oxygen breathing equipment with regulator (*or preferably, full face-mask with demand regulator*) attached to hose and line with seat at 9 m (30 ft).

11 Upon reaching 9 m (30 ft) victim switches to oxygen breathing.

12 Victim breathes oxygen at 9 m (30 ft) for a minimum of 1 hour.

13. If victim had initial symptoms of pain only, and if signs and symptoms are relieved after 1 hour of breathing oxygen, start slow ascent. If victim had signs and symptoms of CNS disease, keep victim at 9 m (30 ft) on oxygen for one or two additional 30 minute periods. When victim is completely relieved (*or emergency transport arrives or oxygen supply is exhausted*), start slow ascent to surface while breathing oxygen (*or air if oxygen supply is exhausted*)

14 If the in-water recompression is not effective and the supply of oxygen is apparently inadequate, emergency transport to the on-shore recompression chamber should be arranged. Technical divers are strongly encouraged to begin making arrangements for emergency transport to a recompression facility as soon as DCI symptoms become evident. Recompression on oxygen at 9 m (30 ft) should be continued until the oxygen supply is exhausted or transport arrives.

15 Even if victim is asymptomatic when reaching surface, have victim breathe oxygen in the boat until the supply is exhausted. Consult with diving medical officer upon return to shore.

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TECHNICAL DIVING

Carl Edmonds

Key Words

Accidents, deep diving, mixed gas, rebreathing, safety, technical diving.

Introduction

There is considerable doubt as to whether this information should be included in a text dealing with safety aspects of scuba diving. The authors sincerely wish that no normal recreational scuba diver would get involved with this extension of “the diving envelope”.

The proponents of technical diving would have you believe that there is very little risk, either as regards death or injury in normal recreation scuba diving (breathing compressed air to a maximum depth of 30-40 m). This is not true, but it can be supported by selective use (or misuse) of statistics.

The reader should know that most of the diving accidents and deaths that occur in recreational scuba diving are not due to decompression sickness. Indeed the major causes include the hazards of the ocean environment, the stress responses on the individual, equipment failure or misuse and some diving practices which are especially hazardous, such as exhaustion of the air supply, buoyancy problems and failure to follow buddy diving practices.

Nevertheless, by concentrating mainly on decompression sickness, it can be made to appear that the accident rate is small for recreational scuba divers. And so it is, if restricted to that particular illness. When divers purport to reduce the incidence of decompression sickness by various techniques, while at the same time increasing the hazards from the more common diving problems, one has to question the motivation.

In Australia, a number of experts in “technical diving” have succumbed to the problems inherent in this activity. Their deaths, usually soon after a marketing campaign to promote this activity, have probably served to protect many younger and less experienced divers.

Definition

I use technical diving to cover diving in excess of the usual range for recreational scuba divers, no-decompression, open circuit, air breathing scuba diving to 40 m. Technical diving may involve an extension of duration at any depth, the depth itself (in excess of 30-40 m), changing the gas mixtures to be used, or using different types of diving equipment. All these fall into the realm of technical diving.

Decompression and deep diving using only compressed air have added risks. Technical diving developed in an effort to avoid some of these risks.

It is important, when discussing technical diving, to specify which type, as the risk varies from little or no additional risk (compared with recreational diving) to an extremely high one, such as with re-breathing equipment. The risks increase as the gas mixture deviates from normal air and with increased complexity of the equipment.

Diving on 32% oxygen, 68% nitrogen instead of air to a maximum of 40 metres on a no-decompression conventional air profile, could possibly incur slightly less risk than a recreational scuba air dive.

The technical diver

The technical diver is, or should be, a very experienced scuba diver, having logged at least 500 dives before entering this new field. It is usually a male, oriented towards technical toys. He often has a high intelligence but an even larger ego, frequently is obsessional in his attention to detail (which may increase his chances of survival), often studious and attracted to risk taking behaviour with a reduced safety margin, even if it risks death.

He will apply considerable funds and time to his project. Often this has commercial implications, and he may well be involved in wreck salvage, equipment manufacture, marketing and sales, diver training, or other commercial ventures.

The diver attempts to select the theoretically ideal gas mixture for the ascent and descent (travel mixes), the bottom (bottom mix) and the decompression staging (usually oxygen).

Problems

Technical diving involves more complex equipment, for producing, supplying and delivering the various gases other than air. With an increase in the complexity of the equipment there is an associated increase in the likelihood of human error at all three stages.

Problems develop from:

Mixing and transport of gas;
Handling it at the dive site;
Analysing the gas and confirming that it is the one appropriate for the dive to be performed;
Selection of appropriate gases during the dive.
Different gases require different cylinders together with the various attachments; manifolds, O rings, contents gauges, high pressure hoses, and separate regulators.

The handling of mixtures with higher than normal oxygen percentages implies greater risk of fire and explosion.

When there are various gas mixtures being breathed, the safe profile of the dive may be very complex. Decompression regimes are often unproven and inadequate factual information is available regarding the physiological interactions of the gases.

There is considerable doubt regarding many of the physiological assumptions on which technical diving is performed. It is claimed that the equivalent air depth (EAD) can be used to determine the influence of the gas mixture on the diver, and this has been related to both nitrogen narcosis and decompression sickness (DCS). There is, in fact, no really good evidence that this EAD is appropriate to either.

There are also the physiological implications of breathing oxygen at varying partial pressures, as well as the often increased carbon dioxide retention with both high oxygen diving and deep diving. The use of gas mixtures is also likely to influence the transfer of inert gases in many ways, far more complex than can be sensibly deduced from a simplistic formula. Anyone who doubts this should peruse one of the more sophisticated texts on such topics as nitrogen narcosis and the counter diffusion of gases.

Financially there are increased initial capital outlays, operating and maintenance costs.

The main purpose of technical diving is to extend the environments into which diving is performed. This usually means an increase in the hazards associated with such environments. The exception is a reduction of the nitrogen narcosis of deep diving, by the use of helium. Most of the other problems with deep diving are aggravated. Not only can the depth or duration of the dive be extended, but so can the actual diving terrain. This is the reason why many wreck divers and cave divers have embraced this activity.

The result is that the mix-gas diver often wears a large amount of equipment, extremely complex and bewildering, especially when other environmental problems develop during the dive. The likelihood of equipment problems has been compounded greatly. Other related difficulties include buoyancy variations and sometimes the need for a full face mask, so that drowning is less likely and rescue becomes more possible.

Because of the different equipment and gases, and the extension of the environments, the techniques for accident management and rescue have to be altered to take into account the specific problems. With each variation from the conventional scuba system, there is a price to pay, and a modification of the first aid and treatment procedures.

Oxygen Pressure

There is little concern about oxygen toxicity with recreational compressed air diving in the no-decompression range. Neurological and respiratory oxygen toxicity are virtually impossible. Also, the amount of oxygen taken in is unlikely to significantly influence any recompression treatments that may be needed for decompression accidents. Neither statement can be applied to technical diving.

It had been assumed that oxygen, by virtue of its replacement of nitrogen, would to some degree reduce the severity of nitrogen narcosis and decompression sickness. Although this is possibly so in theory, the scant experimental evidence that there is available, would suggest that oxygen actually contributes to nitrogen narcosis and decompression sickness.

The handling of gas mixtures, where oxygen or other gases are added to air, can produce some hazards. Oxygen increases the risk of fire and explosion.

Inadequate mixing can result in oxygen pressures being higher or lower than intended. This has implications regarding the safe dive profile.

Higher oxygen levels are also likely to produce a "build up" in the carbon dioxide transport in the blood. This has further implications as regards oxygen toxicity, nitrogen narcosis and possibly decompression sickness.

Oxygen enriched air or nitrox (EANx)

Most of the technical diving now performed involves the use of nitrogen/oxygen mixtures in which the oxygen concentration is greater than that of compressed air. Under these conditions it is very important to specify exactly how much oxygen is being used. Such phrases as 40-60 or 60-40 are not only confusing but often misleading. In Europe 40-60 is more likely to imply 40% oxygen, whereas in the USA it is more likely to imply 40% nitrogen.

The actual percentages used in technical diving do vary with different countries and establishments but the National Oceanic and Atmospheric Administration (NOAA) in the USA have chosen 36% oxygen and 32% oxygen as their two major mixes. These should not be referred to as Nitrox 1 or Nitrox 2, as this could also be misleading.

Any EANx diving has a safe depth range less than air due to neurological oxygen toxicity.

The oxygen pressures that are considered acceptable vary with different authorities, and in many cases there is a confusion between the neurological oxygen toxicity (which can result in nausea, vomiting, seizures, etc.) and respiratory oxygen toxicity, which tends to only occur with prolonged diver exposure. Many of the pressures being quoted in the literature refer to the oxygen pressures observed with re-breathing equipment, when the carbon dioxide levels were not being measured which complicates considerably the actual cause of symptoms. Most of the work carried out during World War 2, and soon after, failed to measure the carbon dioxide levels and therefore their conclusions regarding safe oxygen limits, are open to question.

NOAA states that the maximum oxygen pressure acceptable is 1.6 ATA. The National Undersea Research Centre in North Carolina recommends 1.45 ATA. The Swedish authorities have recommended 1.4 ATA and Dr Richard Vann of the Divers Alert Network has suggested 1.2 ATA. The US Navy give a much greater range, and relate it to the duration of the exposures.

The claimed advantages of EANx diving include a probable reduction in decompression sickness incidence, and a possibility of reduced nitrogen narcosis.

On a theoretical basis, presuming nitrogen pressure as the sole cause of nitrogen narcosis, a 20% oxygen mixture (air) at 23 m could be replaced with a 36% oxygen at a depth of 30 m. to give an equivalent "narcotic effect". Experimental verification for belief in this theory has be sought, but it was unable to be verified (Linnarsson, Bennett).

Although oxygen is used as a treatment to replace nitrogen, when the latter has caused decompression sickness, it has also been contentiously incriminated as a cause in its own right (Donald, Wethersby) or as a contributor (Thalmann) to this disease!

A common claim is made that there is less post-dive fatigue with EANx than there is with air. This has not yet been verified.

Low risk nitrox diving

It is possible to use EANx to obtain possible advantages, with relatively few disadvantages, under certain conditions.

In this type of technical diving, the nitrox mixture, usually 32% or 36% oxygen, replaces air, but the same equipment is used and the same decompression profiles permitted, within the 15-40 metre range.

It has been claimed there is deterioration in the dive equipment by using high oxygen mixtures but this has not been supported.

It is likely, because of the higher oxygen levels inhaled, that there will be a concomitant degree of carbon dioxide retention, based on the common and competitive pathways for the transfer of these gases.

Higher risk nitrox diving

In this type of diving (EANx) the profile of the dive is altered to make allowance for the high oxygen, lower nitrogen levels, based on the EAD or similar calculations. Thus the diver is likely to increase the duration of his no-decompression dive, reduce the decompression stops required or increase the duration or depth of the dive for the same decompression time commitment. Whether this calculation is justifiable under all conditions, has yet to be demonstrated.

The probable only genuine advantage of this kind of diving occurs if “air” stops are followed during decompression, whilst using EANx .

There is a possibility of an increased risk of decompression sickness, due to the effects of oxygen contributing to this disorder, or because of the use of untested algorithms used in commercial nitrox decompression profiles.

The “bent” diver is also more likely to have had a high oxygen dose, contributing to respiratory damage during the recompression therapy, than his air breathing colleague.

There may well be an alteration in the type of decompression sickness sustained with this form of diving because of the increase duration that it frequently entails. The slower half-time tissues are more likely to be affected, and this should be considered during the subsequent recompression therapies, and also the possible increased susceptibility to dysbaric osteonecrosis. The only reason for proposing this is that the dives, being longer, will influence the “slower tissues”.

High risk. Helium and tri-mix diving

There are significant differences in the way the body handles helium to the way it handles nitrogen. Both are inert gases, but helium is much less dense and is also less soluble in some tissues than nitrogen. It does, however, have a much greater speed of diffusion and also conducts heat more rapidly.

The real advantage compared to nitrogen is that it does decrease the incidence of nitrogen narcosis. For dives in excess of 30-40 metres, the risks of nitrogen narcosis can be proportionately decreased as helium replaces nitrogen. It thus tends to be used for dives of greater depths. An additional factor is the reduction in breathing resistance due to its decreased density and other factors, also allowing dives to greater depths.

The effects on decompression sickness likelihood are more complicated. It is probably likely to produce less decompression requirement for the longer dives, but may well require more decompression for shorter dives. Many of the helium and Trimix decompression tables are less well validated than the air tables.

The main problem is that the divers are diving deeper with helium and Trimix than with compressed air and therefore are exposed to all the associated problems of depth (other than nitrogen narcosis and breathing resistance). Barotrauma and DCS risks are aggravated. The environmental difficulties associated with depth include poor visibility, buoyancy problems, excess gas consumption, stress factors and the increase risks and difficulties with first aid, rescue and resuscitation.

There is also a greater conductive heat loss from helium, even though there is some question regarding the respiratory heat loss. Heliox feels colder to breathe and in a helium environment the heat is lost more rapidly. Increased depth aggravates heat loss.

Voice distortion can produce communication problems. At greater depths the high pressure neurological syndrome (HPNS) also becomes relevant.

The difficulties with mixing gases, referred to above are also present with helium and are complicated by the different compressibility of helium, as well as the risk of ascending with low oxygen pressures, which are commonly used with deep helium diving.

Comparison with commercial deep diving is noteworthy. Experience has demonstrated the need for a surface supply of gas, full face masks, communication systems, a standby diver, a wet bell and a recompression chamber on site in order to reduce accidents to acceptable levels. The less trained amateurs appear to have no such requirements.

Very high risk. Rebreathers or circuit sets

Re-breathing equipment has been in use for more than a century, causing many deaths and cases of unconsciousness. Despite the recent electronic mechanisms, the essential problems of re-breathing equipment remain. It is very much a high risk strategy to employ for specific reasons, by professionals.

The value of re-breathing equipment is that it produces fewer bubbles and is therefore more silent. This is of use both in clandestine operations and for marine photography. It is more economical on gas, as the gas is recycled through the diving equipment, in a “circuit”. It can also be constructed with low magnetic materials, which are useful if one is working around magnetic mines.

The main disadvantage that is inherent in all types of rebreathers is the failure of the carbon dioxide absorbent system to work effectively under all diving conditions. This may occur for many, many reasons, but includes an inappropriate canister design. There has been little genuine improvement in canisters over the last 30 years and they were inadequate then. It is surprising how few

RISK ASSESSMENTS OF VARIOUS FORMS OF TECHNICAL DIVING

Low risk nitrox diving

Using Nitrox (EANx) to replace air.
Same equipment as for air
Same profile as an air dive.
Range 15-40 m

Advantages

- Less risk of decompression sickness (DCS)
- Probably less nitrogen narcosis
- Reputed less post dive fatigue

Disadvantages

- Gas mixing, handling and correct usage
- Shallower maximum depth due to oxygen toxicity
- Reputed deterioration of dive equipment (?)
- Possibly more CO_2 retention

Higher risk nitrox diving

Using Nitrox (EANx) to replace air
Same equipment as for air
Profile for Equivalent Air Depth (EAD)
Range 15-40 m

Advantages

- Increased duration of no-decompression dive
- Or less decompression time (shorter stops)
- Or greater duration/depth of dive for same decompression
- If air stops are followed more efficient decompression (less N_2 on board)

Disadvantages

- Gas mixing, handling and correct usage
- Maximum depth limited by oxygen toxicity
- Possible increased risk of DCS (0_2 effect, untested algorithm)
- Possible alteration of DCS and recompression therapy (slower tissues affected by longer dives)
- Possible increase in risk of Dysbaric osteonecrosis (slower tissues affected by longer dives)

High risk. Helium diving

Helium is
- Less dense than nitrogen
- Less soluble than nitrogen
- Diffuses faster than nitrogen
- Conducts heat better than nitrogen

Advantages

- Less narcosis allows greater depth
- Less breathing resistance allows greater depth
- Less decompression for longer dives

Disadvantages

- Gas mixing, handling and correct usage
- Deeper diving possible
- Multiple cylinders of different mixtures needed for deep dives
- Longer decompression for short dives
- Heat loss to the environment and probably through the respiratory tract.
- Voice distortion interferes with communications
- High pressure nervous syndrome (HPNS) at great depths

Very high risk. Rebreathers

Advantages

- Economical
- Silent
- Can be non-magnetic if required

Disadvantages

- CO_2 toxicity
- Dilution hypoxia
- Caustic cocktail
- Deeper, longer dives increase risk of DCS

Oxygen rebreathers (closed circuit)

- Depth limit 8-9 m

Mixed gas rebreathers

- Semi-closed circuits have problems with oxygen supply vs oxygen usage
- Closed circuits depend on sensors to monitor and control oxygen levels
- Oxygen monitors can fail

improvements the manufacturers have included in the carbon dioxide absorbent canisters in the sets now being promoted.

Also, the absorbent itself is not always reliable. It frequently varies in efficiency and this should be tested with each absorbent batch. This is not feasible for the individual diver. The handling and storing of absorbent may result in deterioration in efficiency, as will the degree and type of wetting that may occur.

When diving in sea water, hypertonic saline can enter the system, causing a great reduction in efficiency. The absorbent itself, when combined with carbon dioxide, produces water as a by-product, which can also influence the efficiency. Also when water gets into the re-breathing set, it may collect some of the alkali from the absorbent and then may enter the divers mouth and lungs which can be very unpleasant. This is called a “caustic cocktail”.

The carbon dioxide absorbent must be packed correctly into the canister. This is an skill and requires training. The density of packing influences the efficiency. Lower temperatures also reduce the efficiency of the absorbent.

Often absorbent canisters will work very well at a moderate work load, but when exertion is required, the absorbent canister will frequently fail - especially if it has been in use for a considerable time.

The manufacturers claims regarding the safe duration of carbon dioxide absorption in their diving equipment are optimistic, seemingly being based on gentle swimming, and do not apply to emergency situations where the diver is exerting himself maximally (such as when swimming against a current, or trying to rescue and tow a companion, even on the surface).

The other big disadvantage is that any re-breathing set can produce a dilution hypoxia. Even those that use 100% oxygen can occasionally cause this, usually by incorrect technique of “clearing the set” (and the lungs) of inert gas. It can also occur if there is a small amount of inert gas in the gas cylinder, and especially so when there is a considerable amount of nitrogen or helium, such as with nitrox, heliox or tri-mix diving. It may be induced by an incorrect mix, a leak from the set or obstruction to the inflow, or loss of cylinder pressure.

Sometimes hypoxia will only be occur during ascent. The reduced oxygen pressure is acceptable at depth, but translates to a dangerously low oxygen partial pressure nearer the surface.

Rebreathers require specialised diving protocols, when rescue and resuscitation are needed. It is not just a matter of removing a mouthpiece and replacing it with another. Companion diver drill needs to be tailored for each type of rebreather.

The problems of gas mixing and handling also relate to this equipment.

Oxygen rebreathers are closed circuit sets, used to a maximum depth of about 8-9 m, usually restricted to Naval warfare and have resulted in many cases of unconsciousness and death. Occasionally photographers will use this equipment, but would be unwise to do so, as the companion rescue drill is often required.

Some rebreather sets have a constant flow of nitrox, heliox or trimix gas. They are usually semi-closed circuit sets. With these the oxygen level in the breathing bag or inspiratory tube will vary according to three major factors. These are the volume and mixture of the incoming gas, the energy utilised in metabolism (oxygen uptake) and the gas released as bubbles with ascent. The result is that the inspiratory oxygen range can be a variable quantity which makes the equipment much less safe. The interaction between the input and output of oxygen will result in a variable oxygen percentage and ascent or descent will determine the oxygen pressure. These sets are especially likely to cause dilution hypoxia and hypoxia of ascent.

As hypoxia usually produces no warning before it causing unconsciousness, the use of constant flow rebreathing sets would be considered very unwise. Close attention to the cylinder pressure, ensuring an adequate inflow of gas, and flushing with fresh gas before ascent is essential

The more expensive closed circuit rebreathing sets use sensors to measure the oxygen pressures during the dive and a feed back system adds oxygen or a diluent gas (nitrogen, helium, mixtures), as required, to ensure that the oxygen partial pressure remains within a certain range. This equipment is extremely expensive, often not reliable and should only be used by those with excessive faith in technology.

Anyone who uses a rebreather without a full face mask, being aware of the much greater risk of unconsciousness and subsequent drowning, has got to be stupid and deserves everything they get.

Conclusion

Perhaps the most important thing about Technical Diving is to realise that the majority of the diving deaths that occur in recreational divers occur for reasons which will be aggravated by the use of more complex equipment, in more hazardous environments. Technical diving is therefore, by its very nature, likely to have greater risks than normal recreational diving, other factors being constant.

The margin for error in this type of diving is appreciably less, and therefore it should only be employed by divers with enormous experience, detailed training and meticulous attention to equipment and its use. The advocates of technical diving tend to lay great stress on aspects of safety which are relatively unimportant. They will stress the importance of decompression sickness, and the physiological advantages of oxygen, but will ignore the more frequent causes of diving deaths, such as exhaustion of gas supply, buoyancy problems, stress responses, etc. They will also tend to ignore the areas in which the "technical advances" have been meagre, e.g. the efficiency of carbon dioxide absorbents, in preference to high-tech oxygen sensors and theoretical decompression algorithms.

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This paper is an edited version of Chapter 43 of Diving Medicine for Scuba Divers. 2nd Edition. Melbourne; JL Publications, 1997. The other authors are Drs Bart McKenzie and Bob Thomas. We are indebted to the Publisher for permission to reprint. Diving Medicine for Scuba Divers is available from JL Publications PO Box 381, Carnegie, Victoria 3163, Australia, for $Aust 36.00 plus postage. Fax 03-9886-0200.