●Original Article

Nitrox Diving for Sports Divers in the USA Present Situations and Future

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1991年11／12月号の『アラート・ダイバー』誌（隔月刊のダイバーズアラートネットワーク：DAN・US機関誌）に、私は“レクリエーションダイビングでのナイトロックス？”というタイトルで論説を書きました。その当時、それは疑問文だったのですが、その後８年で答えは完全に“イエス”になっています。しかし、その当時、ダイビング器材メーカー協会（DEMA）もDANも、ほとんどがナイトロックスを使うことを支持していなかったのです。

そうはいっても、ナイトロックスを使うことは何も新しいことではありません。合衆国と英国の海軍は、その種の混合ガスを機雷掃海ダイバー用リブリーザー（訳注：循環式呼吸器；半閉鎖式、閉鎖式などがある）で使っていました。ナイトロックス混合ガスはまた、潜水会社がコマーシャルダイビング用に使っていましたし、科学潜水用に、アメリカ海洋大気局（NOAA）によって開発されてもいました。実際、1989年にNOAAは、「アメリカ水中調査プログラム」で、ハーバーブランチ海洋学研究所と一緒に、“エンリッチドエア・ナイトロックスダイビングに関するワークショップ”と銘打ったワークショップを組織して、科学ダイビング機構やコマーシャルダイビング会社、その他の専門家達も合めて、エンリッチドエアすなわち窒素一酸素（ナイトロックス）ダイビングテクニックに興味がある機関に科学ダイビンクプログラムを紹介したのです。その目的は、当時最新のデータの検討と科学界への適用を検討しようというものでした。そこではナイトロックスを使うレクリエーションダイビングは扱われませんでしたし、特にそれを推薦することもありませんでしたが、どちらにしてもそうなることは認めていました。

In November/December 1991, I wrote an editorial for *Alert Diver*, the bimonthly magazine of the Divers Alert Network (DAN), with the title "Nitrox for Recreational Diving?" It was a question then which has been answered over the last eight years with a resounding "yes". But at that time few of the Diving Equipment Manufacturers Association (DEMA), nor DAN supported the use of nitrox.

The use of nitrox, however, is not new. The U.S. and British Navy used such a mixed gas for mine clearance divers with rebreathers. Nitrox mixtures were also used commercially by diving companies and were also developed by scientific divers, particularly by the U.S. National Oceanic and Atmospheric Agency (NOAA). Indeed in 1989, NOAA's National Undersea Research Program, together with the Harbor Branch Oceanographic Institute. organized a workshop, "Workshop on Enriched Air Nitrox Diving", to bring institutions with scientific diving programs who were interested in enriched air or nitrogen-oxygen (nitrox) diving techniques together with other scientific diving organizations, commercial diving companies and other experts. The purpose was to review the then current data, and its application to the scientific community. It did not address recreational diving with nitrox and specifically did not recommend it but acknowledged that it was happening anyway.

How did nitrox transfer from the scientific community to the unsupervised recreational diving in-

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dustry? Basically it is due to one individual, Mr. Dick Rutkowski. After a U.S. Navy diving career, he became the lead trainer of NOAA divers and doctors. In 1985 he retired as Deputy NOAA Diving Coordinator and the Director of NOAA Training and then decided, in his retirement, to institute his training programs for the recreational diving industry. Now there are a number of new training agencies such as IANTD (International Association of Nitrox and Technical Divers) which Rutkowski started in 1985. At present they have grown to a total of 11 nitrox or mixed gas certifying training agencies in North America teaching nitrox and the green (oxygen) and yellow (nitrogen) cylinders are increasingly more common at dive stores. PADI launched its Enriched Air Diver program in1996 at the DEMA show. What were the advantages and concerns for nitrox to be used by recreational divers that I alluded to in 1991, and are they still valid today? The big advantage is that the lower nitrogen percentage in the two available nitrox or Enriched Air (EAN) mixtures, EAN 32 with 32% oxygen and 68% nitrogen and EAN 36 with 36% oxygen and 64% nitrogen compared to air with 20% oxygen and 80% nitrogen theoretically means longer diver bottom times. Since nitrogen is the causative agent for bubble formation on decompression, resulting in decompression sickness, less of it will enable recalculation of the no stop dive times to give greater bottom time. Even so, this may not reduce the risk of decompression sickness. Indeed, as I will show you later, decompression sickness still does occur in nitrox breathing divers.

The major danger with nitrox, however, is the risk of oxygen convulsions while underwater and drowning. This is not normally a problem for recreational divers breathing air to the suggested limit of 130 ft (41 m) where the convulsion hazard starts at 218 ft (68 m) but at the higher oxygen pressures it is very real. For nitrox 32 the convulsion hazard is only 132 ft (41 m) and for nitrox 36 it is even less at 113 ft (35 m). NOAA allowed a maximum safe oxygen partial pressure of 1.6 ATA. The PADI training association states that 1.45-1.6 ATA is considered to be within the caution zone and currently recommends not exceeding 1.56 ATA. Dr.Vann Vice President of Research at DAN, took an even more conservative view while allowing a cushion for partial pressure increases due to unplanned depth excursions of 1.2 ATA. The U.S. Navy on the other hand, on the basis that "hyperoxic gas mixtures seem to increase arterial carbon dioxide levels compared to air at the same depth" has chosen 1.3 ATA as the current maximum oxygen level for nitrox diving. PADI has pronounced a limit of 1.4 ATA. Who is correct and which should one choose? What risk is accepted? Who is right?

One must remember that oxygen toxicity, as shown by a convulsion, is unpredictable. Its onset time varies widely from individual to individual and from day to day. Further, hard work underwater raises the level of carbon dioxide in the body and this increases sensitivity to oxygen convulsions which can and has led to death by drowning. Further some divers retain CO_2 under normal conditions and are at increased risk of convulsing. Divers are notoriously poor at depth control, whereas diving below 130 ft; (41 m) on air is not necessarily a major problem, with nitrox dropping below only 113 ft (35 m), with nitrox 36, could easily result in oxygen toxicity with no warning signs of the sudden convulsion. DAN data indicate this is now happening in some cases.

A further problem that has caused death by convulsions underwater has been divers making their own mixtures, without proper measurement of the final mix. resulting in an overly high oxygen mixture. In technical divers using several mixtures divers during deep dives have died due to breathing from the wrong regulator at the wrong depth and getting more oxygen than planned. Equipment needs to be free of grease or oils and compressors, too, must be oil firee and fit to compress oxygen without risk of fire or explosion. Most dive shops will wisely have a separate compressor and fittings for nitrox filling.

Divers who intend to breathe nitrox should buy their own oxygen measuring device. This should be used to monitor every tank for every dive before the diver assembles his or her equipment to be sure that the O_2 partial pressure is as planned and use a nitrox only regulator cleared and manufactured for oxygen use.

Let us now return to the original reason why nitrox became popular—longer bottom time. It was also suggested that it would be safer and divers would feel better than diving with air presumably because there would be fewer "silent bubbles" in

Table 1 NAUIEAN Table

Depth (feet)	21%AIR	32%EAN	36%EAN
60	55	100	100
70	45	60	60
80	35	50	60
90	25	40	50
100	22	30	—
110	15	25	—

Table 2 Mixed Gas Diving Injuries

Date	Number of Cases
1990-93	21 (avg 4.2)
1994	10
1995	16
1996	23
1997	30
IANTD Certified Divers 17,780 (1985−96)	

the blood vessels from decompression.

Many divers do indeed say they feel less fatigued but what kind of increased bottom time is being obtained for this and is nitrox really safer from a decompression view? Clearly the same amount of nitrogen in the body before ascent results in the same risk of decompression sickness.

Using the NAUI Enriched No Stop Dive Times below in **Table 1** it is clear that the best advantage is at the shallower depths - an extra 45 minutes at 60 ft (19 m). At 100 ft (31 m) it is only 8 minutes.

Yet nitrox divers seem to forget this and dive deeper than the limits and risk convulsions in the water.

Further, if the diver breathes nitrox to the full bottom time limit of the nitrox or EAN table then the nitrogen risk of decompression will be the same - although the diver has prolonged the bottom time. From my viewpoint, it would be better to limit ALL nitrox dives on 32 or 36 oxygen to no more than 90 ft (29 m). This gives a respectable increase in time on the bottom with a much lower risk of getting into oxygen convalsion problems.

If the diver wishes to dive safer and to feel better than diving with air, then dive with nitrox but use the air tables. Yes, the bottom time will not be longer but there will be less likelihood of decompression sickness, and as we shall see, this remains a problem.

There are various nitrox computers available today to calculate no stop decompression times for multilevel diving. They are based on the standard two mixtures and some let you adjust the oxygen percentage yourself. However, these computers and indeed the tables. too, are mostly based on the same Haldanian principles. Indeed the advent of computers for all kinds of recreational diving has had little or no impact on the incidence of decompression illness in air breathing divers. This led me to maintain in a number of recent activities that the most important factor is the rate of ascent for recreational divers. Most decompression sickness is neurological and the spinal cord saturates in 12 minutes so too fast an ascent will easily form bubbles in the cord. Rates of 60 ft/min (19 m/min) or even the slower 30 ft/min (9 m/min) increasingly suggested today may still be too fast and closer to 10 ft/min (3 m/min) may be better. DAN is presently researching this issue.

Review of diving injuries and fatalities in nitrox and mixed gas diving indicate in **Table 2**, 21 cases between 1990-1993. In 1994 there were 10 cases which increased in 1995 to 16 cases, in 1996 23 cases and in 1997 still more at 30. IANTD reports certi-

Table 3 Comparative Decompression Risks

Air	1,000 cases per 2 million divers or 0.05%
Nitrox(1996)	23 cases per 17,780 divers or 0.12%

fying 17,780 U.S. nitrox divers from 1985−1996 but all may still not be active divers. However, compared to 1,000 cases in 2-3 million divers normally acknowledged for air, with nitrox in 1996 there were 23 cases for 17,780 divers (8 non-certified). Clearly on the basis of this data, nitrox is not, as it is being dived, safer than air. Indeed, from **Table 3**, clearly it is as much as twice as likely to cause decompression illness. Obviously more research is needed and DAN will be collecting more accurate data.

In regard to fatalities between 1990−94 there were eight recreational deaths in divers breathing mixed gas. There were two in 1994, three in 1995, two in 1996 and one in 1997.

If we infer there are two million active recreational divers in the USA and about 90 deaths per year, this means a fatality rate of 0.005%. With mixed gas nitrox taking an average of 2 out of 17,880 trained divers, then the percentage is higher at 0.01%. Much better data is needed but this crude analysis points to some reconsideration as to how nitrox divers dive. DAN injury data show that 90% of those who developed decompression illness were diving deeper than 80 ft (25 m) where the advantages of nitrox are less and the risks greater.

For the future the number of nitrox divers will continue to increase. It is something new and dive shops and training agencies wish to remain competitive. From this speaker's viewpoint, it is necessary to reconsider nitrox diving. Why not one mixture, only EAN 36, and stop breathing nitrox at 90 ft (29 m) . This gives mostly double the bottom time in many cases. There would be less confusion over mixtures and simplify the rules for unsupervised recreational diving.

Those who want still less risk can use EAN 36 but dive with the air tables. Ascent rates should be 30 ft/min (9m/min) or slower and with a 3-5 minute safety stop at 15−20 ft (4.7 - 6.3 m). All nitrox divers should carry an oxygen meter and measure the oxygen content of the cylinder they are about to breathe. Mistakes in filling tanks do occur.

Nitrox has grown rapidly from a highly supervised procedure prior to 1985 to its wide use by unsupervised recreational divers. It is time to carefully collect data and decide if nitrox is as safe as its proponents would like us to believe. DAN will be collecting this data over the next several years. For the present, with the wider use and heavy promotion of nitrox the original controversy and hesitance over the use of nitrox for recreational diving seems to be disappearing. However, this paper raises some concerns which need more data and review and perhaps some adjustments to how divers dive in the future with nitrox.