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THE PADI ENRICHED AIR DIVER COURSE AND DSAT OXYGEN EXPOSURE LIMITS

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Key Words

Mixed gas, nitrogen, oxygen, recreational diving, safety, training.

Introduction

In January 1996, PADI International released an Enriched Air Nitrox dive training program which is fully supported with educational materials for the student and instructor. This paper will review some of the philosophy, highlights, content and treatment of this topic found in the course. The purpose of the course is to familiarise divers with the procedures, safety protocols, hazards, risks, benefits and theory of no-decompression diving with oxygen enriched air containing 22% to 40% oxygen. The emphasis is on diving with EANx 32 and EANx 36 (also known as NOAA Nitrox I and II). Training emphasises the importance of proper procedures to ensure safety, and realistically balance the pros and cons of enriched air diving. Instructors are encouraged to elaborate beyond the material in the course outline to accommodate individual student interests and aspects of enriched air diving unique to the local environment.

The goals of this program are:

1 To enable a diver to plan and make no-decompression dives using enriched air blends containing 22 to 40% oxygen, remaining within accepted dive table and oxygen exposure limits.

2 To enable a diver to obtain, and care for, equipment used in enriched air diving.

3 To enable a diver to avoid the possible operational hazards and underwater hazards associated with oxygen.

There are two enriched air training dives required for certification. These may not exceed 30 metres (100 ft), or exceed a PO_2 of 1.4 bar, whichever is less.

An overview of enriched air

Enriched air is any nitrogen/oxygen gas mixture with more than 21% oxygen. Enriched air is sometimes called nitrox. However, the term nitrox includes nitrogen/oxygen mixes with less than 21% oxygen, which are used by commercial divers to reduce oxygen exposure when remaining under pressure for days at a time (saturation diving). These types of nitrox are made by mixing pure nitrogen and pure oxygen, rather than by adding oxygen to air. For clarity, the terms “enriched air” or “enriched air nitrox” are preferred by PADI.

Most of the special training one needs to dive safely with and handle enriched air relates to its higher oxygen content. The primary application of enriched air is to extend no-decompression limits beyond those of normal air. Based on US National Oceanic and Atmospheric Administration (NOAA) tests, Navy tests dating back more than 50 years, 20 years field experience by scientific divers and field experience in thousands of recreational dives, the no-decompression limits for enriched air are generally considered as reliable as those for normal air tables and computers. However, there is a trade off. As one reduces nitrogen exposure, one increases oxygen exposure. Therefore, much of what needs to be taught to students deals with keeping oxygen exposure within safe limits. Practically speaking, depending upon the dive depth and breathing rate, dives may be limited by enriched air supply rather than no-decompression limits. Therefore, in some cases, planned dive profiles and planned repetitive dives may not be able to take advantage of the additional time enriched air offers.

Decompression limits for EANx are calculated using the equivalent air depth (EAD) which is the shallower depth at which an air breathing diver would be exposed to the same partial pressure of nitrogen. The diver using EANx uses the time available at the EAD for calculating the time available at the deeper depth.

Because one absorbs less nitrogen using enriched air, one might expect that using enriched air within normal air no-decompression limits would substantially improve safety. This is probably *not* true. The decompression illness (DCI) incidence rate is already so low that it is unlikely that simply reducing nitrogen can produce a *meaningful* risk reduction. Although there has been no study of this, statistical estimates suggest that using enriched air within normal air limits only reduces mathematical risk a fraction of a percent. The DCI incident rate is estimated as 0.004% (one in 25,000 dives) to 0.001% (one in 100,000 dives); if one cuts that by half (which is very unlikely), the best one could do is reduce incidence by 0.002 percent or 1 case in 50,000 dives. Therefore, it is inaccurate to suggest that enriched air is "safer" than air in any meaningful way. Used properly, both are safe and have impressive safety records. Used improperly, enriched air has more potential risk due to oxygen toxicity. Safety stops, avoiding factors that predispose one to DCI (such as dehydration), avoiding sawtooth profiles and other safe diving practices probably reduce one's risk far more significantly than using enriched air within normal air limits. Admittedly, some divers feel any mathematical DCI incidence risk reduction, even though tiny, still makes it worth using enriched air for dives than can be expected to be made safely with normal air. This is a personal choice without any safety concerns, provided enriched air procedures are followed.

Although enriched air reduces nitrogen, many diving physiologists do not believe enriched air significantly reduces narcosis when making deeper dives.[1,2] This is because oxygen under pressure appears to have similar narcotic properties to nitrogen under pressure. Thus, while enriched air has less nitrogen, it has about the same potential for narcosis. Although some divers say they experience less narcosis with enriched air, it is wisest to assume enriched air will not reduce narcosis. Some divers claim they feel better after a dive with enriched air. There is little objective evidence for feeling less tired or better after diving with enriched air, but it has been cited frequently. This may simply be a psychological effect.

Compared with air diving, diving with enriched air offers longer no-decompression times, but it also has five disadvantages and potential hazards.

1 Potential for oxygen toxicity
Much of what is taught is the PADI EANx program deals with staying within oxygen time and depth limits. Exceeding safe oxygen limits can be extremely dangerous. This is the most serious of the potential hazards unique to enriched air diving.

2 Special equipment
Because of the higher oxygen content, enriched air diving requires a dedicated cylinder and may require other equipment exclusively for enriched air diving. It can also be very hazardous to fill an enriched air cylinder from a conventional air source. Special equipment also includes a properly calibrated oxygen analyser to verify cylinder content; enriched air equipment also requires special maintenance.

3 Availability
Enriched air is readily available in some areas, in others one will not find it at all.

4 Proper gas blending and handling
One must ensure that one is diving with the blend of enriched air one intends to use and that no one confuses one enriched air cylinder for another or for normal air. It can be very hazardous for someone to use enriched air accidentally, or the wrong blend accidentally.

5 More complex dive planning
Enriched air diving requires more planning steps, with more potential for error and less tolerance for error if one makes one. One must use care and double check the dive table and oxygen calculations to avoid both DCI and oxygen toxicity. Monitoring one's depth becomes critical.

Equipment for enriched air diving

The primary concern regarding enriched air and dive equipment is the high oxygen content. Pure oxygen and high oxygen mixes cause materials to burn or explode more readily, even at normal temperatures. High oxygen content may also cause equipment to deteriorate rapidly.

A common guideline in diving is that standard scuba regulators, buoyancy compensation devices (BCDs), submersible pressure gauges (SPGs) and alternative air sources may be used for enriched air blends up to 40%. This is based on recommendations, standards and field experience by NOAA, the US Navy and the US National Institute of Safety and Health. In practice, this guideline has a good record. However, local law may require that all equipment used with enriched air be cleaned to oxygen service specifications, and local practice may also require that specific equipment meet oxygen service standards and include specific marketing or tags. Regulators rated for 300 bar (4,500 psi) meet oxygen service standards. Some groups within the dive community advocate oxygen service standards for all equipment used with more than 23% oxygen.

Most scuba equipment manufacturers have recommendations and/or modifications for their equipment when it is used with enriched air. Others state that their equipment should not be used for enriched air. Follow the recommendations of all manufacturers' guidelines, contact the manufacturer for information as necessary, as recommendations may change over time. In all cases, gas mixes with more than 40% oxygen (used outside recreational diving and beyond the scope of PADI's course) require the equipment to meet oxygen service specifications.

Enriched air requires a cylinder dedicated specifically to use with enriched air for two reasons.

1 It is critical for safety that no one accidentally confuses the enriched air cylinder for one containing standard air. Therefore, the cylinder must be clearly marked.

2 One method of blending enriched air requires putting pure oxygen in the cylinder. This is called "partial pressure" blending. If partial pressure blending with pure oxygen will be used, the tank and valve must meet oxygen service standards even though the final enriched air blend will have less than 40% oxygen.

As a result, enriched air cylinders have standardised decals and/or tags and colour coding generally agreed upon by the international dive community. These markings ensure that you can readily identify an enriched air tank, determine its contents and determine whether the cylinder can be used for partial pressure blending.

Yellow cylinders should have a 10 centimetre (4 inch) green band around the tank shoulder with yellow or white lettering reading "Enriched Air", "Enriched Air Nitrox", "Nitrox" or a similar designation.

Non-yellow cylinders should have a 15 centimetre (6 inch) band around the tank shoulder. The top and bottom of this band should be a yellow 2.5 centimetre (1 inch) band, with the centre 10 centimetres (4 inches) green. The green portion should have yellow or white lettering reading "Enriched Air", "Enriched Air Nitrox", "Nitrox" or a similar designation.

Enriched air cylinders should have a dated annual visual inspection decal stating that the cylinder has been serviced and inspected for enriched air use. The decal should also indicate if the cylinder does or does not meet oxygen service standards for partial pressure blending.

Additionally, enriched air cylinders should have a contents decal or permanent tag. This decal or tag should, at a minimum, list the oxygen content of the blend the cylinder currently holds, the fill date, the maximum depth for the blend, and the name of the person who analysed the oxygen content to verify the blender's analysis (this should be the diver who will use the tank). Decals are replaced and tags rewritten when the cylinder is refilled.

Besides these markings above, local laws and regulations may require additional or modified markings on enriched air cylinders. Some areas have recommendations or requirements that an enriched air cylinder be used within a given period, such as within 30 days of filling, and the cylinder may be marked accordingly. In other areas, standard air cylinders are stamped "air only", highlighting the need for a dedicated cylinder.

Problems with filling enriched air cylinders

The first is a fire/explosion hazard. Some substances readily burn or explode in the presence of high oxygen concentrations. This includes trace hydrocarbons (lubricants) that may be found in standard compressed air. These trace lubricants may accumulate over time in a compressed air cylinder, raising the potential for fire or explosion hazard if the cylinder is exposed to high oxygen percentages. Similarly, during the filling process compressed gases can back flow into the filling system from an enriched air cylinder. This also poses a potential fire/explosion hazard in the presence of high oxygen concentrations.

The second problem is getting the correct percentage of oxygen in the blend. The amount of oxygen in an enriched air blend is critical. If the percentage of oxygen varies by more than 1%, oxygen exposure, maximum allowable dive depth and no-decompression limits will be affected.

If partial pressure mixing in the cylinder will be used, air used in filling enriched air cylinders must meet oxygen compatibility requirements, Normal compressed air does not meet these requirements. Oxygen compatible air is produced by using special oil-free compressors, special filtration or a combination of both. This is crucial because even trace oil or contaminants may create an explosion/fire hazard. Other methods of producing enriched air do not require putting pure oxygen in the cylinder. These methods greatly reduce filling hazards, but nonetheless, the cylinder must be dedicated for enriched air use and serviced accordingly.

Enriched air blending and filling requires keeping records of system maintenance and fills beyond those required for a conventional compressed air system. Enriched air cylinders should only be filled by reputable, qualified enriched air blenders. Qualified blenders have the proper equipment for producing oxygen compatible air and minimising contamination of equipment that must remain in oxygen service and/or enriched air service. Qualified blenders have the special training required to produce accurate enriched air blends and confirm the accuracy. Qualified blenders have been trained to follow the operational procedures and to maintain the records necessary.

Qualified enriched air blenders and service are identified by checking the gases and procedures used.

1 Gas verification

The operation should be able to show regular analysis of the air it uses for enriched air blending. This air should meet local standards for oxygen compatible air, such as US Compressed Gas Association (CGA) Grade E air standards modified to have no more than 0.1 mg per cubic metre of detectable hydrocarbons or 10 parts per million of carbon monoxide (many operations try to limit it to two parts per million), or Grade J standards. In all cases, the air should be filtered to eliminate detectable particles (dust, etc.).

2 Proper procedures

Cylinders should be properly marked. There should be good records of gas analysis, filling dates, machinery maintenance and operators actions. A lack of these may indicate that the operation is not qualified or prepared to properly support enriched air diving.

Oxygen analysis

Enriched air is analysed by the blender after blending. Nevertheless, the diver who will be using a cylinder of enriched air also must personally verify the oxygen analysis of the cylinder. Do not dive with a cylinder of enriched air if you have not personally verified its contents. Failure to verify cylinder contents could lead to DCS or drowning due to oxygen toxicity if the cylinder contains an enriched air blend different from what you believe it to be. This is an important safety principle that avoids problems by double checking the initial analysis, verifying that the cylinder has been correctly marked for that blend, and confirming that the cylinder was not accidentally confused with another.

Enriched air must be within 1% of the desired oxygen content. If the blend is more than 1% off from the desired oxygen content, you must recalculate your equivalent air depths (EADs) and oxygen exposure based on the actual content, or have the cylinder refilled with the desired blend.

Oxygen Toxicity

Exceeding oxygen limits can cause central nervous system oxygen toxicity (CNS toxicity). CNS toxicity may cause a diver to convulse. Convulsions are not usually harmful in themselves, but underwater the diver is almost certain to lose the regulator and drown. A fatal accident is the primary serious hazard of exceeding safe oxygen limits. Warning signs and symptoms may precede a CNS convulsions, but usually, CNS convulsions occur without warning.

Warning signs and symptoms, if they do occur, include:

1 Visual disturbances, including tunnel vision
2 Ears ringing
3 Nausea
4 Twitching or muscle spasms, especially in the face
5 Irritability, restlessness, euphoria or anxiety
6 Dizziness.

PADI teaches divers to remember these symptoms by remembering VENTID, which stands for vision, ears, nausea, twitching, irritability and dizziness.

Divers are taught to end the dive and ascend immediately in the presence of any of these symptoms.

Heavy exercise is the thought to predispose CNS toxicity, and should be avoided if you near, or will near, oxygen exposure limits, especially if your dive accidentally exceeds 1.4 bar of oxygen. Some drugs, including the decongestant pseudoephedrine (found in Sudafed and other products), are CNS exciters believed to predispose to CNS toxicity. It is generally recommended that divers avoid decongestants when diving, because they may wear off during the dive, leading to nasal congestion with its accompanying problems. If taking a prescription, divers in training are instructed to consult with a physician knowledgeable in diving medicine before using the drug while diving with air or with enriched air.

Carbon dioxide accumulation in the body is also believed to predispose oxygen toxicity.[3] It's important to breathe continuously to avoid retaining carbon dioxide. If one experiences headaches after a dive, as a precaution, consult a physician familiar with diving to make sure you do not retain carbon dioxide.

Pulmonary or whole body oxygen toxicity is caused by prolonged exposure to high oxygen partial pressures. Exposures of several hours are necessary to develop whole body oxygen toxicity and are highly unlikely within the oxygen exposure limits in the PADI EANx program. Symptoms include burning in the throat and chest, coughing and shortness of breath. Pulmonary oxygen toxicity is more of a concern in technical and commercial dives that require long decompression stops using pure or high amounts of oxygen, 50% or more. Nonetheless, divers are advised to discontinue diving for a few days if symptoms are experienced that could indicate pulmonary oxygen toxicity.

Managing oxygen exposure

The high oxygen partial pressures experienced with enriched air must be kept within limits or they pose serious hazards to the diver. The higher the partial pressure, the shorter time that one can safely be exposed to it. Therefore, one must track oxygen exposure with tables much as one tracks nitrogen exposure. Oxygen exposure limits are independent of depth; they relate entirely to partial pressure. The oxygen partial pressure (PO_2) is 0.80 bar at 10 m (33 ft) using EANx 40. Using EANx 36, one has the same PO_2 at 12 m (40 ft). The oxygen exposure limits are the same for both dives.

The maximum PO_2 for PADI enriched air diving is 1.4 bar. 1.4 bar is the recommended maximum because it keeps you well within established oxygen limits appropriate for recreational diving. Planning a dive within 1.4 bar PO_2 also provides a margin for error. Some evidence suggests that as the PO_2 exceeds the 1.3 to 1.4 bar range, the EAD concept becomes less reliable. Staying at less than 1.4 bar PO_2 reduces the likelihood of problems with this. If the planned dive depth would exceed 1.4 bar, either switch to an enriched air blend with less oxygen, or plan a shallower dive.

The contingency PO_2 limit is 1.6 bar. PADI discourages planning dives with a partial pressure this high because there is no room for error. Partial pressures between 1.4 and 1.6 should be considered a margin for error only. Divers at work have had oxygen toxicity convulsions near 1.6 bar while at work. Exceeding safe oxygen limits poses a high risk of oxygen toxicity.

Dive planning tips for PADI EANx

Treat the entire dive as though it were made at the deepest depth/highest partial pressure. Although NOAA limits do not specify minimum surface intervals, and there is no measurable credit for surface interval, it is recommended that one have a surface interval of at least an hour between enriched air dives whenever possible, especially if one exceeds more than 50% of allowable oxygen exposure. This is believed to further reduce the likelihood of oxygen toxicity.

Do not exceed 100% of allowable exposure in 24 hours. Doing so, even at lower oxygen partial pressures, puts one at risk of oxygen toxicity. It is recommended for extra conservatism that one limits one's exposure to 90%. If planned dives would cause one to approach or exceed oxygen exposure limits, switch to an enriched air with less oxygen and/or plan dives to shallower depths. Maximum allowable dive time is always the shorter of no-decompression time or remaining oxygen exposure time. Always check both.

After a dive in which one inadvertenty exceeded the contingency PO_2 limit of 1.6 bar, the oxygen exposure is considered 100%. It is recommended not to dive for at least 12 hours. The Oxygen Exposure Table allows one to track the accumulating oxygen exposure when making repetitive and multilevel dives with differing oxygen partial pressures. This is sometimes called the "oxygen clock". Because people differ in their physiology, no table, computer or other method of measuring oxygen exposure can guarantee that oxygen toxicity will never occur, even within accepted oxygen limits. In rare instances, oxygen toxicity has occurred within the NOAA limits. Stay well within oxygen limits. It is easy to keep one's oxygen partial pressure well within 1.4 bar by using an enriched air with less oxygen and/or by limiting depth.

Analysis of oxygen exposure limits

The PADI Enriched Air Diver course makes use of a new Diving Science and Technology (DSAT) Oxygen Exposure Table, distributed by PADI. This table is based on the commonly accepted NOAA single exposure limits (Table 1).

TABLE 1

NOAA OXYGEN LIMITS FOR SINGLE EXPOSURES

PO_2	Time
0.6 bar	720 minutes
0.7 bar	570 minutes
0.8 bar	450 minutes
0.9 bar	360 minutes
1.0 bar	300 minutes
1.1 bar	240 minutes
1.2 bar	210 minutes
1.3 bar	180 minutes
1.4 bar	150 minutes
1.5 bar	120 minutes
1.6 bar	45 minutes

The DSAT Oxygen Exposure Table allows the user to convert time at particular PO_2s to a percent of allowable exposure. Exposure in 24 hours may not exceed 100%. This methodology makes it practical in the field to track exposure during repetitive dives, multilevel dives and when using more than one blend of enriched air.

NOAA limits extend total exposures for PO_2s from 1.1 to 1.6 with a minimum surface interval of two hours between exposures. The DSAT Oxygen Exposure Table does not allow this additional exposure time and limits 24 hour exposure to the single exposure limits for the following reasons:

1 The PADI course emphasises keeping PO_2s below 1.4 bar, which is an appropriately conservative level for recreational divers. The significantly reduced time at higher PO_2s encourages this and maintains conservatism if 1.4 is exceeded.

2 Within the realm of no-decompression diving with enriched air, there is little need for greater exposure. Divers who stay within 1.4 bar and make progressively shallower dives will not often find themselves limited by oxygen exposure, even with the existing limits.

TABLE 2

US NAVY OXYGEN LIMITS FOR SINGLE EXPOSURES

PO_2	Time
1.0 bar	240 minutes
1.1 bar	120 minutes
1.2 bar	80 minutes
1.3 bar	60 minutes
1.4 bar	50 minutes
1.5 bar	40 minutes
1.6 bar	30 minutes

3 From a training and educational viewpoint, building in the two hour credit would complicate the table and field use. This increases the possibility of error with little real benefit in the majority of diving situations.

Although the NOAA limits have been widely accepted within the technical, scientific and research dive communities, DSAT could not simply accept the limits on that basis alone. Of particular concern were the old U.S. Navy limits (Table 2), which are more conservative.

Another concern was that much of the testing that led to the NOAA limits was conducted using pure oxygen closed circuit scuba. Tests using semi-closed nitrogen/oxygen mixes suggest that the presence of nitrogen might contribute to the onset of oxygen toxicity.

On the advice of Dr Des Gorman, DSAT compared the NOAA limits with the existing data of manned test dives of oxygen exposure and with the published analysis of, and comments on, those tests by Professor Kenneth Donald.[3] Donald is widely regarded as a leading authority on hyperbaric oxygen exposure, having begun ground breaking research into the field in 1942.

Based on Donald's findings, the NOAA limits employed in the Oxygen Exposure Table seem reasonable and well within the limits of manned tests.

1 The limit of 45 minutes at 1.6 bar seems very conservative and appropriate. Most of the published body of testing oxygen exposure involves PO_2s greater than 1.6 bar. This makes extrapolating to lower PO_2s difficult, but there is a significant (approximate) overlap at the range edge that supports the NOAA limits. Tests by Donald using pure oxygen at 25 fsw (7.5 m), where the PO_2 is 1.75 bar, resulted in few cases of oxygen toxicity and, with only one exception, those that did occur involved underwater exercise and durations beyond 45 minutes. Donald reported that "The Admiralty Experimental Diving Unit was unable to demonstrate oxygen poisoning in the range of 0 to 20 fsw." Using pure oxygen, this is the PO_2 range of 1.0 to 1.6 bar.

Against this data set, a shorter time limit of 45 minutes at the higher PO_2 limit of 1.6 bar seems reasonable. With the emphasis on a maximum PO_2 of 1.4 bar, the exposure in the DSAT table seems appropriate. The time limits for PO_2s below 1.4 bar stem more from pulmonary oxygen toxicity concerns than from CNS (acute) toxicity[4] An analysis of the exposure limits on the DSAT table when calculated as Oxygen Tolerance Units (OTUs) shows a maximum of approximately 300 OTUs at a PO_2 of 1.0 bar, which conforms with the daily OTU dose recommended by the Repex oxygen exposure limits for repeated daily exposure to oxygen.[6]

2 Donald discounted the old Navy limits as unrealistically conservative. In *Oxygen and the Diver*, he says "Time limits were also given from 30 minutes at 1.6 bar to 240 minutes at 1.0 bar. These time limits appear to have been quite arbitrary and unrelated to acute or pulmonary oxygen poisoning. These restrictions cause a considerable limitation in the scope of mixture diving." According to Donald, the US Navy limits may have resulted because tests by Lanphier seemed to show a possible reduction in oxygen tolerance when breathing nitrogen/oxygen mixtures.

3 Donald did not believe the evidence supported the idea that nitrogen/oxygen mixtures increase the probability of oxygen toxicity. He cites the limited data that Lanphier based his conclusion on, and cites experiments that show the nitrogen has neither a positive nor negative effect. Donald stated "Thus [Lanphier's] total evidence that, contrary to the Royal Naval findings (Donald, 1943 (i) & (ii)) and experience, oxygen was more toxic when breathed in oxygen-nitrogen mixtures is of little formal significance".[3]

4 A more recent question involves the role of carbon dioxide retention in causing oxygen toxicity. Although few individuals retain carbon dioxide, especially when using conventional open circuit scuba equipment, recent tests support the limit of 1.4 bar of oxygen as appropriate when an individual's carbon dioxide retention is not known.[6]

Field data support both the DSAT limits and Donald's research and experience. The NOAA limits have been in use more than a decade, with virtually no incidence of oxygen toxicity reported within the proposed range. With the additional conservatism built in, the DSAT Oxygen Exposure Table appears to be well suited for use by recreational divers.

Computer dives using enriched air

The optimum method for diving enriched air with a computer is to use an enriched air computer. Following the manufacturer's instructions, one programs these computers with the blend one is going to use, the computer tracks no-decompression status and oxygen exposure. If one already owns an air dive computer, one can use enriched air with it. The simplest way is to plan the dive as a standard single depth enriched air dive using EADs and tables. Then, dive with the air computer. During the dive, one can use whichever gives more no-decompression time, the computer or the EADs and tables. However, remember that repetitive dives must be calculated based on what one followed in the first dive.

It is important to plan and track oxygen exposure, especially for long multilevel dives. Plan dives to ascend in levels, calculate each level's oxygen exposure separately and add them together. Start at the deepest point of the dive and progressively work shallower, stay at or above the depth levels on which one based the oxygen exposure. If one does not track oxygen levels, one must base one's oxygen exposure on the deepest depth and total dive time. If only making one or two dives, one may find this much simpler.

Diving emergencies and enriched air

If a diver convulses underwater (possibly due to oxygen toxicity), the generally recommended action is to handle the emergency as one would for an unconscious diver underwater. This recommendation is based on US Navy procedures, which the Divers Alert Network (DAN) defers to in this situation because there has been little study of this in recreational diving.

a Hold the diver's mouthpiece in (if still retained). Do not attempt to replace it if it is out of the mouth.

b Immediately bring the diver to the surface and check for breathing.

c Establish ample positive buoyancy for both rescuer and victim.

d Call for assistance as needed and available and begin in-water rescue breaths if the victim is not breathing. Take the diver to the boat or shore and help remove the diver from the water.

e Once out of the water, check for a pulse and breathing. If they are absent, begin or continue rescue breaths and/or CPR. In any case, contact emergency medical care. If the diver is breathing, begin first aid for DCI as a precaution.

f Even if the diver appears fully recovered, the patient should be examined by a physician.

Some experts recommend that if a diver's mouthpiece is in place, one should hold it there and not begin the ascent until the convulsion subsides. After the convulsion ends, bring the diver immediately to the surface. This recommendation is based on the fact that a convulsing diver may hold his breath. In any case, the primary concern is getting the diver to the surface to prevent drowning, so one can begin first aid and get help.

If a diver is suspected of having decompression illness after an enriched air dive, administer oxygen first aid and obtain emergency help exactly as one would if the diver had been diving using air. If possible, inform emergency personnel and the recompression facility that what the diver's time and depth was, that the diver was using enriched air, and what the blend was. In a DCI emergency, if you run out of emergency oxygen before you can get a breathing patient into emergency medical care, have the patient breathe any enriched air available. While not as beneficial as 100% oxygen, enriched air has more oxygen than air.

For any questions or comments regarding the PADI EANx course, contact the authors.

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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_2 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.[1]

Shallow water blackout

A number of unexplained cases of impairment or loss of consciousness were reported some 55 years ago[1,2] among those swimming with pure oxygen rebreathers at depths less than 25 feet (7.5 m, 1.8 bar PO_2). 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[3] 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_2 build-up, as would usually be associated with hypoxia, because the CO_2 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[3] 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_2 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_2