●Original Article

Evaluation of Diving Accidents Between Nitrox and Air Dives

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アメリカ合衆国で最初の全国的なトレーニングプログラムを，YMCAが1959年に制定してから，レクリエーションダイビングにおいて多くの進歩がありました。レクリエーションダイビングとダイビング器材のほとんどすべてが発展してきたのです。レクリエーションダイビングの推奨安全指針でさえも，現在の安全潜水実施に関する知見と知識を反映してこの間に修正されてきたのです。スクーバレギュレータや浮力調整具（BC），ウェイトシステムの設計，それにマスク，フィン，保護スーツ（すなわちウェットスーツとドライスーツ）のデザインなどはすべて，ダイビングの手軽さ，快適さ，そして時には安全性を向上させてきたのです。

減圧コンピュータの導入はダイビングの方法を一変させ，ダイバーは印刷したテーブルを使って煩わしい計算をしないでも，マルチレベルダイビングや繰り返し潜水が可能になりました。

今日，一般のレクリエーションスクーバダイバーがスクーバダイビングで使えるオプションの中で多くの論議があるものに，ナイトロックスや混合ガスといった圧縮空気でないガス混合体を使うものがあります。

“混合ガス”とは，組成ガス，つまり不活性ガスと酸素を混合した呼吸ガスのことです。“ナイトロックス”とは，窒素と酸素のみからなる混合ガスのことで，酸素の割合は空気の21%以上であることも以下であることもあります。“エンリッチドエア・ナイトロックス”（EAN）とは，21%より高い酸素割合（すなわち，酸素32%と酸素36%）のナイトロックス混合体（EAN32およびEAN36）で，通常は酸素に空気を混ぜることで作ります。“ヘリオックス”すなわち“オキシヘリウム”はヘリウムと酸素の混合ガスで，“トライミックス”とは，ヘリウムと窒素，酸素の混合体をいうのが普通です。

あらゆる形態の混合ガスダイビングの中で，レクリエーションダイバーおよびテクニカルダイバーはEANを使うナイトロックスダイビングを最も頻繁に行っています。レクリエーションダイビングで混合ガスを使うことに関しては論争があります。なぜなら，過去において，混合ガスはコマーシャルや軍事，科学ダイビングを行う時にしか使われなかったからです。このことは，混合ガスダイビングが非常に複雑で，トレーニングがさらに必要であること，および，平均的なレクリエーションダイバーが受けていると考えられる以上の直接管理を必要とすることによるものでした。

Abstract

There have been many advances in recreational diving since the first national training program was instituted in the USA by the YMCA in 1959. Almost everything about recreational diving and diving equipment has evolved. Even the recommended safety guidelines for recreational diving have been modified over the years to reflect current understanding and knowledge of safe diving practices. Innovations in tbe design of scuba regulators, buoyancy compensators, weighting systems, and the design of masks, fins and exposure suits (i.e., wet-and drysuits) have all added to the ease, comfort and, sometimes, the safety of diving.

The introduction of decompression computers revolutionized the way divers are able to perform multidepth and repetitive dives without cumbersome calculations using printed tables.

Today, a much-discussed option available to scuba for the general recreational scuba diving public is the use of gas mixtures other than compressed air, such as nitrox or mixed gas.

“Mixed gas” refers to a breathing gas that has been mixed from component gases, inert gases and

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Table 1 Mixed-Gas Certification by Gas Mix

Gas Mix	Certified	Non-Certified	Total
Nitrox (29−37%)	19	2	21
Nitrox (>40%)	4	0	4
Nitrox (80% - decompression stop mix)	2	1	3
Nitrox and Trimix	0	0	0
Trimix (O_2- N_2- He)	2	0	2
Heliox (O_2- He)	0	0	0
TOTALS	27	3	30

oxygen. "Nitrox" refers to a mixed gas containing only nitrogen and oxygen, and the oxygen fraction may be more or less than the 21 % found in air. "Enriched-air nitrox" (EAN) refers to nitrox mixes (EAN 32 and EAN 36) having an oxygen fraction higher than 21 % (i.e. 32% and 36% oxygen), usually made by mixing oxygen with air. "Heliox" or Oxyhelium" is a gas mixture of helium aud oxygen and "trimix" usually refers to a mixture of helium, nitrogen and oxygen.

Of all forms of mixed-gas diving, recreational and technical divers perform nitrox diving using EAN the most frequently, The use of mixed gas in recreational diving is controversial, because in the past, mixed gas was used solely in commercial, military and scientific diving operations. This implied that mixed-gas diving was too complex and required much more training and direct supervision than the average recreational diver might receive.

All that changed in 1985, when Dick Rutkowski of Key Largo, FL, retired from the Natinal Oceanic and Atmospheric Agency (NOAA), which trained scientific divers in nitrox, and began the International Association of Nitrox and Technical Divers (IANTD) to start instructing recreational divers in the use of nitrox. The course followed the policies and procedures developed by the National Oceanic and Atmospheric Administration for nitrox diving. By the end of 1997, there were a total of 11 nitrox or mixed-gas certifying agencies in North America including PADI which started in 1996.

In previous years there were not enough cases of mixed gas diving for meaningful analysis to collect and follow up. Between 1990 and 1994, however, DAN recorded 31 cases. In 1995, 16 cases were sent to DAN and in 1996, 23 cases were recorded. The 1997 data is based on 30 scuba-certified divers using EAN or mixed gas who were injured and required treatment in a hyperbaric chamber.

From 1994 to 1997 there were eight recreational deaths in which the divers were using mixed gas. In 1997, one death occurred; two deaths occurred in 1996; three occurred in 1995; and two in 1994 using mixed gas.

In 1997, there was an increas in the number of EAN and other mixed-gas divers contactiug DAN for consultation. A total of 68 calls were made to the emergency line regarding mixed-gas diving. Forty-three of these divers reported symptoms consistent with decompression sickness, and 26 divers were treated with hyperbaric therapy.

It is difficult to determine the true incidence of injury and deaths. This is because there is no way of knowing how many mixed-gas or EAN divers participate in diving each year or how many dives are made. While IANTD reports certifying approximately 17,780 U.S. nitrox divers from 1985 to 1996, it is nonetheless impossible to determine how many of these divers are still active in nitrox and mixed-gas diving. However, at the end of this paper an attempt is made, based on the evidence available, which shows more risks diving with EAN than air.

The reported cases in this database are also not well distributed, with 16 of the 30 cases (62 %) occurring in Florida. Two deaths each occurred in California and Washington. One case each was reported in Missouri, New Jersey, Maine, Penusylvania, North Carolina and Rhode Island. There were four deaths outside the U.S., in the Cayman Islands, Truk, Dominican Republic and Mexico.

Diver Characteristics

Divers trained in the use of mixed gases do differ from air divers in the amount of specialized training they receive and in the operational procedures they are required to follow when using oxygen-enriched diving mixtures. In addition, EAN and mixed-gas divers need to be well informed about the potential for oxygen toxicity and convulsions. This risk is not usually encountered by a diver using compressed air but is a significant risk with mixed-gas diving.

In the 1997 injury population of 30 divers (**Table 1**) , there were four divers who used a nitrox mix with oxygen concentrations of greater than 40 % oxygen and three were usiug an 80 % oxygen mix as the gas mix used at their decompression stop.

Two divers in this population were diving with trimix. Surprisingly 10%, or 3 divers, were not even

Table 2 Age Distribution of Nitrox or Mixed-Gas Injury Cases (%)

Age	1997	1996	1995
20-24	13.3	8.7	18.8
25-29	13.3	17.4	31.2
30-34	23.3	30.4	18.8
35-39	20.0	30.4	18.8
40-44	10.0	8.7	12.4
45-49	16.8	4.4	0.0
50-54	3.3	0.0	0.0
TOTALS	100.0	100.0	100.0

Table 3 Age Distribution of Air Injury Cases (%)

Age	1997	1996	1993-95
10-14	0.4	0.4	0.8
15-19	4.9	2.7	3.2
20-24	7.5	7.2	8.5
25-29	12.4	19.5	17.1
30-34	18.8	18.4	19.8
35-39	20.8	20.5	18.8
40-44	12.2	15.5	14.4
45-49	12.8	6.6	8.7
50-54	6.6	4.8	5.0
55-59	2.2	3.1	2.5
60-64	0.7	1.0	0.6
>=65	0.7	0.2	0.6
TOTALS	100.0	100.0	100.0

Table 4 Sex of Nitrox or Mixed-Gas Injury Cases

Sex	1997	1996	1995
Female	16.7	13.0	12.5
Male	83.3	87.0	87.5
TOTAL	100.0	100.0	100.0

certified to use mixed gas.

The gas mix used by the one diver who died in 1997 was nitrox. This diver was not certified in mixed-gas diving.

It is difficult to draw any conclusions about EAN and mixed-gas divers because of the small number of cases and the limited data. Characteristics of air divers can, however, be compared to those of mixed-gas divers.

The largest fraction of mixed-gas divers (43.3 %) are in the 30-39 year age range (**Table 2**). In contrast, air divers are more evenly distributed over the 25- to 49-year-old range (**Table 3**). Mixed-gas certiflcation often requires an advanced diver certification, and, likely, divers with more experience-this favors older divers, Also, there appears to be a trend towards participation of older divers (>40) that may reflect a wider interest in this type of diving.

Males dominate the mixed-gas population, with 83 % of all injury cases involving men(**Table 4**), c.ompared to only 69 % males in air-diving injuries (**Table 5**).

Because most mixed-gas divers generally have

Table 5 Sex of 1987-1997 Air Injury Cases (%)

Gender	1997	1996	1993-95	1990-92	1987-89
Female	31.0	36.0	29.8	27.0	24.2
Male	69.0	64.0	70.2	73.0	75.8
TOTAL	100.0	100.0	100.0	100.0	100.0

Table 6 Conventional Disense Categories (Mixed Gas %)

Final Diagnosis	Frequency	1997	1996	1995
DCSI	7	23.3	34.8	12.5
DCSII	21	70.0	65.2	87.5
AGE	2	6.7	0.0	0.0
TOTALS	30	100.0	100.0	100.0

Table 7 Canventional Disease Diagnosis with Air (%)

Final Diagnosis	1997	1996	1995-93	1992-90	1989-87
DCSI	24.6	25.3	25.3	19.3	21.0
DCSII	66.8	62.7	65.7	68.3	63.0
AGE	8.6	12.0	9.0	12.4	16.0
TOTALS	100.0	100.0	100.0	100.0	100.0

an advanced certification, it is not surprising to find that a majority of these injury cases were certified at the advanced or instructor level. In contrast to air-diving iujuries where 40 % of all injuries were in divers diving less than 2 years or with 20 or fewer dives, almost all injuries in mixed-gas divers occurred in divers with more than 121 lifetime dives (80 %). Fourteen (46.7 %) of the divers had been diving for 10 years or more. So it is the experienced diver who is diving and getting injured with nitrox diving rather than the novice with air diving or those with less than 10 years diving experience.

Decompression Illness in Mixed·Gas Divers

"Decompression illnes" is the general term for arterial gas embolism (AGE) and decompression sickness (DCS, which includes DCS I and DCS II). The frequency of each diagnosis is shown in **Table 6**.

Approximately the same pcrcentage of DCI cases were incldents of DCS II in mixed-gas - (70 %), compared to air divers (66,8 %) (**Table 7**).

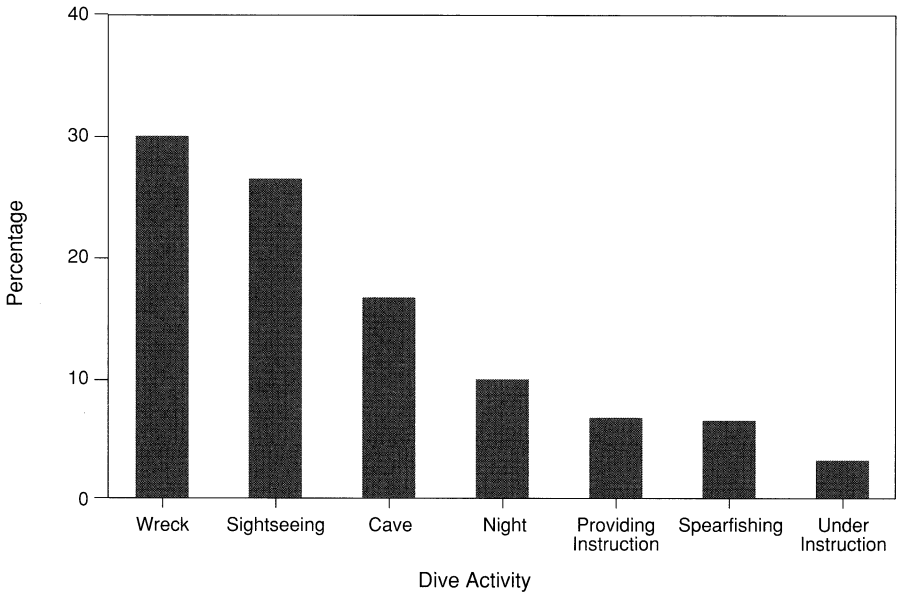
Two individuals (one male, one female) had symptoms of DCI but continued to dive. Their symptoms included pain, decreased skin sensations, fatigue and headaches.

Mixed-gas divers who used emergency oxygen first aid were similar with 56.7 % compared to 59.3 % for air divers.

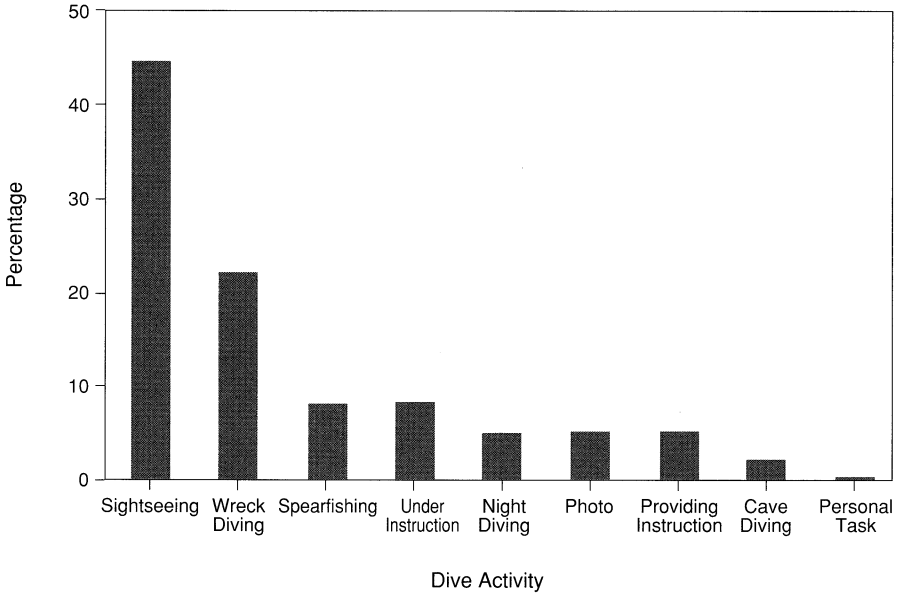
Four of the seven (57 %) DCS I cases called for assistance within 12 hours to report for recompression. One waited two days to call for assistance, and another diver waited three days.

Twelve of the 21 (57.1 %) DCS II cases called for assistance within 12 hours; five more (23.8 %) waited an additional 12 hours to call and report for treatment. Three individuals (14.3 %) waited two days to call for assistance and one individual waited four days to call for assistance. Both AGE cases called for assistance within one hour of symptom onset. These are very similar to the behavior of air divers.

Twelve out of 30 divers had residual symptoms after treatment. With this small a population, the binomial distribution (a standard statistical test) was used to estimate the incidence level. The 95 % confidence limits are 16.6-46.5 % which brackets the 33 % incidence reported for air divers. This means that there is no significant difference in the chance of residual symptoms between the two populations.



Graph 1 Primary Dive Activity (Mixed Gas)



Graph 2 Primary Dive Activity (Air)

Dive Profile Information

The activity of mixed-gas diving appears to be linked to more specialized dive activities, compared to that of recreational air divers (**Graph 1**). Wreck and cave divers were among the first scuba divers to utilize mixed gases for recreational scuba and use this technology widely today.

It is not surprising, therefore, to find these activities are more popular in the mixed gas population when compared to air diving (**Graph 2**).

Sixteen of 30 mixed gas divers (53.3 %) were injured on the first day of diving, which is almost the same as for air divers at 48.6 %. Mixed gas divers tend to be more frequent divers with 80 % having been diving within the last 30 days compared to

Table 8 DCS Dive Attributes Among Mixed-Gas Injured Divers

Attribute	Frequency	1997	1996	1995
≥ 80fsw	27	90.0	91.3	81.3
No decompression	17	56.7	34.8	31.3
Exertion	17	56.7	30.4	50.0
Single Day	16	56.3	52.2	50.0
Current	16	53.3	30.4	43.8
Single Dive	12	40.0	60.9	62.5
Square	9	30.0	47.8	62.5
RapidAscent	4	13.3	0.0	12.5

Table 9 Dive Attributes Among Injured Divers Dingnosed with DCS (Type I and II) by Percentage (Air)

Attribute	1997	1996	1993-95	1990-92	1987-89
Within limits	85.2	80.7	92.4 +	**	**
No Decompression	82.3	85.9	82.4	80.0	78.5 *
Multilevel	72.4	64.2	57.0	64.1	51.9 *
≥ 80fsw	71.2	64.5	71.4	64.5	74.6 *
Repeat Dive	68.3	66.4	62.2	68.2	52.9
Multiday	52.3	54.1	52.2	48.7	51.0 *
Exertion	49.6	58.4	57.6	49.3	29.8
Single Day	47.7	45.9	47.7	51.3	53.3
Current	43.8	50.1	50.8	50.5	40.7
Single Dive	31.7	33.6	37.7	32.6	32.7 *
< 2 Yr Experience	28.3	32.0	32.0	30.9	26.1
Square	27.6	34.6	37.6	35.8	42.8 *
Fatigue	26.6	28.2	30.6	34.5	34.1
Rapid Ascent	22.8	24.0	23.6	21.9	24.3
Buoyancy	15.3	15.5	12.5	11.6	13.6

* These percentages are from 1989 only.
** The blank Fields for the category "Within Limits" from 1987-1993 indicate a change in analysis meiked.
\+ These percent ages are from 1994 and 1995 only.

only 48.7 % with air.

The style of diving is differernt for mixed gas divers and is reflected in the dive profile data in **Table 8**. Comparison with air dives in **Table 9** shows that mixed gas divers tend to make deeper (≥80 fsw/24 msw) dives, more decompression dives (43.3 % versus 17.7 %) and made more single dives (40.0 % versus 31.7 %). Interestingly, due probably to their greater experience, the history of rapid ascent was almost twice as likely with the air divers (23 %) compared to 13 % for mixed gas divers.

Over 70% of mixed gas divers (21 of 30 divers) were using a diving computer to help calculate their dive which was greater than the 59.5 % for air divers. This would also reflect on the use of mixed gas on nitrox cornputers now on the market.

Comparative Dccompression and Fatality Risks

Review of diving injuries and fatalities in nitrox and mixed gas diving indicate in **Table 10**, twenty one 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 certified 17,780 U.S. nitrox divers from 1985-1996

Table 10 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)	

Table 11 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 %

but all may still not be active divers today. However, compared to the 1,000 cases in 2 or 3 million divers normally acknowledged for air, with nitrox in 1996 there were 23 cases for 17,780 divers (8 non-cerified). Clear]y on the basis of this data, nitrox is not, as it is being dived, safer than air Indeed, from **Table 11**, 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 recreationa1 divens 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 much 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 decomprcssion illness were diving deeper than 80 ft (25 m) where the advantages of nitrox are actually 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 only one mixture, only EAN 36, and stop breathing nitrox at 90 ft (29 m). This gives almost double the bottom time. There would be less confusion over mixtures and simplify the rules for unsupervised recreational diving with nitrox.

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 recrentional 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 disappearing. However, this paper again raises these concems, which need more data and critical review and perhaps some adjustments to how divers dive in the future with nitrox.