talking and taking his BIBS out of his mouth to do so. It was two and a half hours before the second began to recover by which time a decompression schedule had begun from an initial emergency recompression.

It was later found that at 55 m they had, in error, switched from 10/90 to pure oxygen.

At that depth the PO<sub>2</sub> was 6.5 bar. The civilian consultant to the Royal Navy, Professor Bill Paton, said later "Didn't you realise that oxygen could be an anaesthetic?" and quoted an earlier paper of his to support this.<sup>10</sup> Certainly it was oxygen and certainly no obvious fit was seen. They both were deeply unconscious for a long time and, as also reported by Donald,<sup>1</sup> oxygen neurotoxicity is not confined to epileptiform fits.

Oxygen, not surprisingly, also potentiates narcosis. Fenn<sup>11</sup> suggested that this was a direct action, rather than one associated with the known potentiation associated with carbon dioxide retention.

## Carbon dioxide

It was proposed that nitrogen narcosis is enhanced by carbon dioxide retention by Case and Haldane.<sup>12</sup> This was demonstrated by Hesser et al.<sup>13</sup> who, while holding both  $PN_2$  and  $PO_2$  constant, had subjects inhale various  $CO_2$  mixtures to increase alveolar  $PCO_2$ . The interaction caused tracking task errors to be significantly increased.

However carbon dioxide retention is not the cause of depth narcosis<sup>14</sup> and, indeed, the symptoms of depth narcosis and of carbon dioxide at depth are quite different.<sup>15</sup>

## Deep water blackout

After recognising the potential effects of  $CO_2$ , oxygen and nitrogen at raised pressure, the concept of deep water blackout began to take shape. It was based on a few well-observed cases. These may be relatively anecdotal, but where else to begin?

The current depth limit for working divers on air for most countries is around 50 m (165 ft) and this is a sensible limit. However, in the days when the Navy limit was set at 180 feet (55 m), some deeper interventions were allowed for selected tasks such as aircraft salvage.

A ditched helicopter which sinks must be retrieved rapidly before corrosion sets in if the cause of the accident is to be found and possible additional aircraft losses are to be prevented. On call for this purpose the Royal Navy had a special team that would dive to around 250 ft (76 m) on the Deep Air Oxygen Table 13 when needed. Typically this would be for a 16-minuted bottom time at 250 ft (76 m) which requires 35 minutes of decompression with in-water oxygen stops from 60 ft (18 m). This might appear to be reckless diving but not so. The essential difference between military diving and "extreme recreational diving" lies in the assessment of hazards and in maintaining control of the risks. Some sport divers will go solo to deeper than 90 m (300 ft) on a single scuba tank of compressed air, carrying no spare regulator or tank.

In contrast, many navy divers did the deep air dive, but only as a member of a team. The team, as many as 8 in all, would support *only one diver* in the water at any time. The dive would be on a *surface supplied hose* leading via a demand valve to a *full face mask*. At the surface control gas panel the diver's supply would be switched to oxygen when he reached 18 m (60 ft) but, as he was at the end of a 300 ft (90 m) hose, to breathe down the volume of air would take him approximately until he reached his 30 ft (9 m) stop. A challenge for a decompression mathematician, but a diving procedure that proved to be safe operationally for a well equipped team.

Because of the need for the "Helicopter Team" to keep in practice between their fortunately rare emergency call-outs, they used to come to the Deep Trials Unit periodically for a deep air diving experience in the controlled environment of the wet pot of a large chamber complex. It was here that one could watch on television screens how well divers performed on air at deep depths. The wet pot was about 2 metres deep and pressurised to 8.4 bar. It was fitted with a "trapeze" against which the diver had to push very hard while swimming to keep a particular mark in place on the wall in front of him. On several occasions individuals were obviously narcotic, attempting to disassemble their equipment or responding to commands in an aimless manner. On surfacing, "That was a good dive", they had no memory of this and when shown the video of their errors, they would assert that "It must be somebody else". Thus the team became well informed of the hazards of deep air.

More worrying were the occasional lapses of several divers into unconsciousness. The divers were, of course, wearing a full face mask, so there was never any risk of drowning, and the unconsciousness was over in less than a minute but, for anyone using a half-mask and a mouth-piece, that would have been long enough to get into serious trouble. My certain recollection is that it was those who exercised hardest who got into trouble. The possible factors for deep water blackout appear to be:-

*carbon dioxide*: associated with a short burst of motivated hard exercise. Some members of the group might also have been in the category of  $CO_2$  retainers

*oxygen* : greater than  $PO_2$  1.6 bar;

*nitrogen* : at these depths narcotic at rest and potentiated by carbon dioxide.

It remains a phenomenon that may deserve a full investigation but, regardless of any scientific study, it will always be there waiting to catch just some of the uninformed.

Those who have attempted to break the depth record for compressed air scuba have probably not been fully informed. They have done so in ignorance of the risks and some have paid the ultimate price. Among the survivors of deep air diving one can expect an attitude, common towards doctors in early experimental deep diving, "We don't want you telling us not to do it. Just let us get on with it. Then you can tell us later how we did it." The answer is that they were fortunate, unlike those who have not yet resurfaced.

## Conclusions

Using one definition of "Technical Diving", which is that at some point in a technical dive there is a change of breathing mixture, deep air diving is **not** technical diving. Extreme scuba diving on air is just stupid.

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**ARTICLES OF INTEREST REPRINTED FROM OTHER JOURNALS****BUOYANCY****Key words**

Buoyancy, training, reprints.

Buoyancy control is one of the most important skills to master if your diving is to be safe, let alone comfortable or good for the environment. You may have been diving for quite a long time but are you diving at your correct buoyancy?

First you should plan your buoyancy and the extent to which you can change your buoyancy according to the type of dive. If you need to work on the bottom, carry out photography, dive with trainees or carry out decompression stops you may need to be able to adjust your buoyancy so

that you are a kilogram or two negative near the surface at the end of the dive as well as at any other time. But if you are carrying out a very standard "look and see" dive with no decompression then you need to be close to neutral buoyancy throughout the dive.

If you are negative you run the risks of

- 1 Uncontrolled descent into unintended depths
- 2 Stirring up the sea bed, which is bad for marine life and for visibility.
- 3 A reduced margin of safety if you need to ascend relatively rapidly, if you need to help another diver surface, or if you meet descending currents.

How do you achieve neutral buoyancy ? The very first piece of training comes in the pool when you demonstrate neutral buoyancy. Both instructors and