Diving practices in technical divers' community and behaviour towards self-reported unusual symptoms

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Abstract
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Introduction: The use of gas mixtures containing helium for deep recreational diving is increasingly common, involving complex logistics and decision-making compromises. The characteristics and inherent risks of this practice remain poorly documented. This study aims to provide an epidemiological inventory of practices and diving-related incidents within the technical diving community.
Methods: An international online survey was disseminated on social networks targeting certified trimix divers. It collected demographic data, diving experience, and dive management practices, along with self-reported unusual symptoms, treatments, and outcomes following trimix dives.
Results: A total of 558 questionnaires were analysed, predominantly from males (92%), mostly over 46 years old (61%), with high certification levels and recreational diving purposes. Forty-two percent reported one or more medical risk factors related to diving. Rebreather use was prevalent (79% at least occasionally). Decompression was primarily managed using compartmental models (85%) with gradient-factors adjustment. Dive planning varied significantly among individuals. Gas density at depth frequently exceeded the current recommendations. Ten percent had experienced symptoms suggestive of gas toxicity, mainly related to nitrogen narcosis. Thirty-six percent (199/558) reported experiencing, at least once, symptoms of diving-related incidents, with 61% (n = 121/199) expressing certainty. In 48% (120/261) of incidents involving decompression sickness (DCS) or breathing symptoms, no treatment was initiated. Among episodes involving DCS symptoms (n = 254), 42% received normobaric oxygen, and 23% sought medical advice, while 16% were treated with hyperbaric oxygen. Only 2.5% reported probable long-lasting sequelae.
Conclusions: The diversity of practices highlights the lack of robust scientific data supporting them. The accident rate in mixed-gas diving may be higher than in typical scuba air diving, though mostly of mild severity. Treatment appears to be neglected despite divers' high knowledge levels. Continued research into decompression and the physiological effects of these dives is essential, along with ongoing awareness and education efforts in diving first aid within this exposed community.

Introduction

'Technical diving' is variably defined but experts agree that the term applies when helium based mixed-gases are used to conduct deeper and longer dives. These dives entail a rapidly accumulated decompression obligation and specific risks associated with exceeding the limits of recreational diving.[1]

Although training standards for technical diving vary by certification agencies, all require advanced recreational diving experience, often including an enriched air nitrox qualification.[2,3] Thus, the technical community might be more experienced with a high level of diving related knowledges than traditional recreational divers from which they are derived. Despite sharing a common legacy, the specific characteristics, practices, and habits of this technical community remain poorly documented. It is unclear whether this in-depth training combined with risk management awareness can influence planning and behaviour in the event of an accident.

Dive profile elaboration is critical to consider for technical divers. The execution of trimix dives involves a wide range of planning approaches, including equipment consideration, gas management, decompression strategies, and more with many differences within this community.[4] Many procedures remain untested and have not yet been developed nor validated for these types of dives.[5]

Diving exposes the diver to a risk of decompression sickness (DCS), and hyperbaric oxygen therapy (HBO) is the definitive treatment.[6] A DAN Indo-Pacific study suggests that recreational diving population is getting older, increasing the likelihood of medical conditions,[7] and the magnitude of this in the technical diving community remains unknown. While many thousands of technical dives have been conducted safely, the incidence of DCS is unidentified. Clinical expression of DCS might differ from recreational epidsodes.[8–10] In Finland, there has been a rise in treated cases among technical divers, likely linked to the activity's growing popularity. Technical divers are more likely to receive normobaric first aid oxygen (FAO_2) before HBO treatment compared to recreational divers.[9] A recent study indicated a high incidence of DCS among Finnish technical divers, with most of them opting for self-treatment of mild symptoms without consulting a physician or receiving HBO.[11] Therefore, incidents may be under-reported in this population as observed in non-technical recreational divers.[12]

The objective of this survey was to establish the demographic profile and current practices of technical divers. Additionally, it examined the incidence of pathological symptoms and associated healthcare interventions. Exploring the technical divers' characteristics and activities will facilitate risk assessment, ultimately helping to better meet the community's needs.

Methods

The study was approved by the data protection officer of Western Brittany University in accordance with the European Union's General Data Protection Regulation (ref-21042). Participation was voluntary, and responses were confidential.

DATA COLLECTION AND PROCESSING

A cross-sectional survey was conducted using bilingual (English and French) anonymous questionnaires via Google Forms (Google LLC, CA, USA) to facilitate international dissemination. The survey was tested by twelve 'mixed-gas recreational divers of varied experience and revised before distribution. It was shared through social media (Facebook®, Menlo Park, CA, USA) within technical diving groups from 21 December 2021 to 20 February 2022. Participation was limited to divers certified in mixed-gas bounce diving. The average time to complete the questionnaire was estimated at 10 minutes. It included 32 mandatory questions, plus four additional questions specifically for rebreather users. Among the 32 questions, six were conditional, leading to 26 further questions related to each specific condition investigated (*Supplementary Appendix 1).

The first part of the survey gathered information about sex, age, weight, height, home country, putative diving risk factors such as active smoking, arterial hypertension, diabetes mellitus, heart disease history (heart attack, valvular disease, or arrhythmia) and low physical activity (defined as moderate intensity exercise below 60 minutes per week). Obesity was defined by a BMI ≥ 30 $kg.m^{-2}$. Diving experience was assessed by the total years of scuba and trimix practice, the certification level and the number of dives. Questions regarding diving equipment mainly used in open circuit (OC) and rebreather (RE) and type of diving suit were included. There were questions on the diving environment such as sea, lake, cave, water temperature typically encountered, and affiliations were also investigated.

The second part of the survey was designed to collect information on the decompression algorithm used, oxygen partial pressure (PO_2) setpoint (in rebreather diving), bottom gas mix preferences, and gradient factors (GFs) for Bühlmann's model users across three target depths: 50, 80 and 100 metres of seawater (msw). Based on answers, the inspired PO_2, the equivalent narcotic depth (END, i.e., the air diving depth that would produce the same amount of narcosis as the trimix at its target depth) and the gas density for each maximal depth were calculated.[1]

The third part was oriented to occurrence of subjective clinical symptoms as previously described,[12] actions taken in response to symptoms (i.e., self or medical treatment) and long-lasting sequelae after symptoms in mixed-gas diving. Questions regarding gas-toxicity covered symptoms of narcosis (i.e., unusual euphoric feeling, concentration disorders or alteration in judgement at depth), loss of consciousness (LOC) at depth, or high-pressure nervous syndrome (HPNS, i.e., uncontrollable shaking of limbs or whole body excluding cold shivering, usually only apparent at extreme depths). Symptoms compatible with DCS were suggested by unusual tiredness, arm, leg, or articular pain, dizziness, vomiting, ear ringing, or hearing impairment, and acute back pain, tingling, or a decreased limb strength. Persistent breathing difficulties after surfacing, with or without foamy sputum, were also investigated. Given narcosis is a predictable biochemical consequence of deep

***Footnote:** Supplementary Appendix 1 is available to download from: https://www.dhmjournal.com/index.php/journals?id=354 diving, it was not classified as a diving-related incident in this study. Similarly, barotrauma, the leading cause of diving injury and primarily affecting beginners, was not investigated and not considered in this definition.[12]

STATISTICAL ANALYSIS

Most responses were analysed descriptively. Continuous variables are presented as mean (standard deviation [SD]) when normally distributed and median and interquartile range (IQR) when normality test fail. Categorical variables are presented as counts and percentages. Comparisons between discrete variables were performed using Fisher's exact test. Data processing and analyses were conducted using R version 4.3.2 basic configuration. Statistical significance was defined as a P-value < 0.05.

Results*

*Originally submitted tables which, in Tables 2, 4 and 5 include detailed data broken down by nationality of respondents, have been included in *Supplementary Appendix 2.

During the study period 559 responses were received. One was excluded due to incoherent answers.

DESCRIPTION OF THE TRIMIX DIVER COMMUNITY

Thus, 558 were collected for analysis purpose (514 males and 44 females). The age classes were 18–25 for 11 (2%), 26–35 for 66 (11.8%), 36–45 for 143 (25.6%), 46–55 for 212 (38%) and older than 55 years for 126 (22.6%) divers. The distribution by country is shown in Table 1. Table 2 depicts medical conditions known as a risk factors declared by divers including obesity. Twenty-three (4.1%) divers reported at least two risk factors. All were male (Table 3). Considering obesity as a risk factor, 323 (57.9%) reported none, including 32/44 (72.7%) of the females.

In relation to scuba diving experience, 16 (2.9%) declared practising diving for less than five years, 77 (13.8%) between 6–10 years, 161 (28.9%) between 11–20 years and 304 (54.5%) for over 20 years. The trimix experience is shown in Table 1. Three-hundred-forty-seven (62.2%) held the highest trimix certification level, including 20/44 (45.5%) of the females. Dive parameters associated with different certification levels vary, but an indicative classification is as follows: Helitrox/basic mixed-gas diver – maximum depth 45 msw and helium fraction ≤ 35%; Trimix/mixed-gas – maximum depth 60–70 msw and minimum oxygen fraction 16–19%; Advanced Trimix/advanced mixed-gas – maximum depth 100–120 msw with unlimited helium fractions and hypoxic mixes as required.

Four hundred and four (72.4%) technical divers were engaged solely in recreational diving activity. One-hundred-and-five (18.8%) reported a teaching activity (instructor), and 30 (5.4%) had other professional diving activity such as military, media, scientific diving. Sixteen (2.9%) combined these two activities, while seven (1.3%) were involved exclusively in other professional activities without any recreational diving practice. Six (13.6%) females reported diving for occupational purposes. More than one training organisation in their technical diving certifications were reported by 255 (45.7%). The agencies most represented were TDI (Technical Diving International, n = 260, 46.6%) and IANTD (International Association of Nitrox and Technical Divers, n = 217, 38.9%).

CURRENT PRACTICES

Rebreathers were used, at least occasionally, by 441 (79%) of respondents. Open circuit scuba was used exclusively by 75/191 (39.3%) of 'mixed-gas' and 36/347 (10.4%) of 'advanced mixed-gas' certified divers (Table 1). Age range did not influence the apparatus preference (P = 0.09). Dry suits were used by 479 (85.8%) divers, among which 156/479 (32.6%) also utilised a dry suit heating system. Divers reported mainly practising technical diving in their home country for 357 (64%) and abroad for 88 (15.8%). The others dive equally between the two. They dive, at least in part, in cave or lake (and quarry) for 145 (26%) and 202 (36.2%) respectively (Figure 1).

To manage decompression, 476 (85.3%) divers declared using the Bühlmann's model while 75 (13.4%) used bubble models (Reduced Gradient Bubble or Varying Permeability Models). Seven (1.3%) didn't answer. The survey focused on user-adjusted low-GF and high-GF for Bühlmann algorithm (Figure 2). The setting remained unchanged by 162/476 (34%) irrespective of the depth. The calculated median (IQR) density of bottom gas was 5.8 (5.5–6.9) and 5.9 (5.3–6.6) $g.L^{-1}$ in OC and RE respectively. Sixteen/301 (5.3%) respondents for rebreather diving didn't use helium at 50 msw (i.e., they used air diluent), while 4/186 (2.2%) used heliox (i.e., oxygen-helium mix with no nitrogen) for 100 msw dives. Values exceeding ideal and recommended maximum gas density are shown in Table 4. For rebreather dives, the chosen trimix diluent resulted in a $PO_2 \leq 1.1$ bar at the maximal depth for 236/301 (78.4%), 204/234 (87.2%), 174/186 (93.6%) and an END ≤ 30 msw for 233/301 (77.4%), 139/234 (59.4%), 138/186 (74.2%) at 50, 80 and 100 msw respectively. At maximal depth, a $PO_2 > 1.4$ bar and > 1.6 bar were exceeded for 18/205 (8.8%) and 6/205 (2.9%) OC respondent divers. Rebreathers allow breathing at a constant PO_2 'set point' chosen by the user. The most common PO_2 set point declared was 1.3 bar (n = 302/441, 68.5% and n = 247/441, 56% at the bottom and during the

*Footnote: Supplementary Appendix 2 is available to download from https://www.dhmjournal.com/index.php/journals?id=354

Table 1

Comparative table of the entire study population, distinguishing between divers with no reported incidents and those with at least one (n = 121) diving-related incidents; only responses expressing certainty of a symptomatic problem (or not) are considered. Diving-related incidents encompassed biochemical (gas related – but not nitrogen narcosis), decompression sickness or pulmonary symptoms during or after trimix dives. France-OT – overseas French territories; NZ – New Zealand; UK – United Kingdom

Parameter	Questionnaire options	Overall *n* (%)	No Diving incident *n* (%)	≥ 1 Diving incident(s) *n* (%)
Experience since first trimix certification (Years)	< 1	35 (6.3)	20 (8.2)	2 (1.7)
	1–5	201 (36)	100 (40.8)	34 (28.1)
	6–10	152 (27.2)	56 (22.9)	39 (32.2)
	11–20	130 (23.3)	55 (22.5)	29 (24)
	> 20	40 (7.2)	14 (5.7)	17 (14.1)
	Sum	558 (100)	245 (100)	121 (100)
Level of trimix certification	Helitrox	20 (3.6)	11 (4.5)	–
	Trimix	191 (34.2)	103 (42)	23 (19)
	Advanced Trimix	347 (62.2)	131 (53.5)	98 (81)
	Sum	558 (100)	245 (100)	121 (100)
Number of trimix dives	< 20	85 (15.2)	46 (18.8)	12 (9.9)
	20–50	129 (23.1)	65 (26.5)	15 (12.4)
	51–100	98 (17.6)	46 (18.8)	20 (16.5)
	101–500	172 (30.8)	62 (25.3)	46 (38)
	> 500	74 (13.3)	26 (10.6)	28 (23.1)
	Sum	558 (100)	245 (100)	121 (100)
Frequency of trimix practice (Dives per year)	< 5	90 (16.1)	47 (19.2)	11 (9.1)
	6–10	111 (19.9)	58 (23.7)	16 (13.2)
	11–20	121 (21.7)	57 (23.3)	22 (18.2)
	21–30	94 (16.8)	32 (13.1)	28 (23.1)
	> 30	142 (25.5)	51 (20.8)	44 (36.4)
	Sum	558 (100)	245 (100)	121 (100)
Trimix breathing equipment used	Rebreather	282 (50.5)	124 (50.6)	104 (52.3)
	Open Circuit	117 (21)	61 (24.9)	31 (15.6)
	Both	159 (28.5)	60 (24.5)	64 (32.2)
	Sum	558 (100)	245 (100)	121 (100)
Country of residence	France	221 (39.6)	106 (43.3)	43 (35.5)
	UK	61 (10.9)	22 (9)	17 (14.1)
	Belgium	54 (9.7)	28 (11.4)	11 (9.1)
	Germany	41 (7.4)	17 (6.9)	10 (8.3)
	Switzerland	30 (5.4)	11 (4.5)	8 (6.6)
	USA	24 (4.3)	10 (4.1)	4 (3.3)
	France-OT	22 (3.9)	11 (4.5)	2 (1.7)
	Canada	19 (3.4)	8 (3.3)	5 (4.1)
	Australia-NZ	12 (2.2)	6 (2.5)	2 (1.7)
	Other	74 (13.3)	26 (10.6)	19 (15.7)
	Sum	558 (100)	245 (100)	121 (100)
Most common water temperature (°C)	< 8	107 (19.2)	45 (18.4)	24 (19.8)
	8-20	331 (59.3)	144 (58.8)	72 (59.5)
	20-25	70 (12.5)	32 (13.1)	15 (12.4)
	> 25	50 (9)	24 (9.8)	10 (8.3)
	Sum	558 (100)	245 (100)	121 (100)

Table 2
Medical risk factors related to diving reported by respondents; the total of 555 only relates to subjects for whom body mass index (BMI) information is available; + Ob – number of respondents with both the specified condition and a BMI ≥ 30 kg.m^{-2}

Sex	General population		Overall conditions				Detailed risk factors and obesity (Ob)									
		BMI kg.m^{-2}	BMI ≥ 30 kg.m^{-2}		All risk factors (Cumulative)		Arterial hypertension		Diabetes mellitus		Heart disease		Low physical activity		Smoking	
	N	Mean (SD)	*n* (%)	Mean (SD)	*n* (%)	+ Ob *n* (%)	*n*	+ Ob *n* (%)	*n*	+ Ob *n* (%)	*n*	+ Ob *n* (%)	*n*	+ Ob *n* (%)	*n*	+ Ob *n* (%)
Male	511	26.9 (3.8)	98 (19%)	32.8 (2.8)	163 (32)	38 (23)	41	14 (34)	16	4 (25)	11	3 (27)	88	21 (24)	40	6 (15)
Female	44	24.9 (5)	7 (16%)	34.3 (3.1)	8 (18)	3 (38)	2	1 (50)	–	–	–	–	4	2 (50)	2	–
Total	555	26.8 (3.9)	105 (19%)	32.9 (2.8)	171 (31)	41 (24)	43	15 (35)	16	4 (25)	11	3 (27)	92	23 (25)	42	6 (14)

Table 3
Accumulated medical risk factors related to diving reported by technical diving subjects

Condition	*n* (%)
Subjects with no risk factors	386 (69.2)
Subjects who declared one risk factor, *n* = 149 (26.7%)	
Low physical activity	76 (13.6)
Smoking	29 (5.2)
Arterial hypertension	28 (5)
Diabetes mellitus	9 (1.6)
Heart disease	7 (1.3)
Subjects who declared two risk factors, *n* = 18 (3.2%)	
Low physical activity + Smoking	6 (1.1)
Arterial hypertension + Low physical activity	5 (0.9)
Arterial hypertension + Smoking	3 (0.5)
Arterial hypertension + Diabetes mellitus	2 (0.4)
Heart disease + Smoking	1 (0.2)
Diabetes mellitus + Low physical activity	1 (0.2)
Subjects who declared three risk factors, *n* = 2 (0.4%)	
Arterial Hypertension + Low Physical Activity + Smoking	1 (0.2)
Arterial hypertension + Diabetes mellitus + Low physical activity	1 (0.2)
Subject having declared four risk factors, *n* = 1 (0.2%)	
Arterial hypertension + Diabetes mellitus + Heart disease + Low physical activity	1 (0.2)
Subjects who declared five risk factors, *n* = 2 (0.4%)	
Arterial hypertension + Diabetes mellitus + Heart disease + Low physical activity + Smoking	2 (0.4)
Total	***n* = 558**

ascent time respectively). From the 6-msw decompression stop, 338/441 (76.6%) declared setting their PO_2 ≥ 1.4 bar (Table 5).

SELF-REPORTED ABNORMAL PATHOLOGICAL SYMPTOMS

Self-reported diving-related symptoms covered all participants' mixed-gas diving experiences, including gas toxicity, DCS, and pulmonary symptoms (Table 6). The most frequent gas-toxicity symptom was 'euphoric feeling'. It

Figure 1

Trimix diving environment related by nation of residence; France-OT – Overseas French territories; NZ – New Zealand; UK – United Kingdom; USA – United States of America

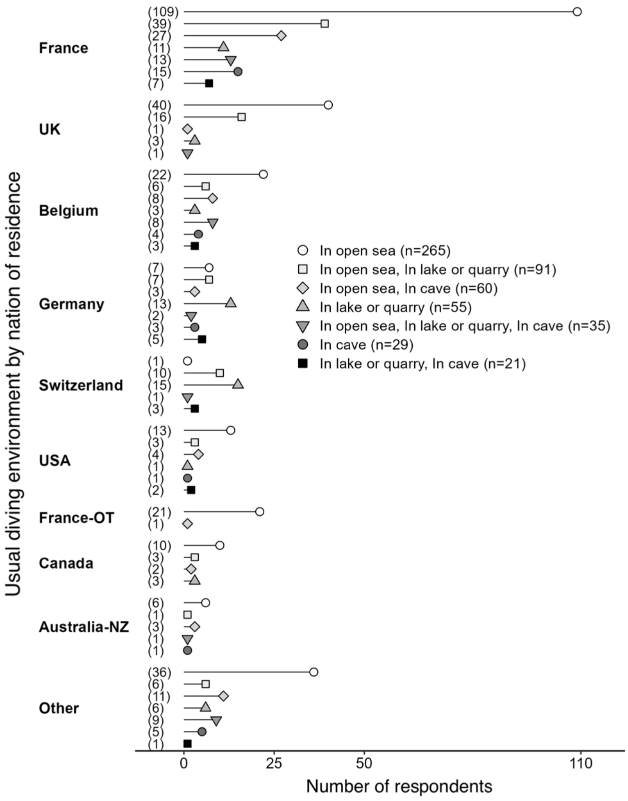
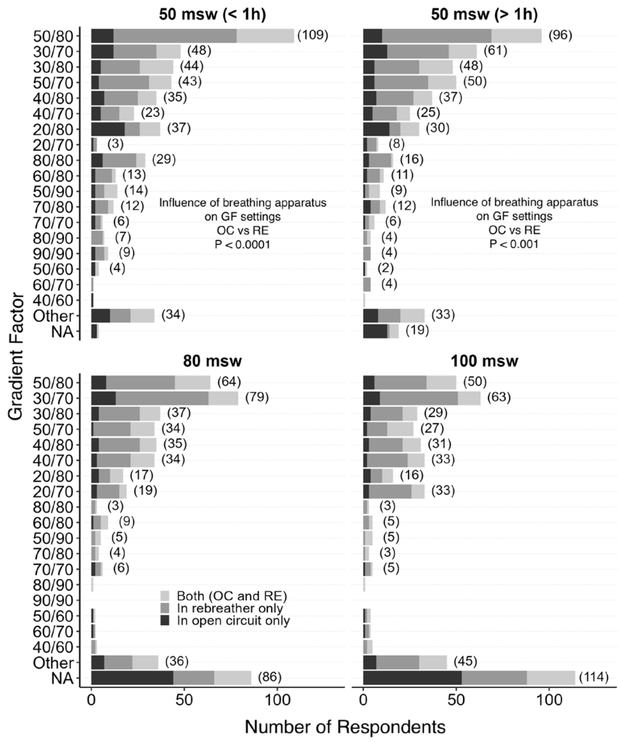


Figure 2

Gradient Factor (GF) choices related to dive profile; the one-hour limit in the 50 msw dives is the total ascent time (TTS; Time to surface) including ascent with any decompression obligations. GF are expressed by a combination of low / high (see text for an explanation). A total of 53 different combinations were declared regardless of the dive profile. For a 50 msw dive, the TTS had no significant effect on settings (P = 0.6). However, the breathing apparatus (OC vs RE) used led to significant differences in GF parameters regardless of dive time (see figure). GF settings were not significantly influenced by depth at 80 and 100 msw (P = 0.4) nor by the breathing apparatus at those depths (P = 0.1)



was noted by 3/20 (15%) of basic trimix divers and 39/538 (7.3%) with higher levels of certification.

Sixty-four percent (n = 359) of divers reported having never experienced any diving-related incidents, among which 114/359 (31.8%) remained uncertain. Conversely, 199 (35.7%) experienced an incident at least once. That concerned 13/44 (29.6%) of the females, independently of the degree of certainty. Fifty-nine (10.6%) divers declared more than one event. Seven (1.3%) (five definite) respondents experienced breathing trouble, exclusively in rebreather diving. All were male and no one was older than 55 years old.

Regardless of the type of DCS symptoms and the degree of certainty (n = 254 events), FAO_2 was received in 107/254 (42.1%) events and medical advice was sought in 59/254 (23.2%). Forty-one/254 (16.1%) were treated with HBO (Table 7). In 120/254 (47.2%) events, divers did not report having initiated any treatment. When musculoskeletal pain was declared, 33/101 (32.7%) took antalgic drugs by themselves. Divers received significantly more frequent care when the symptoms were identified as pathological with certainty rather than with a doubt (P < 0.0001). When symptoms appeared more severe, suggestive of inner-ear or neurological conditions, divers were more likely to consult a doctor than in other cases (n = 12/31, 38.7% vs n = 47/222, 21.2% P = 0.04). However, there was no difference in use of FAO_2 in these more severe cases when compared to milder cases (n = 14/30, 46.7% vs n = 93/220, 42.3% P = 0.7) or even in accessing HBO treatment (n = 7/31, 22.6% vs n = 34/223, 15.3% P = 0.3). Five/199 (2.5%) divers declared suffering from long-lasting sequelae after DCS symptoms. Four received FAO_2 and only one HBO treatment. After they experienced breathing issue, only two divers used FAO_2, and one sought medical advice.

Discussion

DEMOGRAPHIC DESCRIPTION

The use of rebreathers has become mainstream in technical diving, particularly for deep dives. This study reveals significant variations in planning behaviors, with some diver practices not always aligning with current recommendations. This could highlight either a lack of robust scientific data

Table 4

Proportion of divers exceeding the ideal (5.2 g·L^{-1}) and maximum recommended (6.2 g·L^{-1})[21] gas density on dives stratified by depth and underwater breathing apparatus used; gas density calculation was based on respired gas at maximum depth. For rebreathers, the calculation is based on mixed-gas diluent composition and the bottom oxygen partial pressure set point breathed in the loop; msw – metres of seawater

Breathing apparatus	At 50 msw			At 80 msw			At 100 msw		
	Overall *N* (%)	> 5.2g·L^{-1} *n* (*n/N*%)	> 6.2g·L^{-1} *n* (*n/N*%)	Overall *N* (%)	> 5.2g·L^{-1} *n* (*n/N*%)	> 6.2g·L^{-1} *n* (*n/N*%)	Overall *N* (%)	> 5.2g·L^{-1} *n* (*n/N*%)	> 6.2g·L^{-1} *n* (*n/N*%)
Rebreather	301 (54.8)	181 (60.1)	27 (9)	234 (60.5)	200 (85.5)	113 (48.3)	186 (62.4)	172 (92.5)	80 (43)
Open circuit	113 (20.6)	85 (75.2)	21 (18.6)	41 (10.6)	36 (87.8)	30 (73.2)	21 (7.1)	21 (100)	17 (81)
Both	135 (24.6)	69 (51.1)	14 (10.4)	112 (28.9)	75 (67)	48 (42.9)	91 (30.5)	67 (73.6)	33 (36.3)
Total	549 (100)	335 (61)	62 (11.3)	387 (100)	311 (80.4)	191 (49.4)	298 (100)	260 (87.3)	130 (43.6)

Table 5

Oxygen partial pressure setpoint selected by rebreather users related to the phase of the dive; DNK – don't know / no position

Partial pressure of oxygen set point							
1.1 bar *n* (%)	1.2 bar *n* (%)	1.3 bar *n* (%)	1.4 bar *n* (%)	1.5 bar *n* (%)	1.6 bar *n* (%)	DNK *n* (%)	Sum *n* (%)
During bottom time							
14 (3.2)	98 (22.2)	302 (68.5)	22 (5)	3 (0.7)	1 (0.2)	1 (0.2)	441 (100)
During ascent							
	59 (13.4)	247 (56)	76 (17.2)	45 (10.2)	12 (2.7)	2 (0.4)	441 (100)
From 6-msw decompression stop							
		99 (22.5)	74 (16.8)	87 (19.7)	178 (40.4)	3 (0.7)	441 (100)

supporting these guidelines or a diversity in teaching and individual approaches. Estimating the number of technical divers is challenging, but recent data suggest there are about 20,000 active rebreather divers worldwide.[13] Among this community, the number of mixed-gases certified divers remains unknown. While the proportion of trimix divers represented by the present study cannot be estimated, this work provides one of the first representations of this community that moves beyond anecdotal evidence.[14]

In recreational diving, it is common knowledge that there are more males than females, and most of divers hold beginner level certifications and dive occasionally. Most divers are age 30–40, with females representing 17–37% of the population.[15] In contrast, technical divers are generally older, with two-thirds of respondents over 46 years old; a trend consistent with other recent studies.[9,11,13] Significant diving experience remains a prerequisite for technical diving and most respondents have reached the maximal trimix certification. However, this may evolve with the possibility of training in 'light' recreational trimix (helium fraction < 35% and 45 msw maximal depth) from advances diver with a minimum experience of 40-50 dives.[2,3] Female representation, already low in recreational diving, is even smaller in technical diving, ranging from 7–16% in previous studies, and 8% in the present study.[11,16] This sex disparity could partly be explained by how the survey was distributed, as social media usage differs by gender.[17] Additionally, gender differences in diving practices have been noted, with technical and equipment-focused aspects potentially contributing to a predominantly male community.[18] However, a new generation of female divers is emerging, increasingly participating in traditionally male-dominated activities.

One third of technical divers reported having a condition considered as a medical diving risk factor that is consistent with the recreational diving community, with a progressive increase with age.[7,19] Despite this, the prevalence of most conditions is lower than in the global population and may be the subject of preventive actions.[20] Obesity, a major risk factor for metabolic and cardiovascular diseases, is over-represented among divers. Most of the cardiorespiratory diseases or diabetes were historically considered a contraindication for scuba diving though this position has evolved through better understanding and medical supervision of these conditions in diving. Promoting physical exercise associated with health and diet rules must be

Table 6
Self-reported diving-related symptoms in trimix diving; HPNS – high pressure nervous syndrome

Event evocative of gas effect/toxicity			
Questionnaire response	Narcosis *n* (%)	Loss of consciousness *n* (%)	HPNS *n* (%)
Never reached depth > 100 msw			284 (50.9)
Definite no	464 (83.2)	545 (97.7)	255 (45.7)
Probably not but doubtful	52 (9.3)	6 (1.1)	10 (1.8)
Yes, potentially but doubtful	22 (3.9)	3 (0.5)	3 (0.5)
Definite yes	20 (3.6)	4 (0.7)	6 (1.1)
Total	558 (100)	558 (100)	558 (100)

Event evocative of decompression sickness					
Questionnaire response	Unusual intense tiredness *n* (%)	Musculoskeletal pain *n* (%)	Dizziness / hearing trouble *n* (%)	Neurological trouble *n* (%)	Breathing trouble *n* (%)
Definite no	307 (55.0)	417 (74.7)	519 (93.0)	531 (95.2)	545 (97.67)
Probably not but doubtful	129 (23.1)	40 (7.2)	18 (3.2)	17 (3.1)	6 (1.1)
Yes, potentially but doubtful	61 (10.9)	39 (7.0)	3 (0.5)	4 (0.7)	2 (0.4)
Definite yes (one time)	27 (4.8)	34 (6.1)	14 (2.5)	5 (0.9)	4 (0.7)
More than one time	34 (6.1)	28 (5.0)	4 (0.7)	1 (0.2)	1 (0.2)
Total	558 (100)	558 (100)	558 (100)	558 (100)	558 (100)

encouraged to limit the risk of medical incidents. Periodic assessments by a competent diving practitioner should be appropriate for these exposed divers to prevent risk.

DIVING HABITS

Training agencies typically limit technical diving training to depths of 100–120 msw, making the dive profiles in this study representative of mainstream technical diving.[1–3] One of the major challenges for divers is the uncertainty surrounding decompression safety, which involves various factors such as algorithm configuration, gas choices, oxygen exposure, and ascent speed.[5]

To minimise nitrogen narcosis and gas density, higher helium fractions are used at greater depths.[1] Divers are proficient in managing oxygen exposure and calculating END. However, gas density often exceeds rebreather recommendations, which set an ideal gas density at 5.2 $g.L^{-1}$ and a goal of not exceeding 6.2 $g.L^{-1}$.[21] Exceeding these limits increases the work of breathing and can impair the ventilatory response to rising CO_2 levels, potentially leading to hypercapnia, immersion pulmonary oedema (IPO), and even fatal outcomes.[22,23] In OC, pulmonary constraints are presumed to be lower, allowing for higher tolerances, although no international consensus exists. For instance, French commercial diving regulations set a maximum gas density of 9 $g.L^{-1}$. Very few divers have reported respiratory symptoms suggestive of IPO, despite the suspected contribution of the hydrostatic load potentially induced by rebreather use and increased gas density.[23] The reasons for limiting helium fraction are cost considerations (especially in OC diving) and shortening the decompression obligation by reducing the 'helium penalty'.[5] The financial aspect must be no longer be a concern in technical diving since rebreather use is becoming more common. From this point of view, it seems important to raise community awareness of the impact of gas density on the risk of hypercapnia and the potential increased risk of DCS with CO_2 retention during bottom phase of a dive.[24]

Choosing the right decompression algorithm is a delicate balance between minimising time in the water and ensuring a safe decompression.[5] Compartmental models such as Bühlmann's, and related derived algorithms are widely used. There was previously a widespread belief that bubble algorithms, which promote 'deep-stops', were more efficient but recent data support the opposite.[5,16] User-adjustable GFs result in a modified decompression profile so that the low-GF number influences the depth of the first-stop, while the high-GF number affects the duration of shallower stops.[5] The numbers themselves represent the percentage of the allowable Buhlmann supersaturation in the notional leading tissue (closest to the Bühlmann supersaturation limit) at the first stop (low number) and on arrival at the surface (high number). Planning strategies vary widely between divers,

Table 7
Symptoms suggestive of decompression sickness and healthcare management; DNK – don't know / no position; FAO_2 – normobaric first aid oxygen; HBO – hyperbaric oxygen

Symptom description	Questionnaire answers	FAO_2			Seek medical advice			Receive HBO therapy		Long lasting sequelae		
		Yes	No	DNK	Yes	No	DNK	Yes	No	Yes	No	DNK
Unusual intense tiredness	Yes, potentially but doubtful	13	46	2	3	57	1	2	59			
	Yes (one time)	10	17	0	3	24	0	3	24			
	More than one time	16	18	0	10	24	0	5	29			
	Total	39 (32.0)	81 (66.4)	2 (1.6)	16 (13.1)	105 (86.1)	1 (0.8)	10 (8.2)	112 (91.8)			
Musculoskeletal pain	Yes, potentially but doubtful	7	31	1	6	33		3	36	2	34	3
	Yes (one time)	27	7	0	15	19		14	20	1	33	0
	More than one time	20	8	0	10	18		7	21	0	26	2
	Total	54 (53.5)	46 (45.5)	1 (1.0)	31 (30.7)	70 (69.3)		24 (23.8)	77 (76.2)	3 (3.0)	93 (92.1)	5 (5.0)
Dizziness and hearing trouble	Yes, potentially but doubtful	0	3		0	3		0	3	0	3	0
	Yes (one time)	8	6		7	7		4	10	1	12	1
	More than one time	0	4		2	2		0	4	0	4	0
	Total	8 (38.1)	13 (61.9)		9 (42.9)	12 (57.1)		4 (19.1)	17 (81.0)	1 (4.8)	19 (90.5)	1 (4.8)
Neurological trouble	Yes, potentially but doubtful	2	1	1	0	4		1	3	1	3	
	Yes (one time)	3	2	0	3	2		2	3	0	5	
	More than one time	1	0	0	0	1		0	1	0	1	
	Total	6 (60)	3 (30)	1 (10)	3 (30)	7 (70)		3 (30)	7 (70)	1 (10)	9 (90)	

with choices often based on experience or beliefs rather than scientific evidence.[4] The use of GFs is not directly linked to experimentally validated decompression profiles.[5] Our study shows that divers tend to lower their GF settings with increasing depth. The practice of deep stops has been heavily debated, particularly for air dives, where nitrogen loading is high.[25] The optimal decompression path, especially when managing both helium and nitrogen, remains unresolved. Helium's lower solubility and faster washout suggest decompression should begin earlier in helium-based dives, though without reaching the classical 'deep stop' thinking.

During decompression, the inspired oxygen fraction is progressively increased to accelerate the elimination of inert gases. In OC, the gas mixes carried and breathed determines the PO_2 at each depth, requiring gas switches to optimise decompression during ascent. Oxygen toxicity is less of a concern in OC since the PO_2 peak is generally breathed for relatively short periods. However, in rebreather diving, high PO_2 levels are maintained throughout most of the dive, typically at a set point of 1.3 to 1.4 bar, which is considered safe. Short exposures to 1.6 bar are tolerated by most agencies.[2,3] Although most divers respect these limits, two-thirds reported using a $PO_2 \geq 1.4$ bar during decompression. Oxygen toxicity is cumulative and can lead to seizure and drowning. Exceeding current exposure limits doesn't appear to cause significant decrease in lung function, although some symptoms consistent with oxygen toxicity (chest tightness or dry cough) have been described by technical divers.[26] Given that decompression times often exceed two or three hours, exposure to high PO_2 levels during the ascent may quickly exceed safe neurological toxicity thresholds.[27] Other factors, such as hypercapnia, thermal stress, and medication, can exacerbate susceptibility. A reasonable balance can be achieved by keeping $PO_2 \leq 1.3$ bar during the bottom phase, where the reduction in inert gas uptake is modest to safely manage oxygen during shallow decompressions stops.

DIVING RELATED INCIDENTS

More than a third of respondents reported symptoms suggestive of diving-related incidents. Although not considered as an injury or incident, narcosis was rarely mentioned due to compliance with END limits. Most serious gas-toxicity symptoms seem uncommon but remain life-threatening. This contrasts with military diving, where equipment and procedures are different, and where gas toxicity was found to be the most common diving incident, with hypercapnia and hyperoxic seizures frequently reported.[28]

DCS may present with a wide range of symptoms sometimes making the diagnosis difficult. In retrospective recreational diving surveys, the incidence of self-reported symptoms was around two per 10,000 dives and 15% of divers reported potential DCS histories. Severe cases accounted for 15–27% of these reports.[12,29] The incidence may be higher among technical divers, but few data are available.[9,11] This was previously discussed by Tuominen, who reported an incidence of 91 per 10,000 dives, with 31% of divers experiencing DCS symptoms during a one-year follow-up period.[11] Nearly all reported symptoms in technical diving are considered 'mild' as characterised by an international consensus.[30] Constitutional symptom and musculoskeletal pain are predominant (88% of cases), while neurological impairment is uncommon in helium mixed-gas diving, consistent with the literature.[9,11]

Several studies have demonstrated that first aid for diving injuries is often inadequate.[11,12,18] In recreational diving, 32% of divers with symptoms did not receive any treatment.[12] In the present study, half of the respondents did not undertake any treatment. Although technical divers are presumed skilled with easy access to oxygen, only 42% used FAO_2. Neglect of these symptoms seems to be related to the estimated level of severity, as has already been highlighted elsewhere.[12] This behavior may lead to the appearance of distant complications such as dysbaric osteonecrosis (DON) in this population, though despite the theoretical risk, clinically apparent cases still seem rare.[10] Among recreational divers who have presented DCS symptoms, 23% have declared long-term consequences compared to only 2.5% in our population.[12] The predominance of mild symptoms in technical diving might explain this difference.[11] However, DON may become symptomatic years later, potentially leading to an underestimation of their severity in the absence of systematic imaging evaluation. Raising awareness about the recognition of symptoms and proper first aid still appears necessary among these exposed divers.

LIMITATIONS

This study faced several limitations. Firstly, the dissemination channel may have introduced recruitment bias, and the response rate is unknowable. The most active divers on social media are likely those more engaged in the community. Their presence may be age- or sex-dependent. Secondly, there is a significant imbalance in the respondents' distribution by country, with a predominant representation from Europe. Consequently, no formal analysis of regional variation could be drawn. Finally, like all surveys, the methodology induces recall bias, leading to potential over- or under-reporting of symptoms frequency, severity or reactions.

Conclusions

The diversity of practices highlights the lack of robust scientific data supporting them, and controversies and discussions are still ongoing. The issue of gas density does not appear to concern divers, even though it could have detrimental effects. The incident rate in mixed-gas diving may be higher than in recreational diving, albeit with mostly mild severity. Treatment of DCS symptoms often appears to be neglected despite divers' high level of knowledge. The prognosis often appears to be favorable, although it could be speculated there might be an increasing incidence of DON over time. Continued efforts in awareness and education regarding training standards and diving first aid are essential for this exposed community. The results of this study could provide valuable insights to enhance training recommendations and inform future research initiatives.

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