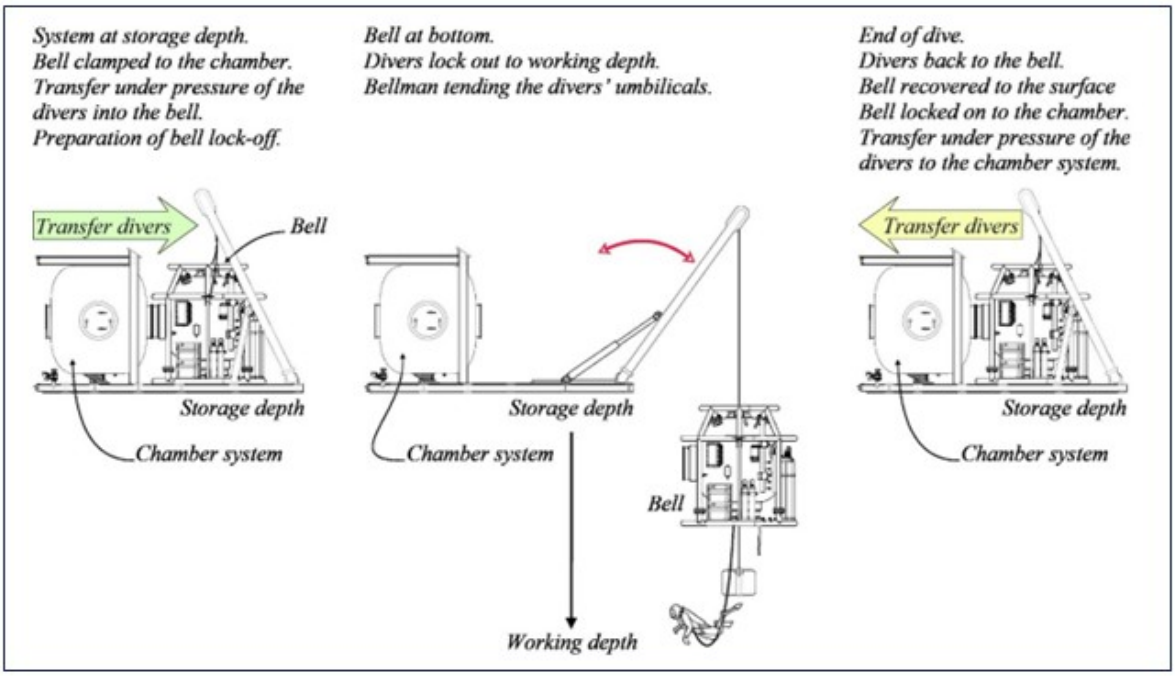
Diving and Hyperbaric Medicine

The Journal of the South Pacific Underwater Medicine Society and the European Underwater and Baromedical Society©

SPUMS *Volume 56 No. 1 March 2026* EUBS



Excursion procedures in saturation diving

Full face masks for ventilation in dive rescue

10,000 open access post-dive Doppler recordings

Lung ultrasound changes in deep breath-hold divers

Timing of HBO in sudden hearing loss

Scuba tank fills for calculating accident rates

Decision regret and shared decision making in HBOT

Transgender people and occupational diving

Outcomes after recompression in inner ear DCS

Irrigation diluents after caustic cocktail ingestion

Dual rebreathers for deep long dives

E-ISSN 2209-1491 ABN 29 299 823 713

THE JOURNAL OF DIVING AND HYPERBARIC MEDICINE
***Diving and Hyperbaric Medicine* is published online jointly by the South Pacific Underwater Medicine Society and the European Underwater and Baromedical Society**
https://www.dhmjournal.com

EDITORIAL OFFICE

PURPOSES OF THE SOCIETIES

To promote and facilitate the study of all aspects of underwater and hyperbaric medicine
To provide information on underwater and hyperbaric medicine
To publish a journal and to convene members of each Society annually at a scientific conference

E-ISSN 2209-1491; ABN 29 299 823 713

CONTENTS

Diving and Hyperbaric Medicine Volume 56 No. 1 March 2026

1 **The Editor's offering**

Original articles

2 **Exploring the use of full-face masks for ventilation in dive rescue**
Elizabeth A Blizzard, Andrew A Grandin, Dalelynn Sims

8 **An echo from the past: open access repository of over 10,000 annotated Doppler audio recordings of venous gas emboli**
S Lesley Blogg, Arian Azarang, Rachel Lance, Frauke Tillmans, Richard Moon, Virginie Papadopoulou, Peter Lindholm

13 **Changes in lung ultrasound presentation induced by breath-hold diving in a simulated depth competition at Taiwan**
Ying-Jen Chi, Hsiu-Yung Pan, Po-Chun Chuang, Chi-Yung Cheng, Han-Yu Li, Meng-Huan Wu

21 **Review of excursion procedures used in commercial heliox saturation diving**
Jean-Pierre Imbert, Lyubisa Matity, Jean-Yves Massimelli, Christian Cadieux, Jan Risberg, Philip Bryson

41 **Treatment success in relation to timing of hyperbaric oxygen therapy in idiopathic sudden sensorineural hearing loss**
Cheuk-Yin Lun, Kwan-Leong Au Yeung, Yuk-Fai Lau, Wing-Wa Yan, Kin-Bong Tang

48 **Scuba tank fill survey in Victoria, Australia, 1 July 2024 to 30 June 2025**
John Lippmann

52 **Decision regret and shared decision-making in patients undergoing hyperbaric oxygen therapy**
Joost R Meijering, Nurseda Risvanoglu, Julia D van Waard, Johanna H Nederhoed, Rigo Hoencamp, Robert A van Hulst, Dirk T Ubbink

Review articles

59 **Transgender people and occupational diving: a new challenge for diving physicians?**
Pieter-Jan AM van Ooij, Annemarije R Bek, Robert A van Hulst

71 **Outcomes in the treatment of inner ear decompression sickness with hyperbaric oxygen therapy, a systematic review**
Rosanna J Stokes, Jonathan Marsden, Doug Watts, Gary Smerdon, Stephen D Hall, Lisa Bunn

Short communication

83 **Efficacy and safety of potential irrigation diluents following 'caustic cocktail' ingestion**
Adam Lee, Catherine Moore, Adam Griffiths

World as it is

88 **Dual rebreathers in practice: example experiences from the Wetmules and COBRA Divers**
Daniel Lee, Craig Challen, Gareth Lock

Letters to the Editor

95 **Liver disease and the Diver Medical Participant Questionnaire**
Andrew George Watson, Tiong Yeng Lim

96 **Comment on 'Effects of fluid loss on the physiology of closed-circuit rebreather divers after 100- and 45-metre dives by Tuominen, et al.'**
Peter T Wilmshurst, Christopher Edge

97 **Reply to comment by Peter T Wilmhurst and Christopher Edge**
Laura J Tuominen, Anne K Räisänen-Sokolowski, Richard V Lundell

Obituary

99 **Daniel Mathieu, MD, PhD**
Written by Parmentier E, Germonpré P, Kot J, Marroni A

SPUMS notices and news

100 **President's report**
Neil Banham

102 **Mike Bennett Scholarship**

104 **SPUMS Diploma in Diving and Hyperbaric Medicine**
(Updated June 2025)

105 **SPUMS 54th Annual Scientific Meeting 2026 notice**

EUBS notices and news

106 **President's report**
Bengüsu Mirasoğlu

107 **EUBS Notices and news**

107 **EUBS 50th Scientific Meeting 2026**

109 **Events, courses & meetings**

110 **Diving and Hyperbaric Medicine: Instructions for authors**
(Full version – updated January 2026)

Diving and Hyperbaric Medicine is indexed on MEDLINE, Web of Science® and Embase/Scopus
Articles from 2017 are deposited in PubMed Central®

The Editor's offering

Welcome to the first issue of DHM for 2026, the eighth year of my editorship. This issue has a strong diving focus, but with a substantial range of intriguing subject matter.

Elizabeth Blizzard and colleagues study the possibility of using diving equipment (in this case full face masks) to facilitate ventilation of a non-breathing diver either at the surface or even underwater. Although a measure of last resort, the Thailand cave rescue suggested that it is not impossible. More research is needed.

Lesley Blogg and colleagues have, remarkably, compiled a repository of over 10,000 post-dive Doppler bubble recordings from dives whose key parameters are known along with outcomes in some cases. They have made this repository essentially open access. Their paper in this issue describes the provenance and potential use of this amazing resource.

Ying-Jen Chi and colleagues explore the pulmonary complications of extreme freediving, an issue that has been receiving increasing attention in the literature recently. Their focus was on the use of ultrasound to evaluate lung changes indicative of pulmonary oedema in this extreme sports setting.

Jean-Pierre Imbert and colleagues continue a series of major practice reviews in relation to saturation diving. In this issue they review excursion procedures. Readers may wonder why this is not classified as a review article, but the authors have obtained substantial original data from a large proportion of the global companies that perform this sort of work. Indeed, the fact that they were able to do this in relation to matters that many companies consider commercially sensitive is testimony to the respect and trust accorded them in the industry.

Cheuk-Yin Lun and colleagues performed a retrospective cohort study involving patients treated with HBO for sudden hearing loss. Although this indication has received a lot of positive attention in recent literature, the present study has an interesting focus on timing of HBO treatment and its effect on outcomes.

John Lippmann addresses the age-old problem of deriving a number-of-dives-denominator for calculating diving mortality and complications rates by adopting a rarely used strategy. Assuming one fill = one dive, he assessed numbers of scuba cylinder fills in the state of Victoria over a period for which he had a hard numerator (confirmed DCI and scuba related deaths) and voila! – rare plausible incidence data for scuba injuries.

Joost Meijering, Nurseda Risvanoglu and colleagues study the relationship between application of shared decision making with HBO patients and decision regret after undertaking HBO treatment. I have always respected the objectivity of our Dutch colleagues in confronting some of the field's potentially sensitive issues such as the substantial commitment required of patients undertaking HBO, and managing expectations around uncertain outcomes. I strongly recommend this fascinating paper.

Pieter-Jan van Ooij and colleagues review the contemporary issue of transgender people entering the world of occupational diving. Open disclosure: before this article was submitted, I had naively assumed that simply applying occupational diving standards to diver selection would be a logical path in such scenarios, but it turns out to be (potentially) more complex than that. I am grateful for the guidance this article brings.

Rosanna Stokes and colleagues from the Plymouth group continue their comprehensive illumination of treatment strategy and outcomes in inner ear DCS in this review. This work is part of Rosanna's productive and topical PhD program in the thematic area of inner ear DCS and I offer my appreciation to Rosanna and her supervisors for taking on this difficult work in a topic area of strong personal interest.

There are two papers of substantial relevance to rebreather divers. In the first, Adam Lee and colleagues from the UK military perform a simple experiment to study the pH-lowering efficacy of different diluent solutions that a diver might used to rinse their mouth and upper airway in the event of a caustic inhalation. In doing so they challenge a popular opinion that acidic solutions should be avoided for fear of producing harmful exothermic reactions. In the second, Daniel Lee and colleagues provide a balanced account of the risks and benefits of employing dual rebreather configurations for deep long rebreather dives where carrying adequate open circuit 'bailout' gas for use in rebreather failure is becoming increasingly difficult.

Going into the new year, I would once again like to thank those colleagues who perform reviews for the journal. You are our means of maintaining quality in outputs, and in this era of ever-increasing workloads, I fully understand the challenges of review work. My sincere gratitude to you all.

Professor Simon Mitchell
Editor, Diving and Hyperbaric Medicine

Cover photo: The sequence of events of a saturation diving bell run from Imbert et al. in this issue.

Original articles

Exploring the use of full-face masks for ventilation in dive rescue

Elizabeth A Blizzard[1,2,3], Andrew A Grandin[2,3,4,5], Dalelynn Sims[6]

[1] *Rutgers New Jersey Medical School, Newark, New Jersey, USA*
[2] *Capital Health Life Support Training Center, Pennington, New Jersey, USA*
[3] *Grand Ideas Medical Consulting, Burlington, New Jersey, USA*
[4] *Capital Health Emergency Medical Services, Pennington, New Jersey, USA*
[5] *ChristianaCare LifeNet, New Jersey, USA*
[6] *Brunswick SCUBA, Freeman, Virginia, USA*

Corresponding author: *Elizabeth Blizzard, 43 Bertrand Dr, Princeton, NJ 08540, USA*
ORCiD: *0009-000 2-3070-8811*
eab318@njms.rutgers.edu

Keywords
Diving medicine; Diving research; First aid; Life support; Rescue; Resuscitation

Abstract
(Blizzard EA, Grandin AA, Sims D. Exploring the use of full-face masks for ventilation in dive rescue. Diving and Hyperbaric Medicine. 2026 31 March;56(1):2−7. doi: 10.28920/dhm56.1.2-7. PMID: 41875436.)
Introduction: Early oxygenation is essential in a non-breathing scuba accident victim, but the need to exclude water has thus far prevented underwater ventilation, causing significant delay. The full-face mask (FFM) is a potential solution, but its safety and feasibility in this context has not been established. This is a preliminary study into the utility of FFMs for underwater ventilation.
Methods: The tidal volume and peak inspiratory pressure delivered by the OTS Guardian and Neptune III FFMs were measured using a RespiTrainer Advance Airway Management Trainer and an open circuit scuba system. Ventilations were tested with varying lengths of purge valve depression and degrees of tightness of the FFM. A tidal volume of 350–560 mL was considered ideal. Thresholds considered to be high risk were 700 mL for volutrauma and peak inspiratory pressure > 3.4 kPa for barotrauma.
Results: In all trials, the delivered pressure remained well below the 3.4 kPa threshold. The delivered volume was consistently less than 700 mL in at least one trial condition per FFM, although this required the fastest possible release of the Guardian purge valve without maximal mask tightening. The Neptune remained below 700 ml regardless of technique but required a one second purge valve depression to deliver sufficient volume (> 350 mL).
Conclusions: Recommendations need to be tailored to specific masks styles or brands. However, this form of ventilation could be feasible. Our findings are most directly applicable to ventilation at the surface. Further testing of these and other FFMs in simulation at depth will be necessary to evaluate the masks' use for ventilation. These results merit further investigation.

Introduction

Drowning is generally listed as the most common cause of death in diving-related fatalities.[1,2] In these cases, hypoxaemia is the leading cause of cardiac arrest. Because of this, early treatment of hypoxia is extremely important, and in-water ventilations may be beneficial once the victim reaches the surface.[3–6] In the past this has been accomplished via mouth-to-mouth, mouth-to-pocket mask, or mouth-to-snorkel methods.[4–6]

However, diving accidents may present several scenarios where these methods are insufficient. In military diving and technical diving with overhead environments or decompression, it may not be feasible to return the victim to the surface in time to prevent irreversible brain damage and death from hypoxia.[7] Public safety and commercial divers also frequently wear full face masks (FFMs) due to due to water conditions, and could benefit from the ability to ventilate without risk of contamination both underwater and at the surface.[7] Currently recommended surface ventilation techniques can be difficult to achieve, especially in rough water conditions.

The possibility of delivering ventilation underwater has already been investigated with conventional resuscitation equipment used outside of diving. Mask ventilators, laryngeal tubes, and endotracheal tubes were all found to be unsuccessful, generally due to issues with aspiration and inadequate seals, especially during device placement.[7,8] FFMs provide a potential solution to these problems. These masks cover the mouth and nose of the diver and

seal tightly to the face. This provides the unique advantage that they are likely to be found correctly positioned on an unconscious diver. The mask regulators have purge valves that deliver air forcefully into the mask, usually with the intention of clearing water that has entered the mask. This study evaluated the use of this valve to deliver ventilations.

The only prior study on the use of FFMs for ventilation looked at the Interspiro MK II.[7] This mask initially provided satisfactory ventilation but eventually caused large leaks that lead to massive water entry into the airway. The Interspiro MK II is just one of numerous FFMs available, so further study is required to see if other models might be able to overcome this issue.

This study evaluated two FFMs in a dry environment to determine if they could be a feasible way of delivering ventilation.

Methods

EQUIPMENT CONFIGURATION

The study was conducted using a RespiTrainer Advance Airway Management Trainer (IngMar Medical, Pittsburgh, USA). This mannequin monitors the respiratory rate delivered as well as the tidal volume and peak pressure for each breath (with a breath being defined as the volume delivered by one purge valve depression). The mannequin was factory calibrated by the manufacturer with respiratory mechanics set to a compliance of 50 $mL \cdot cmH_2O^{-1}$ and a resistance of 5 $cmH_2O \cdot L^{-1} \cdot s^{-1}$.[9] A scuba tank supplied compressed air to the FFM, which was applied to the mannequin head. The same person used the purge valve to ventilate the mannequin in all trials. The person providing ventilations was not able to observe the readings on the computer connected to the mannequin.

The mannequin was ventilated using two different FFMs, the Guardian (Ocean Technology Systems, California, USA) (OTS) and the Neptune III (Ocean Reef Group, Genova, Italy). At first, ventilations were delivered using the fastest possible press and release of the purge valve. Next, the purge valve was held for one second and released. The mannequin was ventilated at a rate of one breath every six seconds. Each trial lasted two minutes. In some cases, breaths were delivered that were too small for the mannequin to record. This resulted in fewer data points in some trials.

After completing initial trials, there was concern that the masks had been tightened too much on the mannequin and did not reflect how an actual diver would wear them. To account for this, two additional trials were performed. For each mask, the trial was repeated using the ventilation technique that had given the best results previously. The mask for these trials was tightened according to manufacturer recommendations, just enough that the mask seemed capable of excluding water.

OUTCOME MEASURES AND ANALYSIS

The outcome measures were tidal volumes and peak inspiratory pressures as recorded by the RespiTrainer manikin. Average and standard deviations of each outcome measure were calculated. Google Sheets was used for data analysis and graph generation.

To be safe and effective, purge valve depressions must deliver an adequate tidal volume without causing lung injury. Typically, a tidal volume of 5–8 $mL \cdot kg^{-1}$ of ideal body weight is recommended to meet this goal. Ideal body weight is calculated based on height and gender as suggested by Devine and does not vary in the adult population as much as actual body weight.[10] For each centimeter of height, ideal body weight changes by 0.91 kg. The FFM was expected to deliver a target tidal volume of 350–560 ml based on a male with height of 175 cm and ideal body weight of 70 kg.[9]

Although 5–8 $mL \cdot kg^{-1}$ of ideal body weight is the typical recommended range, it can be safe to exceed this range for patients without significant lung disease. For these patients, volumes greater than 10 $mL \cdot kg^{-1}$ have been shown to be associated with volutrauma and barotrauma.[11] Divers would generally be expected to have relatively healthy lungs and could likely tolerate this 10 $mL \cdot kg^{-1}$ cutoff, which would be 700 mL for the 70 kg ideal body weight adult. Therefore, the FFM should ideally deliver tidal volumes of 350–560 mL though not exceeding 700 mL.

The pressure at which ventilations are delivered also has the potential to cause injury. Previous studies have found that a peak inspiratory pressure greater than 3.4 kPa (35 cmH_2O) increases the risk of pneumothorax or mediastinal emphysema, although some have suggested that peak inspiratory pressures closer to 4 or 5 kPa might be safe.[12] For ventilations given underwater, air in the pleural space or mediastinum would be particularly detrimental as expansion during ascent could cause life threatening compression of the heart and great vessels.[13] Therefore, the more conservative upper threshold of 3.4 kPa was chosen for this study.

Results

Ultimately, both masks were capable of delivering an average tidal volume within the target range of 350–560 mL (Table 1). However, the technique required to do this varied between the masks. For the Guardian, ventilations were appropriate when the purge valve was quickly pressed and released, and when it was depressed for one second, they were excessive. For the Neptune III, ventilations were adequate when given for one second, but too small when the purge valve was pressed for as short a time as possible (Table 1).

Table 1
Results from ventilations delivered by the full-face masks in various trials; SD – standard deviation

Full face mask	Ventilation length	Mask condition	Mean tidal volume (mL) (range, SD)	Mean pressure (kPa) (range, SD)
Neptune III	Shortest possible	Tight	276 (245–322, 33)	0.5 (0.5–0.6, 0.08)
	1s	Tight	500 (375–588, 50)	1.0 (0.8–1.1, 0.09)
	1s	Loose	463 (395–517, 37)	0.9 (0.8–1.0, 0.07)
Guardian	1s	Tight	949 (790–1019, 46)	2.0 (1.6–2.1, 0.1)
	Shortest possible	Tight	604 (344–802, 117)	1.4 (0.8–2.1, 0.3)
	Shortest possible	Loose	416 (321–685, 97)	0.9 (0.5–1.4, 0.2)

Figure 1
Tidal volume results; green lines show ideal volume range (350–560mL); red line indicates the 700 mL high risk threshold for volutrauma; black dots represent individual ventilations; blue hexagons represent mean values. SP – shortest possible purge valve depression; 1s – depression of purge valve for one second

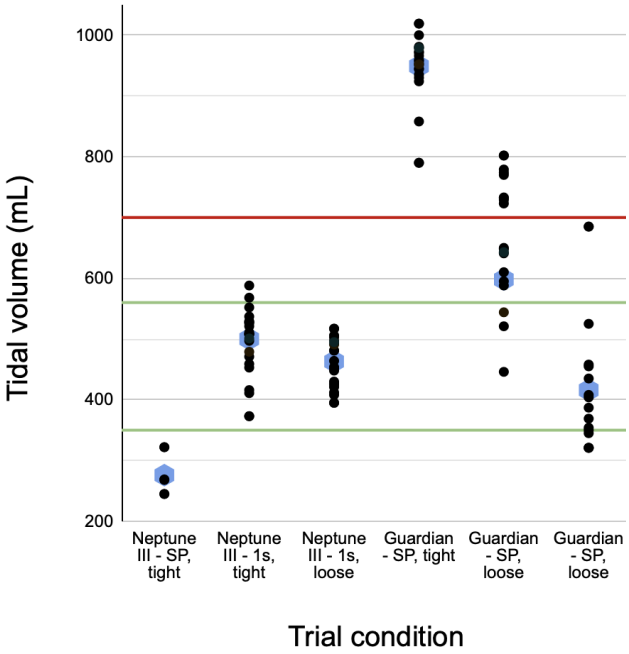
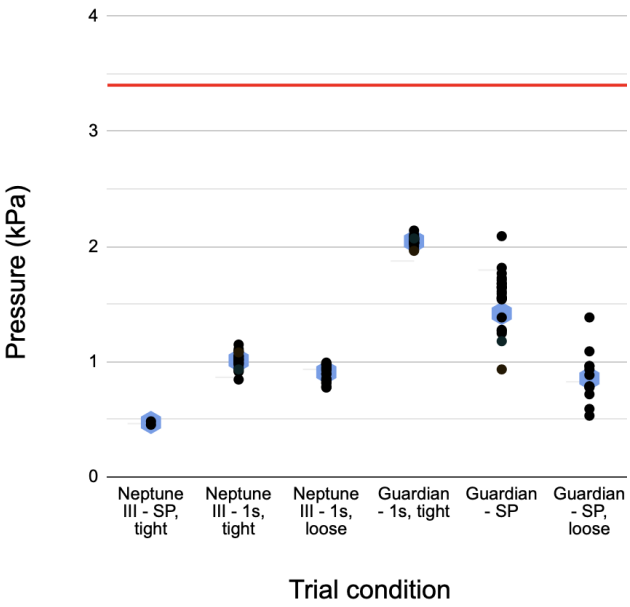


Figure 2
Pressures measured during various ventilation trials; black dots and blue hexagons represent individual and mean values, respectively; red line represents the high-risk threshold for barotrauma (3.4 kPa). SP – shortest possible purge valve depression; 1s – depression of purge valve for one second



In continued testing with fully tightened masks, the masks also differed in reproducibility of the tidal volume delivered. The Neptune III delivered breaths that were more consistent in volume, and they always remained within the target 350–560 mL range when given over one second. By contrast, the Guardian exhibited significant variation. Although the shortest possible depressions of its purge valve provided appropriate average tidal volumes, some breaths were above the target range of 350–560 mL (Figure 1).

Loosening the mask seal did have some effect on whether the mask could deliver volumes within the target range. For both the Guardian and the Neptune III, the average with the looser mask was lower but still above the minimum threshold. All breaths provided by the Neptune III were within the acceptable range. Once again, the Guardian delivered breaths that were more variable, with some that were both too large and too small (Figure 1). However, in this trial, only one breath was above the 560 mL threshold, and all were below the 700 mL threshold.

The peak inspiratory pressure delivered with every breath in each trial was also measured. For all trials, the maximum pressure delivered remained well below the 3.4 kPa limit (Figure 2). Even in the trial where breaths were given from the Guardian over one second and tidal volumes were well over the desired amount; all breaths were well below 3.4 kPa and only slightly above 2 kPa. Outside of this trial, all but one breath was below the 2 kPa threshold.

Discussion

This study evaluated the use of two FFMs for ventilation of divers. Both masks were capable of delivering adequate tidal

volumes within the safety norm (< 700 mL). However, both technique and mask tightening needed to be optimal for this.

A large point of concern with using FFMs to ventilate underwater is that inappropriate assisted ventilations may cause pulmonary barotrauma during ascent. For this reason, breaths larger than 700 mL are concerning. Conversely, breaths below 350 mL would be unlikely to harm the patient as long as they did not delay the ascent to the surface. Given these parameters, to be useful for underwater ventilation, a FFM should be able to consistently deliver breaths below the 700 mL threshold.

The Neptune III met this criterion, as all breaths delivered across all trials were below 700 mL. The Guardian was less consistent in this regard. However, it was able to deliver breaths below 700mL in the trial where breaths were given for the shortest possible interval and the mask was only moderately tightened, which may be more realistic in an emergency situation.[14] The user manual for the Guardian recommends against overtightening, as it may cause discomfort and leaking.[15] However, further research is needed to confirm safety of using both masks for emergency underwater ventilation via purge valve. It is also worth noting that these findings were for a person with an ideal body weight of 70 kg, or a height of about 1.75 m in a male. Some divers, particularly females or teenage divers, might have an ideal body weight significantly smaller than this. Additional research will need to consider differing body habitus and how this might affect the safety or efficacy of the studied techniques.

FFMs will require testing in an underwater environment. In a previous study, researchers tested one brand of FFM, the Interspiro MK II, and found that it was not effective in providing ventilations underwater.[7] The authors noted significant issues with seal leakage and found that large amounts of water entered the manikin's airway. They also noted decreasing tidal volumes at depth. This effect was seen only with the FFM and no other ventilation methods tried by the authors. This highlights that underwater conditions may differ from surface testing, and that the results of this study cannot be generalised to underwater use without further testing. It is important to note that the study by Winkler et al., tested only one FFM, and testing of other masks underwater is needed.[7]

The pressure delivered by a mask is also an important safety factor to consider. Both masks used in this study delivered breaths well below the dangerous threshold of 3.4 kPa under both conditions tested. This was likely because of relief and exhaust systems built into the masks that are designed to allow comfortable exhalation and prevent excessive pressure buildup. Despite low peak pressures, the masks were able to effectively inflate the lungs of the manikin used in this study. Given the pressure changes that occur at depth, this may or may not be true for a real person underwater, and further research will be needed on this point. However, these results are encouraging because they suggest that if attempted ventilations are not effective, they are more likely to not provide an effective breath delivery than to cause harm as the gas can vent through the exhalation and relief mechanism as designed. It should be noted that the mannequin is factory-calibrated prior to reaching the end user. As such, calibration was not performed by the authors, and this may impact the accuracy of pressure measurement.

Findings from the Thailand cave rescue using an Interspiro Divator mask suggested that pressures may increase underwater.[14] Van Waart et al., reported that average ventilation pressures at the surface were below 3.4 kPa, although some were as high as 5.31 kPa. At a depth of 0.5 m, pressures of 3.99 kPa were observed.[14] Potentially, additional depth could further increase pressures, resulting in unsafe conditions despite surface results suggesting safety. It should be noted that ventilations in this study were performed by untrained volunteers and demonstrated wide variability. Ventilations may have been influenced by factors such as size, gender, and enthusiasm. This is consistent with findings from another paper investigating use of traditional scuba regulators for ventilation.[16] Further studies will be needed to determine whether full face masks could be used for assisted ventilation of a submerged victim. Additionally, the equipment worn by a diver might impact lung compliance or ability to maintain an open airway. The mannequin in this study included only a head and lungs and could not account for these factors.

Even if further testing reveals that FFMs are not useful for underwater ventilation, they could be helpful for ventilation at the surface. In industrial or public safety diving, FFMs may be worn to protect from contaminated water. In this scenario, it would not be safe for the patient or rescuer to remove masks and deliver ventilations using currently recommended techniques. Assisting ventilation by use of the FFM may be easier than other alternatives even in relatively clean water.

The present study indicates that recommendations for ventilation with a FFM might need to be model specific – the Guardian performed best with shortest possible depressions of the purge valve, while the Neptune III required one second intervals. This complicates recommendation development because there are many different models of FFM, and testing all of them would prove logistically challenging. Even within the same model, maintenance of regulators (or lack thereof) could also impact their performance and ability to deliver consistent volumes or pressures. The OTS Spectrum and ScubaPro in particular introduce wide variability, as they integrate any standard second stage regulator a diver might be using into a FFM via a mouthpiece connector. Given the variety of FFMs available, testing and providing a recommendation tailored to each mask would be extremely difficult if not impossible. Even if this could be done,

delivering breaths safely and effectively in an emergency would require the rescuer to know the exact type of mask and regulator used by the patient and look up the proper technique before use. This would necessitate significant planning before an accident and would likely not be feasible for rescuing anyone other than a well-known dive buddy.

The pressure results from this trial might suggest a way to mitigate this issue. Even in trials where tidal volume was very large, pressure remained well below the maximum limit. This was likely because regulators, including those in FFMs, are designed to allow a release of exhaled gas once a certain pressure is reached. When the purge valve is pressed, a diaphragm, valve, or exhalation channel opens at a pressure set by the manufacturer, limiting the pressure inside the mask and airway when attempting ventilations. The pressure limitation by this relief mechanism likely affects the amount of time that the purge valve must be pressed to give a desired tidal volume. Specifically, the Guardian and the Neptune III have distinctly different mechanisms to allow the exhalation of gas through their relief mechanisms. The Guardian uses a valve system, while the Neptune III uses a gradient of pressure between the inside and outside of the mask without a mechanical mechanism. If specific mask design features listed by the manufacturer could be correlated with trial results, it could be possible to provide recommendations for how long to press the purge based on brand or style of mask or regulator. This would allow for more general recommendations that would be easier for divers to implement.

This study has some limitations. It was performed on a mannequin, at the surface, and with one experienced paramedic delivering ventilations. Caution and further study are needed before applying these results to real patients, other rescuers (especially laypeople), or underwater environments. These results should not be used to justify patient use until further testing can be conducted.

Conclusions

Ventilation with a FFM could be feasible, although different techniques were required based on the mask and regulator used. Further testing is necessary before assisted ventilation by FFM can be recommended for a submerged victim. Our current findings are directly applicable to ventilation at the surface, which could be an easier alternative and have particular utility in rough or contaminated water and resource-limited environments. Further testing in-water at depth will be necessary to evaluate the masks' use for ventilation in the underwater environment. After sufficient study, addition of underwater ventilation into dive rescue training could be lifesaving in overhead, military, or decompression diving. These results merit further investigation.

References

1 Casadesús JM, Aguirre F, Carrera A, Boadas-Vaello P, Serrando MT, Reina F. Diving-related fatalities: multidisciplinary, experience-based investigation. Forensic Sci Med Pathol. 2019;15:224–32. doi: 10.1007/s12024-019-00109-2. PMID: 30915609.

2 Tillmans F, editor. DAN annual diving report 2020 edition: A report on 2018 diving fatalities, injuries, and incidents. Durham (NC): Divers Alert Network; 2021. PMID: 35944087. [cited 2025 Feb 7]. Available from: https://www.dansa.org/annual-diving-report.

3 Berg KM, Bray JE, Ng K, Liley HG, Greif R, Carlson JN, et al. 2023 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations: summary from the basic life support; advanced life support; pediatric life support; neonatal life support; education, implementation, and teams; and first aid task forces. Circulation. 2023;148(24):e187–e280. doi: 10.1161/CIR.0000000000001179. PMID: 37942682. PMCID: PMC10713008.

4 Richardson D, editor. PADI rescue diver manual. Rancho Santa Margarita: International PADI; 2010.

5 Mitchell SJ, Bennett MH, Bird N, Doolette DJ, Hobbs GW, Kay E, et al. Recommendations for rescue of a submerged unresponsive compressed-gas diver. Undersea Hyperb Med. 2012;39:1099–108. PMID: 23342767.

6 Winkler BE, Eff AM, Eff S, Ehrmann U, Koch A, Kähler W, et al. Efficacy of ventilation and ventilation adjuncts during in-water-resuscitation--a randomized cross-over trial. Resuscitation. 2013;84:1137–42. doi: 10.1016/j.resuscitation.2013.02.006. PMID: 23435218.

7 Winkler BE, Muth CM, Kaehler W, Froeba G, Georgieff M, Koch A. Rescue of drowning victims and divers: is mechanical ventilation possible underwater? A pilot study. Diving Hyperb Med. 2013;43:72–7. PMID: 23813460. [cited 2024 Feb 27]. Available from: https://dhmjournal.com/images/IndividArticles/43June/Winkler_dhm.43.2.72-77.pdf.

8 DuCanto J, Lungwitz Y, Koch A, Kahler W, Gessell L, Simanonok J, et al. Mechanical ventilation and resuscitation underwater: Exploring one of the last undiscovered environments - A pilot study. Resuscitation. 2015;93:40–5. doi: 10.1016/j.resuscitation.2015.05.024. PMID: 26051809.

9 Dafilou B, Schwester D, Ruhl N, Marques-Baptista A. It's in the bag: tidal volumes in adult and pediatric bag valve masks. West J Emerg Med. 2020;21:722–6. doi: 10.5811/westjem.2020.3.45788. PMID: 32421525. PMCID: PMC7234703.

10 Devine BJ. Gentamicin therapy. Drug Intell Clin Pharm. 1974;8:650–5.

11 Salyer SW, Steven W. Essential emergency medicine for the healthcare practitioner. Philadelphia (PA): Saunders/Elsevier; 2007. p. 844–913.

12 Gammon RB, Shin MS, Buchalter SE. Pulmonary barotrauma in mechanical ventilation. Patterns and risk factors. Chest. 1992;102:568–72. doi: 10.1378/chest.102.2.568. PMID: 1643949.

13 Russi EW. Diving and the risk of barotrauma. Thorax. 1998;53(Suppl 2):S20–4. doi: 10.1136/thx.53.2008.s20. PMID: 10193343. PMCID: PMC1765901.

14 van Waart H, Harris RJ, Gant N, Vrijdag XC, Challen CJ, Lawthaweesawat C, et al. Deep anaesthesia: The Thailand cave

rescue and its implications for management of the unconscious diver underwater. Diving Hyperb Med. 2020;50:121–9. doi: 10.28920/dhm50.2.121-129. PMID: 32557413. PMCID: PMC7481118.

15 Guardian full face mask owner's manual. Ocean Technology Systems, California, USA; 2014. [cited 2024 Feb 27]. Available from: https://www.oceantechnologysystems.com/wp-content/uploads/2018/06/Guardian-FFM-F.pdf.

16 Winkler BE, Froeba G, Koch A, Kaehler W, Muth CM. Oxylator and SCUBA dive regulators: useful utilities for in-water resuscitation. Emergency Medicine Journal. 2013;30:579–82. doi: 10.1136/emermed-2011-201067.

Acknowledgements

We thank PADI for the development of the rescue diver class and curriculum, which sparked the initial idea for this investigation. We thank representatives from OTS and Neptune who provided detailed information about the relief and exhaust systems of their products to support interpretation of these results.

Conflicts of interest and funding: nil

Submitted: 1 March 2025
Accepted after revision: 7 November 2025

HBOE
HBOEvidence

HBOEvidence

HBOEvidence is seeking an interested person/group to continue the HBOEvidence site. The database of randomised controlled trials in diving and hyperbaric medicine: hboevidence wikis.unsw.edu.au. The HBOEvidence is in the process of being integrated into the SPUMS website.

Those interested in participating in this project can contact:
Neil Banham president@spums.org.au

An echo from the past: open access repository of over 10,000 annotated Doppler audio recordings of venous gas emboli

S Lesley Blogg[1,2], Arian Azarang[3], Rachel Lance[4,5], Frauke Tillmans[4,6], Richard Moon[5], Virginie Papadopoulou[3], Peter Lindholm[1,7]

[1] *Department of Emergency Medicine, University of California San Diego, USA*
[2] *SLB Consulting, c/o Home Park Barn, Kirkby Stephen, Cumbria, UK*
[3] *Department of Radiology, The University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA*
[4] *Divers Alert Network, Durham, North Carolina, USA*
[5] *Departments of Anesthesiology and Medicine, Center for Hyperbaric Medicine and Environmental Physiology, Duke University, Durham, North Carolina, USA*
[6] *Lampe Joint Department of Biomedical Engineering, The University of North Carolina at Chapel Hill and North Carolina State University, Chapel Hill, North Carolina, USA*
[7] *Department of Physiology and Pharmacology, Karolinska Institute, Sweden*

Corresponding author: *Professor Peter Lindholm, 200 W Arbor Drive, MC8676, San Diego, CA 92103, USA*
peter.lindholm@ki.se

Keywords
Artificial intelligence; Bubbles; Decompression sickness; Measurement; Venous gas embolism

Abstract
(Blogg SL, Azarang A, Lance R, Tillmans F, Moon R, Papadopolou V, Lindholm P. An echo from the past: open access repository of over 10,000 annotated Doppler audio recordings of venous gas emboli. Diving and Hyperbaric Medicine. 2026 31 March;56(1):8–12. doi: 10.28920/dhm56.1.8-12. PMID: 41875437.)
Introduction: Doppler ultrasound measurements have been recorded since the 1970s across the world and provide a valuable data resource for learning, analysis, and potential training of deep learning algorithms to recognise and grade venous gas emboli (VGE) allowing assessment of decompression sickness (DCS) risk.
Methods: We collected a 'big database' of Doppler recordings and associated metadata. Audio tapes with recorded Doppler data were converted to digital files, then cut into individual recordings and matched with their metadata, including subject and pressure profile information. The audio signals and their Doppler grades were then processed further for suitability to train an algorithm to identify VGE.
Results: A total of 10,099 Doppler ultrasound recordings were compiled. Divers ($n = \leq 311$; 170 identified, ≤ 141 unidentified) were male, with a median age of 31.5 years among the 170 identified divers. The maximum depth of the dives included ranged from 24 m (80 feet) to 91.4 m (300 feet). The timing of the Doppler measurements ranged from two minutes post-dive to 594 min post-dive, with a median time of 52 min. Breathing gases included air, nitrox, and heliox. DCS was noted in only 12 individuals. The dataset centred around lower VGE loads (Spencer Grades 0, I, and II).
Conclusions: This database represents a landmark in DCS investigation as the audio dataset and metadata collected have been released under a public domain license for further use. The large number of data points has also allowed the development of a deep learning algorithm that can grade bubble loads without a human operator.

Introduction

Decompression sickness (DCS) remains a major concern for commercial, military, and recreational diving. In diving research, circulating bubbles detected with ultrasound, which are also termed venous gas emboli (VGE), are used as markers to estimate the level of decompression stress a diver has been subject to during a dive and then further gain a measure of the likelihood of DCS occurring.[1] Once the diver returns to atmospheric pressure, VGE are monitored and recorded using precordial (PC) or subclavian (SC) Doppler ultrasound (audio), or with transthoracic 2D cardiac imaging to determine the load circulating in the body. The more VGE in the circulation, then generally the higher the risk of DCS.[1,2]

Doppler ultrasound measurements have been made and recorded since the 1970s by varying dive research bodies across the world. The technique uses a transducer to transmit sound waves into the body, and the resulting echo allows operators to detect moving objects in the blood vessels and heart.[1] Bubbles strongly reflect sound waves and so can be detected by this method.[1] Most of these measurements made historically were recorded onto audio cassettes and digital audio tapes (DAT) for storage. In 2020, the US Office of Naval Research supported an effort from various US academic institutions to gather these recordings from around the world, then digitise and store the data online for safeguarding and future research efforts. The University of California at San Diego (UCSD) and University of North Carolina at Chapel Hill along with other partners including

the Divers Alert Network (DAN), Duke University (all US-based), the Karolinska Institute, Sweden, and QinetiQ, UK, have been involved in the efforts to collate this large database of previously acquired Doppler audio recordings and metadata. It represents a vast undertaking in terms of locating data, obtaining permissions for inclusion, digitising, cutting, and pairing recordings to their metadata with the end goal to make these historic and valuable Doppler data available to the diving community. These data include PC (over the heart) and / or SC (over the subclavian veins) measurements during rest and limb movement (flex) for each diver.

One obstacle to making use of such data is that a high degree of training and practice is necessary for an operator to assess and grade audio bubble signals correctly. To the untrained ear, little can be made of the audio signals thus rendering the data worthless. However, efforts have been made to develop computer-based programs to do the job of grading bubble loads. The development of machine learning algorithms requires well-curated data sets for training, validation, and testing. Large amounts of data are key to producing reliable, high-performance algorithms and this was another reason that the collection of these data was recognised to be of benefit and actioned. This paper aims to document these collection and collation efforts, to briefly describe the data and how they have been used to date, and to show the potential for further studies to come.

Methods

ETHICAL APPROVAL

This study was determined exempt from Institutional Review Board requirements under US Federal Policy for the Protection of Human Subjects ("*Common Rule*") 45CFR 46.104(d) (4) by the University of California at San Diego (UCSD) Institutional Review Board (IRB) (determination #805229).

COLLECTION AND ORGANISATION OF RAW DATA FOR DATABASE REPOSITORY

Both analogue audio tapes and digital audio tapes (DAT) tapes were available with recorded Doppler data. To convert audio tape signals to digital files, an audio cassette player with an audio line out socket, and left and right male Radio Corporation of America (RCA) coaxial stereo phono leads was used (Yamaha MT400 multitrack cassette mixing/recording unit). The RCA leads were then connected to a USB audio interface with a digital output device (Behringer UCA202, Behringer Switzerland) to digitise the analogue audio signal and transfer it to a personal computer. DAT tapes were treated similarly, using a Sony DAT player (Sony Group Corp, Tokyo, Japan) attached to the audio interface device.

The open-source program Audacity (https://www.audacityteam.org/) was used to record the signal, which could then be cut and manipulated for further use and storage. Settings in Audacity for this program were as follows: sampling rate at 44100 Hz, Microsoft Multimedia Environment input set to microphone (USB Audio CODEC), 2 (stereo) recording channel. Files were saved in the free lossless audio codec (FLAC) format, whose files are roughly 50% size of waveform audio file format (WAV).

DATA SEGMENTATION

Following digitisation, each Doppler audio recording was segmented into individual clips corresponding to discrete measurements for each diver. Typically, one clip (~20 s) represented a resting Doppler recording at a specific time after surfacing, followed by a second clip recorded during movement at the same session. Each segment was then verified against the available metadata and catalogued accordingly.

Each Doppler recording originally contained examiner commentary superimposed on the audio channel, which was routinely provided during acquisition to document the measurement site, subject identifier, date, and physiological condition (e.g., movement or rest). In order to isolate the Doppler ultrasound signal alone (necessary for developing or testing computer-automated Doppler ultrasound analysis software for example), these spoken annotations were systematically trimmed, leaving only the Doppler ultrasound component.[3] This ensured that all recordings are deidentified and represent physiological signals only without overlapping speech, thereby facilitating signal processing, machine learning analysis, and reproducibility. The trimming was performed without altering the acoustic characteristics of the Doppler trace itself, preserving both signal fidelity and grading validity.

METADATA COMPILATION

For storage in the repository, the dive series' original filenames were used where possible with sequential numbering, for example, THe4008_00001, where THe4008 is the name of the test dive recorded on the audio tape. These files would be labelled THe4008_00001 and THe4008_00002 and so on, and represented the sequential recordings made for each diver over time that was captured on the audio tape. Metadata for each clip, which included the original Kisman Masurel (KM) grades as given by the operators monitoring the dives and making the measurements at the time, were then recorded into an Excel file and saved for use.[4]

KM grades are non-linear measures of the relative bubble load detected in the venous circulation, with the KM code ranging from Grade 0 (no detectable bubbles) through grades I, II, and III, up to IV sequentially reflecting higher loads of bubbles present.[4] For quality control purposes the original KM grades assigned were randomly checked by an experienced Doppler operator (SLB) as they were saved

Table 1
Correspondence between the Spencer and Kisman-Masurel venous gas emboli assessment scales[1]

Spencer grade	Kisman-Masurel grades
0	[000]
1	[111] [112] [113] [211] [212] [213]
2	[121] [122] [123] [221] [222] [223]
3	[232] [233] [242] [243] [332] [333] [342] [343]
4	[444]

into the Excel sheet, to make sure that the files matched the metadata grades originally assigned to them.

The metadata collected included (although not in every case): filename, anatomical site (PC or SC), SC left or right, rest or flex, KM code, KM grade, KM decimal grade, dive maximum depth (metres or feet), gas, oxygen partial pressure, helium partial pressure, atmospheres absolute (atm abs) or Bar, time to maximum depth, total dive time, age, sex, data origin, DCS occurrence, type of DCS, DCS symptom(s), Doppler post-dive time, wet or dry dive, in water, study identifier, and subject identifier. All Doppler measurements had been made using a Techno Scientific Doppler monitor (Techno Scientific Inc., Ontario, Canada). These structured metadata enabled secondary analyses linking Doppler findings to decompression stress, physiological conditions, and instrumentation characteristics.

For user navigation and data retrieval, audio recordings were curated into two primary anatomical site folders (PC and SC). Within each, subfolders correspond to bubble grade classifications derived from the KM code and expressed as equivalent Spencer grades, which can be achieved by conversion from the KM codes, as shown in Table 1.[3] This hierarchical organisation enables efficient browsing and targeted download of recordings by both site and VGE grade.

The KM code provides a very detailed multi-parameter description of VGE load, but this level of complexity makes it harder to use directly for a deep learning model development as it expands the number of categories and reduces the number of samples per class. In contrast, the Spencer grading system is a simpler ordinal scale that summarises the VGE load into five distinctive classes. To facilitate reuse for algorithm benchmarking or VGE classification, the recordings were also organised according to both anatomical site and converted Spencer grades derived from the KM code (see Table 1). This secondary categorization was introduced solely to streamline machine learning development based on Spencer grades and does not affect the structure of the raw repository.

REPOSITORY STRUCTURE AND ACCESSIBILITY

The completed database was thoroughly validated for internal consistency by cross-checking, for each recording, the metadata across subject, dive, and bubble grade information using automated column-wise verification routines. All initial discrepancies were subsequently reviewed and manually double-checked (authors SLB, AA, VP) before finalising the dataset. In addition, each entry was verified to ensure that its associated audio file adhered to the correct naming convention and was stored in the appropriate folder corresponding to its anatomical location and grade classification.

To ensure reproducibility and transparency, the complete curated dataset has been made publicly available via Zenodo (https://doi.org/10.5281/zenodo.16877955) under a public domain license. Files are organised by anatomical site (PC or SC) and labeled consistently with their original recording series. Metadata enable linkage of Doppler findings with experimental context and decompression parameters, supporting a wide range of secondary analyses.

Results

PUBLIC AVAILABILITY

The dataset and metadata collected in this study have been released under a public domain license to encourage widespread use within the scientific community and beyond. Researchers may freely download, analyse, and incorporate the recordings for applications such as algorithm benchmarking, training of machine learning models for automated VGE detection, decompression risk modelling, and educational purposes.

DATASET COMPOSITION BY RECORDING SITE

The data collection process, which included identification of suitable recordings, discovery and reconciliation of matching metadata, digitisation of files, cutting of files, insertion into

Table 2
Distribution of recordings by site and Spencer grade

Spencer grade	Precordial (*n*)	Subclavian (*n*)	Total (*n*)
0	2,586	4,407	6,993
I	406	1,022	1,428
II	359	441	800
III	504	280	784
IV	63	31	94
Total	3,918	6,181	10,099

the database, and finally quality control of the historical grades assigned to the files, took over four years of work. A total of 10,099 Doppler ultrasound recordings were compiled into the final database. Of these, 3,918 recordings (38.7%) were obtained from the precordial site, and 6,181 recordings (61.2%) were acquired from the subclavian sites (right and left). This distribution provides broad coverage across both clinically relevant monitoring locations, which differ in their sensitivity to VGE and in their practical applicability for decompression monitoring.

DESCRIPTIVE DATA

All the identified divers ($n = 170$) whose data were included were male, with a median age of 31.5 years. For these individuals, the originally assigned de-identified subject IDs were retained to maintain consistency with source records. In some cases, subjects participated in both air and heliox dives and were therefore assigned multiple identifiers in the original records, typically one ID for their air dives, another for their heliox dives, and an additional unique identifier that cross-referenced both sets of dives. In such cases, only the primary subject ID was retained in the 'Subject ID' column of the database, while the additional original identifiers were recorded in a separate metadata column for reference.

There were an additional 141 sets of data that belonged to unidentified subjects (i.e., those with missing or inaudible IDs in the audio recordings). A small subset of these datasets may have derived from the same subject (repeated dives) and so would reduce this number from 141 but as there was no way to determine this, these data were treated as standalone IDs. To ensure traceability within the database, unidentified subjects were assigned dummy identifiers consisting of the capital letter 'U' followed by a unique three-digit number. These identifiers were allocated systematically based on the recording structure and reconciliation with original experimental documentation.

The total number of distinct subjects represented in the database is therefore estimated at 311. Based on available historical records, we are confident that all unidentified subjects were also male and had demographic characteristics comparable to those of the identified group. All subjects were drawn from military personnel and scientific staff working with the military, or commercial tunnelling employees.

The maximum depth of the dives included ranged from 24 m (80 ft) to 91.4 m (300 ft). Total dive time ranged from six minutes (91.4 m dives) to 4 h 11 min (tunnelling exposures). For 15 dive profiles, data were available for time to maximum depth; this parameter ranged between nine and 180 min.

The timing of the Doppler measurements ranged from two minutes post-dive to 594 minutes post dive, with a median time of 52 minutes. Dives were made in water, in a dry hyperbaric chamber, in a dry tunnelling environment, or in a wet hyperbaric chamber.

Breathing gases included air, oxygen in nitrogen (all with a partial pressure of oxygen [PPO_2] of 0.7 atmospheres absolute [atm abs]), and heliox (also PPO_2 0.7 atm abs)

Decompression sickness was noted in only 12 individuals within this database, with 10 subjects reporting Type 1 symptoms (pain), one reporting both Type I and Type II (pain and motor deficits), and one reporting Type II symptoms only (sensory and motor deficits).

DISTRIBUTION ACROSS SPENCER GRADES

Bubble grades occurred from 0 to KM grade IV, that is, across the whole grading range. Subsequently, each recording was annotated according to the Spencer grading system, resulting in five levels of VGE load.[5] The distribution of recordings across grades is shown in Table 2. The dataset was predominantly composed of lower VGE loads (Grades 0, I, and II), which accounted for 91.4% of the audio files, while higher VGE loads (Grades III and IV) represented only 8.6% of the total.

Discussion

This database represents a landmark in DCS investigation and open resources, as it is the first publicly available collection to include the original Doppler audio recordings rather than only the bubble grades assigned by investigators. By sharing the underlying audio clips, this resource enables independent verification of VGE assessments and supports the development of automated analysis methods. The dataset has already facilitated the creation of a deep learning

algorithm capable of grading bubble loads without a human operator.[6] Although other datasets may contain larger numbers of participants or DCS cases, none have previously made the raw Doppler signals accessible for unrestricted scientific use.

Up until this point, deep learning has not been utilised for the detection and classification of VGE in post-dive Doppler audio data. However, with the realisation of this large data base, a bubble classification model developed previously using lab-generated synthetic bubble data was then fine-tuned on a subset of these real-world data. This resulted in a model that achieved an average ordinal accuracy of 83.8% for precordial and 90.4% for subclavian Doppler across all five Spencer grades. Importantly, an average of 77.8% and 93.8% binary classification accuracy was demonstrated between low and high VGE grades for PC and SC, respectively, and 84.6% and 80.9% between 'no VGE' and 'VGE present' for PC and SC, respectively.[6]

With regards to the data themselves, perhaps the most notable point is that of the ~311 subjects included in the data set, only 12 experienced DCS following a dive. Most of the dives included in the database were to test various tables or help develop computer algorithms, so may not have been very conservative in their dive profile. The one contrast to this was the 46 data points included that represented monitoring in three subjects working on the Belfast tunnelling project, where KM grades ranged from 0 to IV, but as would be hoped in the workplace, there was no occurrence of DCS. Although the overall number of DCS cases is low, reflecting the rarity of the condition, the dataset remains highly valuable for studies focused on VGE characterisation, Doppler signal analysis, and algorithm benchmarking. However, analyses aimed at identifying or modelling DCS risk factors should account for the limited number of clinical DCS events and the resulting statistical constraints.

The database may be limited in the fact that no female divers' data are included, but unfortunately this is the nature of using historical data drawn mostly from military sources, an environment where only now are women becoming more common in the work force. Positively, there was a relatively good range in diver age, from 17 to 45 years, so giving a good representation of active divers across age groups.

Overall, the metadata are rich enough that many other investigations and studies could be made from this database. We have already published a study comparing PC and SC bubble grades in an attempt to clarify which bubble monitoring site is preferential.[7] We welcome other workers using the data for their own research and the audio files can also be used as a training resource for operators wishing to hone their skills.

References

1 Nishi RY, Brubakk AO, Eftedal O. Bubble detection. In: Brubakk AO, Neuman TS, editors. Bennett and Elliott's physiology and medicine of diving. Edinburgh: Saunders; 2003. p. 501–29.

2 Currens JB, Doolette DJ, Murphy FG. Venous gas emboli (VGE) in 2-D echocardiographic images following movement: grading and association with cumulative incidence of decompression sickness. Diving Hyperb Med. 2025;55:44–50. doi: 10.28920/dhm55.1.44-50. PMID: 40090025. PMCID: PMC12263276.

3 Azarang A, Blogg SL, Currens J, Lance RM, Moon RE, Lindholm P, et al. Development of a graphical user interface for automatic separation of human voice from Doppler ultrasound audio in diving experiments. PLoS One. 2023;18(8):e0283953. doi: 10.1371/journal.pone.0283953. PMID: 37561745. PMCID: PMC10414643.

4 Kisman K, Masurel G. Method for evaluating circulating bubble grades detected by means of the Doppler ultrasonic methods using the "*K.M. Code*" (English translation of "*Masurel G. Methode d'Evaluation des Degrés de Bulles Circulantes Révélées par la Détection Ultrasonore à Effet Doppler "Code K.M". Repère 283 CERTSM 1983*"). Toulon, France: Centre d'Études et de Reserches Techniques Sous-Marines; 1985.

5 Spencer MP, Johanson DC, editors. Investigation of new principles for human decompression schedules using doppler ultrasonic blood bubble detection. 1974.

6 Azarang A, Le DQ, Hoang AH, Blogg SL, Dayton PA, Lance RM, et al. Deep learning-based venous gas emboli grade classification in doppler ultrasound audio recordings. IEEE Trans Biomed Eng. 2023;70:1436–46. doi: 10.1109/TBME.2022.3217711. PMID: 36301781.

7 Blogg SL, Azarang A, Papadopoulou V, Lindholm P. Agreement of precordial and subclavian Doppler ultrasound venous gas emboli grades in a large diving data set. Diving Hyperb Med. 2025;55:2–10. doi: 10.28920/dhm55.1.2-10. PMID: 40090020.

Acknowledgements

Thanks to Geoff Loveman and QinetiQ, UK, for enabling the inclusion of their datasets in the repository. Thanks to Helena Housley for assistance in cutting the recordings.

Conflicts of interest and funding

This work was funded by: The Department of the Navy, Office of Naval Research (ONR award numbers N000142012590 and N000142312548). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The Karolinska Institute, Fraenkel fund for aviation research Dnr: 2019-01046. Dr Blogg is the Deputy Editor of *Diving and Hyperbaric Medicine* Journal, and a member of the journal's editorial board. She played no role in managing the peer review process for this manuscript, nor in the decision to publish.

Submitted: 27 October 2025
Accepted after revision: 7 December 2025

Changes in lung ultrasound presentation induced by breath-hold diving in a simulated depth competition at Taiwan

Ying-Jen Chi[1], Hsiu-Yung Pan[2], Po-Chun Chuang[2], Chi-Yung Cheng[2], Han-Yu Li[3], Meng-Huan Wu[2]

[1] *Department of Emergency Medicine, Pingtung Hospital of the Ministry of Health and Welfare, Pingtung, Taiwan*
[2] *Department of Emergency Medicine, Kaohsiung Chang Gung Memorial Hospital, Chang Gung University College of Medicine, Taiwan*
[3] *Department of Family Medicine, E-Da Dachang Hospital, Kaohsiung, Taiwan*

Corresponding author: *Dr Meng-Huan Wu, Department of Emergency Medicine, Kaohsiung Chang Gung Memorial Hospital. No. 123, Dapi Road, Niaosong District, Kaohsiung 833, Taiwan*
andy04219@hotmail.com.tw

Keywords
Freediving; Imaging; Immersion pulmonary oedema; Lung

Abstract
(Chi Y-J, Pan H-Y, Chuang P-C, Cheng C-Y, Li H-Y, Wu M-H. Changes in lung ultrasound presentation induced by breath-hold diving in a simulated depth competition at Taiwan. Diving and Hyperbaric Medicine. 2026 31 March;56(1):13–20. doi: 10.28920/dhm56.1.13-20. PMID: 41875438.)

Introduction: Acute respiratory symptoms after diving are common among competitive breath-hold divers. These symptoms, including shortness of breath, cough, haemoptysis, and chest discomfort, are often linked to immersion pulmonary oedema (IPO) or pulmonary barotrauma. This study aimed to evaluate the incidence, clinical presentation, and risk factors of IPO using portable ultrasound devices in a depth competition for breath-hold divers in Taiwan.

Methods: This observational study was conducted during a competition around Liuqiu Island, Taiwan. Twenty-five breath-hold divers participated. Lung ultrasonography was performed pre- and post-diving, along with measurements of basic vital signs. Symptoms and diving history were recorded. The primary outcome measure was B-line score before and after diving.

Results: Following the dive, 7/25 (28%) of divers reported acute respiratory symptoms, 10/25 (40%) showed ultrasound evidence of increased extravascular lung fluid, and 2/25 (8%) met the clinical criteria for IPO, presenting with both symptoms and hypoxaemia ($SpO_2 \leq 95\%$) alongside positive B-lines. B-line scores significantly increased from a median of 4 (range 1–4) to 7 (range 3–13) ($P = 0.048$). Male sex, higher body mass index, and elevated pre-dive systolic blood pressure were significantly associated with positive ultrasound findings. Among all factors, only diving depth remained statistically significant associated with increased post-dive B-line scores (regression coefficient = 0.046) ($P = 0.007$).

Conclusions: The incidence of post-dive acute respiratory symptoms was 28%, and 8% of participants exhibited clinical features of IPO. Positive lung ultrasound findings were observed in 40% of divers, mostly asymptomatic. Maximum diving depth was significantly associated with increased post-dive B-line scores.

Introduction

Breath-hold diving, also known as freediving, is becoming increasingly popular worldwide and has evolved from a recreational activity into a competitive sport. Acute respiratory symptoms following freediving are commonly reported among divers performing deep dives.[1,2] These symptoms include shortness of breath, cough, haemoptysis, chest discomfort, and may even be accompanied by otolaryngological symptoms such as sputum production and voice changes, or neurological symptoms like fatigue. These clinical features are believed to result primarily from two pathophysiological mechanisms: pulmonary barotrauma, related to lung pressure changes during descent, ascent, breath-hold packing, or diaphragmatic contractions, and immersion pulmonary oedema (IPO) associated with central blood pooling and increased pulmonary capillary pressure.[3–5] Collectively, these manifestations are often referred to as 'lung squeeze' within the freediving community. To better categorise these clinical events, the term freediving-induced pulmonary syndrome (FIPS) has recently been proposed as an umbrella term encompassing both conditions, particularly when the exact aetiology cannot be clearly distinguished.[3]

During immersion, the central distribution of blood leads to pulmonary hypertension.[1] When transpulmonary capillary pressure exceeds the balance between hydrostatic and oncotic forces across the alveolar–capillary membrane, fluid may leak into the alveolar space, impairing gas exchange and compromising the blood–gas barrier.[4,6] Compared to other water-based activities such as scuba diving, snorkelling, or surface swimming, freediving causes profound changes in lung volume due to increasing ambient pressure with depth. As divers descend, the reduction in lung volume may lead to

alveolar atelectasis and pulmonary vascular engorgement; mechanisms that may contribute to the development of IPO and associated respiratory symptoms. These events are more likely to occur at depths where lung volume falls below the residual volume, a phenomenon that has been reported to occur in many divers at depths beyond 36 m.[1,7] Involuntary diaphragmatic contractions in the 'struggle phase' of apnoea is also postulated to cause blood shifting from pulmonary capillaries to alveoli by creating negative intrathoracic pressure.[8]

Recent clinical studies have used portable ultrasound devices to evaluate divers. Vertical artifacts, known as B-line artifacts or ultrasound lung comets, increase after diving and may indicate extravascular lung fluid accumulation from IPO.[8–10] To investigate the incidence, clinical presentation, and risk factors of IPO in East Asia, a region with limited research, and to establish a suitable lung ultrasound assessment method for prehospital settings, participants of a competition in Taiwan were evaluated using a portable ultrasound device.

Methods

This study was approved by the Foundation Institutional Review Board (approval no. 202100900B0) and conducted according to The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

PARTICIPANTS

A total of 25 breath-hold divers (16 males and 9 females) participated in the study, with a mean age of 31 (standard deviation [SD] 5) years (range 23–41), height of 169 (SD 8) cm, and weight of 61 (SD 10) kg. Among the participants, 23 were Taiwanese, one was Japanese, and one was British. Informed consent was obtained in writing after explaining the study protocol. The competition organiser was also informed and agreed to cooperate during the event.

STUDY SETTING

To minimise disruption, the study was conducted during a 'simulation' competition three days before the formal event. The competition used a floating system with a buoyancy device on top and a weighted descent line in the open ocean near Liuqiu Island in southern Taiwan. A dive boat followed the system and transported participants after their dives. Once onboard, participants were asked to remove their wetsuits. Sonographic and vital sign measurements were taken within 30 minutes of surfacing. Pre-dive measurements were taken hours earlier on land, and participants were prohibited from diving for at least 12 hours beforehand. According to data from the Central Weather Bureau of Taiwan, the average surface water temperature around Liuqiu Island was 25.7°C, with a low of 23.3°C.

MEASUREMENTS

Lung ultrasonography was performed by the same operator (Y-J C) using a Philips Lumify C5-2 curved-array transducer (Amsterdam, Netherlands). The settings included: lung preset, mechanical index 0.7, image depth 11 cm, and gain 36. The 'after-diving' ultrasound was performed within 30 minutes of surfacing. B-lines were defined as wedge-shaped, laser-like vertical hyperechoic signals originating from the pleural line, extending to the bottom of the screen without fading, and moving in synchronisation with lung sliding. We obtained 6–12 lung ultrasound views, depending on areas not covered by the swimsuit (worn underneath the wetsuit), as shown in Figure 1. Views were taken at the mid-clavicular/mid-axillary and paravertebral lines over both the upper and lower portions on each side, with a 10-second video clip recorded for each view. Two experienced ultrasonography physicians, blinded to the divers' conditions, interpreted the clips and reached consensus on the number of B-lines in each view.

B-lines are vertical reverberation artifacts seen on lung ultrasound, generated when fluid accumulates in the interstitial space. This finding can be observed in conditions such as pulmonary oedema, interstitial lung diseases, and interstitial pneumonia.[11] Three or more B-lines in a single-rib interspace in at least two different intercostal spaces or an increase in more than five B-lines from all studied views after diving were defined as positive findings. These findings, indicating increased extravascular lung fluid, were denoted as 'suspect pulmonary oedema'. The B-line score was used to assess the extent of extravascular lung fluid, calculated by adding the number of B-lines in each view, with a score of one for each B-line. The normalised B-line score was calculated as the total number of B-lines detected in all scanned views for each diver, divided by the number of views successfully obtained.

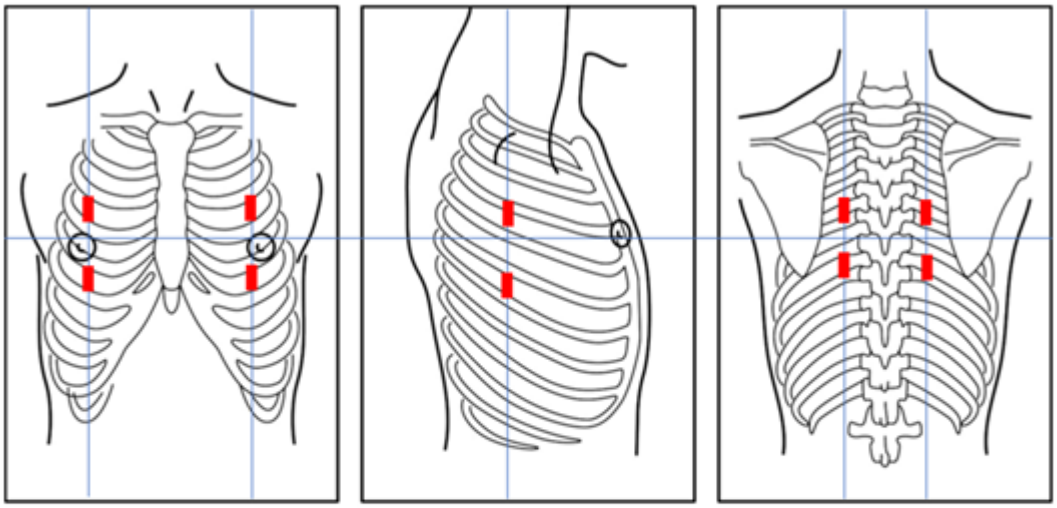
Participants' pulse rate, body temperature, and oxygen saturation were measured before and after diving, while blood pressure was measured prior to diving. Symptoms such as shortness of breath and chest discomfort post-dive were recorded. Divers completed a post-dive questionnaire on underwater conditions and their diving performance. Diving history, illnesses, underlying conditions, and personal history were noted during registration. Training time per month was calculated from the reported training frequency, with 'daily' assumed to be 28 times per month and 'weekly' four times. Adjusted diving experience was calculated by multiplying the diving years by the training frequency factor: (daily × 1, weekly × 0.8, monthly × 0.6, seasonal × 0.4).

DATA ANALYSIS

Continuous variables, such as body height, weight, age, and B-line score, are presented as medians and first to

Figure 1

Ultrasound views for measurement. The upper views are located at the 2nd or 3rd intercostal space along the mid-clavicular lines, the 3rd or 4th intercostal space along the mid-axillary lines, and the 4th or 5th intercostal space along the paravertebral lines. The lower views are at the 4th or 5th intercostal space along the mid-clavicular lines, the 5th or 6th intercostal space along the mid-axillary lines, and the 6th or 7th intercostal space along the paravertebral lines. The percentages shown beneath each view indicate the scan completion rate among all participants. * Views used for subgroup analysis



	Right (pre/post)	Left (pre/post)
Upper	84%/100%*	88%/100%*
Lower	60%/76%	28%/32%

	Right (pre/post)	Left (pre/post)
Upper	88%/92%*	88%/100%*
Lower	56%/64%	52%/64%

	Right (pre/post)	Left (pre/post)
Upper	24%/32%	24%/28%
Lower	80%/88%*	80%/92%*

third quartile (Q1–Q3). Categorical data are presented as numbers and percentages. Linear regression was used to analyse the association between variables and differences in normalised B-line score pre- and post-diving, presented as unstandardised regression coefficients (B) and 95% confidence intervals (CIs).

Results

Among 25 enrolled participants, 23 pre-dive and 25 post-dive lung ultrasound scans were obtained. The median diving experience of these divers was 4.0 years (range 3.0–5.0 years). After adjusting for their frequency of diving (as described above) the adjusted median experience was 3.5 years (range 2.4–4.8 years). The sea conditions and weather during the event were generally calm and warm, although some divers reported encountering currents during their dives. Among the participants, 3/25 (12%) used a monofin for constant-weight dives, 3/25 (12%) did not use any fins, 10/25 (40%) used bi-fins for constant-weight dives, and 9/25 (36%) used the free immersion technique. The median diving depth was 53 m, with a range of 27–77 m and Q1–Q3 = 47–60 m. The median diving time was 109 s (range 98–123 s).

Acute respiratory symptoms, including cough, haemoptysis or bloody sputum, and shortness of breath, were reported in 7/25 (28%) of divers post-dive. Of these seven symptomatic individuals, two presented with both oxygen desaturation ($SpO_2 \leq 95\%$) and a marked increase in B-lines on lung ultrasound. When combined with their symptoms, these clinical findings met the operational definition of IPO. Accordingly, the incidence of IPO in this cohort was 8% (2/25 divers).

Lung ultrasonography findings with marked increase in B-lines were observed in 10/25 (40%) of the participants in the post-dive scans. A significant increase was observed in the post-diving B-line score from a pre-dive median of 4 (range 1–4) to 7 post-dive (range 3–13) ($P = 0.048$). Moreover, the normalised B-line score also increased significantly from 0.5 (range, 0.11–0.7) pre-dive to 1.0 (range, 0.44–1.2) post-dive ($P = 0.039$). The difference in the normalised B-line score before and after diving was 0.17 (range, –0.1 to 1), as detailed in Table 2.

Male sex (46.7% vs. 90%, P = 0.040), a higher median body mass index (19.9 vs. 22.4, P = 0.046), and a higher median systolic blood pressure (SBP) before diving (110 vs. 121 mmHg, $P = 0.027$) were significantly associated with positive ultrasound findings. Additionally, deeper diving depths (50 vs 56 m, $P = 0.055$) showed a trend towards significance, suggesting a potential association

Table 1
Clinical characteristics of breath-hold diving contestants (n = 25); data are presented as number (percentage) and median interquartile range (IQR, 25–75%); AIDA – International Association for the Development of Apnea

Parameter	No pulmonary oedema (n = 15)	Suspect pulmonary oedema (n = 10)
Age (years)	30 (28–37)	26 (26–32)
Male sex	7 (46.7%)	9 (90%)
Body height (cm)	165 (159–173)	172 (170–174)
Body weight (kg)	54 (51–67)	66 (60–71)
Body mass index (kg·m^{-2})	19.9 (18.9–22.5)	22.4 (20.6–23.5)
Smoking cigarettes	5 (33.3%)	3 (30%)
Years of smoking	0 (0–0)	0 (0–0)
Training times per month	4 (4–28)	4 (4–4)
Diving experience (years)	5 (3-5)	3.3 (3–5)
Adjusted diving experience	4 (2.4–5.0)	2.8 (2.4–4.0)
Max diving depth (m)	56 (45–70)	68 (55–71)
Max breath-hold time (seconds)	300 (270–330)	289 (255–310)
Diving system and past history		
AIDA	12 (80%)	10 (100%)
Molchanovs	6 (40%)	2 (20%)
Scuba Schools International	4 (26.7%)	1 (10%)
Immersion pulmonary edema	4 (26.7%)	6 (60%)
Blackout or loss of motor control	9 (60%)	4 (40%)
Problems of controlling pressure	4 (26.7%)	5 (50%)
Chronic disease	1 (6.7%)	0 (0%)
Performance category		
Constant weight	2 (13.3%)	1 (10%)
Constant weight without fins	2 (13.3%)	1 (10%)
Constant weight with bi-fins	7 (46.7%)	3 (30%)
Free immersion	4 (26.7%)	5 (50%)
Diving depth (m)	50 (39–60)	56 (50-65)
Diving times (seconds)	109 (83–118)	114 (108–130)
Vital signs before diving		
Peripheral oxygen saturation (%)	98 (97–98)	98 (98–98)
Heart rate (beats·min^{-1})	77 (68–85)	76 (70–88)
Body temperature (°C)	36.5 (36.4–36.8)	36.9 (36.4–36.9)
Systolic blood pressure (mmHg)	110 (100–117)	121 (119–127)
Diastolic blood pressure (mmHg)	72 (70–77)	79 (69–80)
Vital signs after diving		
Peripheral oxygen saturation (%)	98 (96–98)	98 (97–98)
Heart rate (beats·min^{-1})	89 (77–102)	95 (83–109)
Body temperature (°C)	36.3 (36–36.5)	36.6 (36.3–36.6)
Symptoms after diving		
Cough	2 (13.3%)	2 (20%)
Haemoptysis	2 (13.3%)	2 (20%)
Shortness of breath	0 (0%)	1 (10%)

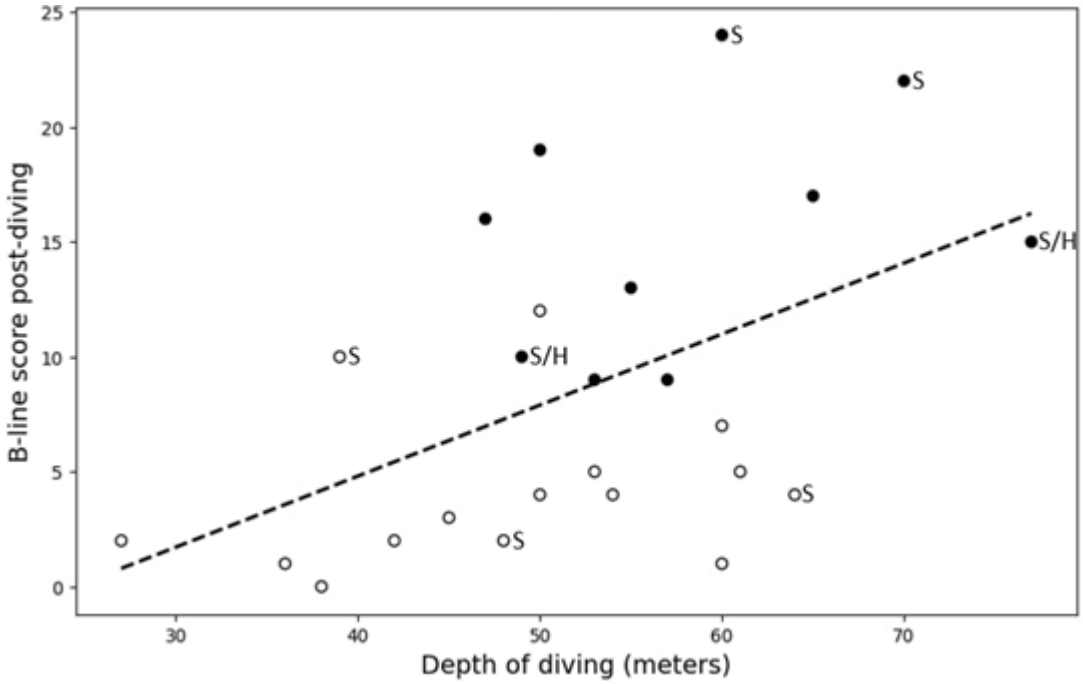
Table 2

Normalised B-line score before and after diving; data are presented as a median interquartile range (IQR 25–75%); * the difference of B-line score and normalised B-line score could be negative if one less B-line is measured after diving

Parameter	Before diving	After diving	P
B-line score	4 (1–7)	7 (3–13)	0.048
Measured views	9 (6–10)	9 (6–10)	0.933
Normalised B-line score	0.5 (0.11–0.7)	1 (0.44–1.2)	0.039
Difference of sonography measurement between before diving and after diving			
Difference of B-line score		2 (-1–8)*	
Difference of normalised B-line score		0.17 (-0.1–1)*	

Figure 2

Scatter plot of post-dive B-line scores versus diving depth; each point represents an individual diver. Suspected pulmonary oedema cases are shown in black. Symptomatic cases are marked with 'S'. Cases with hypoxaemia ($SpO_2 \leq 95\%$) are marked with 'H'. Cases exhibiting both symptoms and hypoxaemia are labelled 'S/H'



that may become significant with a larger sample size. Linear regression was used to identify the factors associated with increased B-line scores after diving. Among the variables analysed, including sex, body mass index, age, SBP before diving, and diving depth, only diving depth showed a statistically significant association (B = 0.046, $P = 0.007$) (Table 3). Figure 2 shows the relationship between the post-diving B-line score and the diving depth.

A subgroup analysis was conducted on 13 participants to account for variability in the number of ultrasound views obtained. In this subgroup, six specific lung regions were consistently scanned for all participants: the upper mid-clavicular and mid-axillary regions, and the lower paravertebral regions on both the left and right sides, with no missing data. Among these participants, seven were classified as negative and six as suspected for pulmonary oedema. Pre-dive B-line scores did not differ significantly between the two groups (median 3 [range 0–4] vs. 4 [1–7], $P = 0.385$). However, post-dive B-line scores were significantly higher in the suspected pulmonary oedema group (2 [1–3] vs. 8 [6–11], $P = 0.003$), supporting the validity of the simplified six-view protocol in detecting changes related to immersion pulmonary oedema.

Discussion

In European studies, the incidence of IPO among swimmers and divers was 1.1–1.8%.[12,13] The incidence may be underestimated owing to rapid recovery, in which patients might not seek medical assistance if their symptoms subside spontaneously. First-line medical providers may not be familiar with IPO, which may lead to underdiagnosis. In our cohort, the incidence of post-dive respiratory symptoms

Table 3
Linear regression of difference of normalised B-line score between before and after diving; adjusted $R^2 = 0.345$ – proportion of variance in difference of normalised B-line score explained by the multiple linear regression model

Variables	B	95% CI	*P*
Male sex	-0.327	(-1.077 to 0.424)	0.368
Age	-0.023	(-0.075 to 0.028)	0.350
Body mass index	0.119	(-0.001 to 0.238)	0.051
Diving depth	0.046	(0.015 to 0.076)	0.007
Systolic blood pressure	-0.013	(-0.046 to 0.020)	0.403
Adjusted $R^2 = 0.345$			

was 28%, which is consistent with a previously reported incidence of 26.4% among freedivers.[1] In the present study, using lung ultrasonography findings, 40% of the divers were found to have increased extravascular lung fluid, with an incidence of IPO during this event of 8%. The higher prevalence observed in our study may be explained by several factors. First, previous reports of IPO prevalence often combined data from swimmers and scuba divers, populations with different diving physiology and potentially different predispositions to pulmonary oedema. Second, because IPO is typically a self-limiting disorder, its prevalence may have been underestimated in retrospective studies, as divers or swimmers who recovered spontaneously may not have sought medical attention. In our study all participants underwent immediate post-dive evaluation with portable lung ultrasound in addition to symptom reporting, which may have increased the detection of cases that would have been missed by recall alone.

Studies have reported subclinical increases in pulmonary fluid among breath-hold divers and ironman athletes, and B-lines observed via lung ultrasound may typically resolve within 24 hours without evident clinical harm.[2,10,14,15] In our investigation, we observed a median pre-dive B-line score of 4, despite participants having rested for at least 12 hours. This score significantly increased to 7 post-dive, suggesting an accumulation and progression of extravascular lung fluid. In the context of depth training, where repeated deep dives are common and safety protocols may be less comprehensive than during official competitions, this subclinical fluid accumulation warrants further attention. However, the clinical threshold at which these subclinical signs may progress to IPO remains unclear. In this study, IPO diagnosis was defined by clinical symptoms, hypoxaemia, and positive lung sonographic findings, following the concepts proposed by Hårdstedt[16] and Ludwig.[17] This study is among the first to focus on Asian-based breath-hold divers, providing insights valuable for the safety and medical preparation of both divers and competition organisers. Based on the 8% incidence of IPO observed in this event, we recognise the importance of adequate on-site preparedness for potential pulmonary complications. Sufficient oxygen supply should be ensured, along with high FiO_2 delivery equipment, such as non-rebreather masks, bag-valve masks, or oxygen regulators,[18] to provide support for multiple affected participants if needed.

Previous studies have identified several factors associated with IPO, including cold-water immersion, strenuous exercise, tight wetsuits, and overhydration. These factors are believed to exacerbate central blood pooling, thereby increasing the risk of IPO.[12,19–21] In this study, none of the divers reported coldness, although some mentioned experiencing mild-to-moderate sea currents during the dive. A positive correlation was observed between higher B-line scores and the male sex, a higher body mass index, depth, and higher SBP before diving. The association between sex and IPO remains unclear. A recent cohort study on breath-hold divers found more B-lines in male divers,[15] which is consistent with our findings. This may be explained by the fact that male divers tend to dive deeper into competition, which may be a risk factor for IPO. Cardiopulmonary risk factors, including hypertension and overweight, have been viewed as predisposing factors for IPO.[22] It should be noted that the divers enrolled in our study were all healthy and young, with no previously reported chronic diseases, and their body mass index was within the normal range. Only diving depth was significantly associated with increased B-line scores in linear regression analysis, suggesting that sex, SBP, and body mass index may be confounding factors.

The relationship between diving depth and IPO varies depending on the type of immersion activity. For example, depth is not considered a major risk factor for IPO in scuba diving.[12] However, in our study, we found a positive correlation between diving depth and IPO in freediving, which is consistent with previous reports.[10,15] During freediving, the volume of the thoracic cage decreases more slowly than that of the lungs. This volume mismatch exacerbates intrapleural negative pressure,[23] increasing the hydrostatic pressure gradient. This phenomenon is more prominent in dives where the diver's lung volume falls below residual volume, increasing the risk of lung injury due to greater blood shift.[24] Lung atelectasis at greater depths has recently been reported in underwater ultrasound studies.[25] Due to the unique pathophysiology and epidemiology of IPO after freediving, the concept of "*depth-induced pulmonary oedema*" was proposed.[15] To account for the broader

spectrum of clinical presentations seen in breath-hold divers, the term freediving-induced pulmonary syndrome (FIPS) has recently been adopted.[3] In a recent study, Yu et al. proposed a classification of FIPS into several distinct phenotypes, including alveolar oedema, interstitial oedema, mixed oedema, alveolar barotrauma, airway barotrauma, and severe FIPS. These subtypes can be differentiated based on clinical findings and symptomatology.[26] In our cohort, IPO was defined by a combination of acute respiratory symptoms, hypoxaemia, and positive B-line findings on lung ultrasound. These features align with the phenotype classified as mixed oedema and severe FIPS. By contrast, divers who exhibited only respiratory symptoms without imaging abnormalities or desaturation may correspond to the airway barotrauma phenotype. However, confirming this diagnosis is challenging in a field setting without appropriate structural evaluation tools, such as laryngoscopy, bronchoscopy, or computed tomography. Although IPO following freediving and other water-based activities may share similar clinical features and partially overlapping mechanisms, the evaluation of fitness to return to diving should differ. The recent SPUMS / UKDMC position statement advises against resuming compressed gas diving after IPO without a comprehensive cardiovascular evaluation.[27] Applying the same criteria to freedivers may not be appropriate, as the pathophysiological context and physical demands of breath-hold diving differ significantly from scuba diving. Finally, while depth remains an important contributing factor, individual variability among divers plays a substantial role. In our study, eight divers who reached depths greater than 50 m showed no symptoms and no ultrasound evidence of pulmonary fluid accumulation. Parameters considering individual factors, such as dive discipline, smoking history, diving experience, and frequency, were evaluated; however, no statistically significant correlations were found.

The lung ultrasound protocol employed in this study was intentionally simplified to facilitate rapid assessment in field conditions. Sonographic images were acquired from six to 12 views along the bilateral mid-clavicular, mid-axillary, and paravertebral lines. Participants were scanned in an upright position, which enabled completion of the examination within 30 minutes after surfacing, even in the confined space of a diving cabin. In earlier ultrasound studies on IPO, researchers typically acquired 28 to 61 intercostal views per participant, with subjects in supine or sitting positions.[10,12,15] Despite the reduced number of scanning sites in our protocol, the B-line counts per view were comparable to those in previously published data, suggesting that the selected views were representative. Additionally, in our subgroup analysis of 13 participants, we observed a similar trend in B-line scores using only six views, specifically the upper mid-clavicular, mid-axillary, and lower paravertebral regions. This supports the feasibility and clinical utility of a six-view lung ultrasound approach. A recent study employed a comparable six-view approach, scanning the bilateral anterior, lateral, and posterior chest regions to record the highest number of B-lines per view (up to three), with a total possible score of 18.[26] Our subgroup findings align with this methodology and offer additional validation. We recommend that future researchers and medical providers consider adopting the six-view protocol, as it offers a practical balance between diagnostic value and operational feasibility, especially in space-limited settings such as diving platforms or boats, while still enabling timely and informative assessments.

This study has some limitations. Firstly, it was a small observational study. Studies with more participants are needed to better clarify the impact of different factors on the presence of B-lines and IPO, as well as to minimise confounders from individuals. The number of B-lines in the pre-test was higher than expected, possibly due to self-performed dive training in the days prior to the study. This suggests that a 12-hour resting period may not be sufficient. Although post-dive lung ultrasound was performed as soon as feasible, unavoidable delays of up to 30 minutes may have reduced B-line detection and led to underestimation of post-dive pulmonary changes. Oxygen inhalation after diving was not limited; hence, the participants may have freely inhaled oxygen regardless of whether they needed it, resulting in a potential overestimation of the oxygen saturation values. In addition, a high fraction of inspired oxygen may promote absorption atelectasis, which could in turn increase the number of B-lines observed on lung ultrasound. Since divers may exert less effort and suffer less mentally and physically in simulation competitions than in formal competitions, the occurrence of IPO may be lower.

Conclusions

The post-dive incidence of acute respiratory symptoms was 28%, and the incidence of IPO, defined by the combination of positive lung ultrasound findings and hypoxaemia, was 2/25 (8%) in this cohort. Positive ultrasound findings indicating increased extravascular lung fluid were observed in 40% of participants. Maximum diving depth was significantly associated with a higher number of post-dive B-lines.

References

1 Cialoni D, Sponsiello N, Marabotti C, Marroni A, Pieri M, Maggiorelli F, et al. Prevalence of acute respiratory symptoms in breath-hold divers. Undersea Hyperb Med. 2012;39:837–44. PMID: 22908840.

2 Linér MH, Andersson JPA. Pulmonary edema after competitive breath-hold diving. J Appl Physiol (1985). 2008;104:986–90. doi: 10.1152/japplphysiol.00641.2007. PMID: 18218906.

3 Lindholm P. Discussion on Terminology. In: Lindholm P, Lang MA, Tillmans F, editors. Proceedings of the San Diego Center of Excellence in Diving/Divers Alert Network workshop on barotrauma and SIPE in freediving; Oct 27-28, 2023. San Diego (CA): Divers Alert Network; 2024. p. 95–8.

4 Mijacika T, Dujic Z. Sports-related lung injury during breath-hold diving. Eur Respir Rev. 2016;25(142):506–12. doi: 10.1183/16000617.0052-2016. PMID: 27903671. PMCID: PMC9487548.

5 Yu E, Dong GZ, Patron T, Coombs M, Lindholm P, Tillmans F. Occurrence and resolution of freediving-induced pulmonary syndrome in breath-hold divers: an online survey of lung squeeze incidents. Diving Hyperb Med. 2024;54:281–6. doi: 10.28920/dhm54.4.281-286. PMID: 39675735. PMCID: PMC12018692.

6 West JB. Invited review: pulmonary capillary stress failure. J Appl Physiol (1985). 2000;89:2483–9. doi: 10.1152/jappl.2000.89.6.2483. PMID: 11090603.

7 Lindholm P, Ekborn A, Oberg D, Gennser M. Pulmonary edema and hemoptysis after breath-hold diving at residual volume. J Appl Physiol (1985). 2008;104:912–7. doi: 10.1152/japplphysiol.01127.2007. PMID: 18202166.

8 Lambrechts K, Germonpré P, Charbel B, Cialoni D, Musimu P, Sponsiello N, et al. Ultrasound lung "comets" increase after breath-hold diving. Eur J Appl Physiol. 2011;111:707–13. doi: 10.1007/s00421-010-1697-y.

9 Boussuges A, Coulange M, Bessereau J, Gargne O, Ayme K, Gavarry O, et al. Ultrasound lung comets induced by repeated breath-hold diving, a study in underwater fishermen. Scand J Med Sci Sports. 2011;21(6):e384–92. doi: 10.1111/j.1600-0838.2011.01319.x. PMID: 21535186.

10 Frassi F, Pingitore A, Cialoni D, Picano E. Chest sonography detects lung water accumulation in healthy elite apnea divers. J Am Soc Echocardiogr. 2008;21:1150–5. doi: 10.1016/j.echo.2008.08.001. PMID: 18926391.

11 Demi L, Wolfram F, Klersy C, De Silvestri A, Ferretti VV, Muller M, et al. New international guidelines and consensus on the use of lung ultrasound. J Ultrasound Med. 2023;42:309–44. doi: 10.1002/jum.16088. PMID: 35993596. PMCID: PMC10086956.

12 Boussuges A, Ayme K, Chaumet G, Albier E, Borgnetta M, Gavarry O. Observational study of potential risk factors of immersion pulmonary edema in healthy divers: exercise intensity is the main contributor. Sports Med Open. 2017;3(1):35. doi: 10.1186/s40798-017-0104-1. PMID: 28975560. PMCID: PMC5626674.

13 Koehle MS, Lepawsky M, McKenzie DC. Pulmonary oedema of immersion. Sports Med. 2005;35:183–90. doi: 10.2165/00007256-200535030-00001. PMID: 15730335.

14 Pingitore A, Garbella E, Piaggi P, Menicucci D, Frassi F, Lionetti V, et al. Early subclinical increase in pulmonary water content in athletes performing sustained heavy exercise at sea level: ultrasound lung comet-tail evidence. Am J Physiol Heart Circ Physiol. 2011;301(5):H2161–7. doi: 10.1152/ajpheart.00388.2011. PMID: 21873499.

15 Patrician A, Pernett F, Lodin-Sundström A, Schagatay E. Association between arterial oxygen saturation and lung ultrasound B-lines after competitive deep breath-hold diving. Front Physiol. 2021;12:711798. doi: 10.3389/fphys.2021.711798. PMID: 34421654. PMCID: PMC8371971.

16 Hårdstedt M, Seiler C, Kristiansson L, Lundeqvist D, Klingberg C, Braman Eriksson A. Swimming-induced pulmonary edema: diagnostic criteria validated by lung ultrasound. Chest. 2020;158:1586–95. doi: 10.1016/j.chest.2020.04.028.

17 Ludwig BB, Mahon RT, Schwartzman EL. Cardiopulmonary function after recovery from swimming-induced pulmonary edema. Clin J Sport Med. 2006;16:348–51. doi: 10.1097/00042752-200607000-00011. PMID: 16858220.

18 Yu E, Valdivia-Valdivia JM, Silva F, Lindholm P. Breath-hold diving injuries – a primer for medical providers. Curr Sports Med Rep. 2024;23:199–206. doi: 10.1249/JSR.0000000000001168. PMID: 38709946.

19 Wilmshurst PT, Nuri M, Crowther A, Webb-Peploe MM. Cold-induced pulmonary oedema in scuba divers and swimmers and subsequent development of hypertension. Lancet. 1989;1(8629):62–5. doi: 10.1016/s0140-6736(89)91426-8. PMID: 2562880.

20 Grünig H, Nikolaidis PT, Moon RE, Knechtle B. Diagnosis of swimming induced pulmonary edema—a review. Front Physiol. 2017;8:652. doi: 10.3389/fphys.2017.00652. PMID: 28912730. PMCID: PMC5583207.

21 Miller CC 3rd, Calder-Becker K, Modave F. Swimming-induced pulmonary edema in triathletes. Am J Emerg Med. 2010;28:941–6. doi: 10.1016/j.ajem.2009.08.004. PMID: 20887912.

22 Peacher DF, Martina SD, Otteni CE, Wester TE, Potter JF, Moon RE. Immersion pulmonary edema and comorbidities: case series and updated review. Med Sci Sports Exerc. 2015;47:1128–34. doi: 10.1249/MSS.0000000000000524. PMID: 25222821.

23 Lai-Fook SJ, Rodarte JR. Pleural pressure distribution and its relationship to lung volume and interstitial pressure. J Appl Physiol (1985). 1991;70:967–78. doi: 10.1152/jappl.1991.70.3.967. PMID: 2033012.

24 Schaefer KE, Allison RD, Dougherty JH Jr, Carey CR, Walker R, Yost F, et al. Pulmonary and circulatory adjustments determining the limits of depths in breathhold diving. Science. 1968;162(3857):1020–3. doi: 10.1126/science.162.3857.1020. PMID: 5725383.

25 Paganini M, Moon RE, Giacon TA, Cialoni D, Martani L, Zucchi L, et al. Relative hypoxemia at depth during breath-hold diving investigated through arterial blood gas analysis and lung ultrasound. J Appl Physiol (1985). 2023;135:863–71. doi: 10.1152/japplphysiol.00777.2022. PMID: 37650139.

26 Yu E, Silva F, Lussier A, Lindholm P. Lung ultrasound as an adjunct to pulse oximetry and respiratory symptoms in the diagnosis of freediving-induced pulmonary syndrome. Wilderness Environ Med. 2024;35:409–16. doi: 10.1177/10806032241281463. PMID: 39279453.

27 Banham N, Smart D, Wilmshurst P, Mitchell SJ, Turner MS, Bryson P. Joint position statement on immersion pulmonary oedema and diving from the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC) 2024. Diving Hyperb Med. 2024;54:344–9. doi: 10.28920/dhm54.4.344-349. PMID: 39675743. PMCID: PMC11779524.

Acknowledgements

We acknowledge the participants and competition organizer, Wen-Yen Wang, for the valuable opportunity to conduct this study. We thank Dr. I-Min Chiu for his contributions to the study design. We also appreciate Meng-Chang Hsiao and Guan-Wei Tsai for assisting with onboard data collection. Our gratitude extends to aunt Wang for providing accommodation and research space during the study. Special thanks to the outstanding athlete, Jay Ku, for inspiring our research on freediving.

Conflicts of interest and funding: nil

Submitted: 17 January 2025
Accepted after revision: 5 January 2026

Review of excursion procedures used in commercial heliox saturation diving

Jean-Pierre Imbert[1], Lyubisa Matity[2], Jean-Yves Massimelli[3], Christian Cadieux[4], Jan Risberg[5], Philip Bryson[6]

[1] *Divetech EURL, 1543 chemin des vignasses, 06410 Biot, France*
[2] *Hyperbaric and Tissue Viability Unit, Gozo General Hospital, Victoria VCT 2520, Malta*
[3] *Centre Hospitalier Universitaire de Nice, 30, Voie Romaine, 06001 Nice, France*
[4] *CCO Ltd, 52/2 moo 3 Tambon Tarpo - Phitsanulok 65000, Thailand*
[5] *NUI, Gravdalsveien 245, 5165 Laksevag, Norway*
[6] *TAC Healthcare Group, Wellheads Industrial Estate, Aberdeen, United Kingdom*

Corresponding author: *Dr Philip Bryson, TAC Healthcare Group, Wellheads Industrial Estate, Aberdeen, AB21 7GA United Kingdom*
ORCiD: *0000-0002-7815-1218*
philip.bryson@tachealthcare.com

Keywords
Decompression sickness; Decompression tables; Excursion dives; Occupational diving; Oxygen

Abstract
(Imbert J-P, Matity L, Massimelli J-Y, Cadieux C, Risberg J, Bryson P. Review of excursion procedures used in commercial heliox saturation diving. Diving and Hyperbaric Medicine. 2026 31 March;56(1):21–40. doi: 10.28920/dhm56.1.21-40. PMID: 41875439.)
Introduction: This study reviews heliox saturation procedures used in offshore commercial diving and focuses on bell excursion dives. It excludes initial compression and final decompression. Our first objective was to trace the history and the reasons behind the successive changes that led to the current practice. Our second objective was to review the current practice and identify problem areas and perspectives.
Methods: We first present the background of excursion diving and reference key procedures from the US Navy, Comex, and international standards. We then review the procedures of 13 anonymised diving companies and compare their sources, designs, and operation parameters.
Results: The current excursion procedures are derived from a few original procedures (US Navy, Comex). It appears that, without relevant scientific support since the 1980s, companies have empirically adapted these procedures to their needs. Two designs prevail: excursions from storage depth and excursions from the deepest depth. Recent innovations offer 'standard' and 'extended' excursions, sliding excursion windows, as well as shallow and deep excursions. Companies participating in the study have a low risk of DCS with excursion diving. Excursions rarely produce immediate DCS symptoms but associated bubble formation could impact the final decompression. The trend is towards reduced excursion distances and explicit post-excursion intervals. Oxygen toxicity remains a general concern in saturation diving, but the PO_2 values used in the procedures reviewed are unlikely to cause pulmonary toxicity according to the dose models in use.
Conclusions: We observed a trend towards harmonisation under the pressure of international standards and through cooperation within industry association committees. We recommend scientific monitoring of saturation divers to measure the decompression stress and support further research and development. We recommend that companies document their procedural developments to record and thus keep the lessons learned.

Introduction

Saturation diving is commonly used in commercial offshore diving.[1] We have previously reviewed the final decompression procedures for commercial helium-oxygen (heliox) saturation diving.[2] This work focuses on excursion procedures.

Our first objective is to trace the historical background and the reasons for the successive changes that led to the current practice. Our second goal is to describe and evaluate this current practice. We have contacted offshore commercial diving companies involved in saturation diving and requested that they provide their diving manuals for review. The review of these company procedures has allowed us to 1) identify their sources, 2) trace their evolution, 3) describe their current practice, 4) estimate their safety performance, and 5) identify problem areas and trends.

We have tried to provide written references in agreement with scientific standards. However, much information related to the development of commercial saturation diving

procedures has not been published in the open domain. Non-referenced information in this review should be considered as the authors sharing their personal experiences.

Background

UNITS

We have adhered to the units commonly used in diving manuals:

- Gas partial pressures are expressed in bar (1 bar = 100 kPa).
- Gas fractions are expressed in percentages.
- While excursion distances and water depths hold the dimension of length, they are conventionally measured by pressure gauges (for instance, a pneumofathometer or 'pneumo'). For this reason, we use metres of seawater (msw) to express water depth and bell pressure (1 msw = 1.0197 kPa according to EN 13319).[3]

Our policy regarding unit conversion is:

- When a company converted original values from feet of seawater (fsw) to msw, we kept the msw values found in the company manual, regardless of the conversion factor used. Most companies use 1 fsw = 0.303 msw according to the IMCA D 022 guidance note.[4]
- For the US Navy (USN) instructions or the companies that only use fsw, we have converted fsw into msw using 1 fsw = 0.30643 msw as specified in the USN diving manual.

BELL SATURATION EXCURSION PROCEDURE

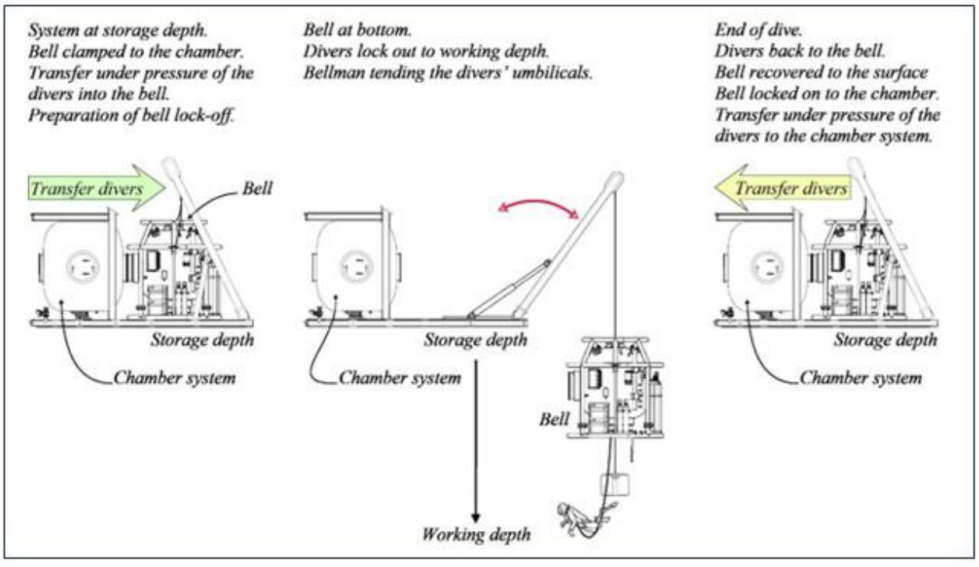
During an excursion dive, divers are deployed from the diving support vessel (DSV) to the worksite in a diving bell (Figure 1):

- The bell is initially locked onto the saturation chamber system. The divers are transferred under pressure (TUP) into the bell. Typically, two divers and a bellman occupy the bell.
- The bell is separated from the system (locked-off) and lowered into the sea. When the ambient hydrostatic pressure equals the bell pressure, the bottom door opens.
- The divers don their gear and lock-out for the job, with their umbilicals tended by the bellman. Divers may intermittently return to the bell to collect tools or for a rest period. At the end of their dive, the divers re-enter the bell and remove their gear.
- The bell lower door is closed and sealed by slight overpressure. The bell is then lifted to the surface.
- The bell arrives on deck and is clamped back onto the chamber system (locked-on).
- The bell is then decompressed to the chamber storage depth, and the divers are transferred under pressure back into the chamber system.

The following terms are defined in bell excursion diving:

- Ascending (or upward) excursion: an excursion shallower than the storage.
- Bell run time: the time elapsed between the lock-off and the lock-on times.
- Combined excursion: an excursion deeper and shallower than the storage depth.
- Descending (or downward) excursion: an excursion deeper than the storage depth.
- Dive time: the time spent by a diver in the water.
- Excursion: a dive or bell exposure at a pressure different from the storage depth.
- Excursion distance: the difference between the deepest and the shallowest depths reached during the excursion.
- Excursion window: the range of the excursion depths defined from the excursion distance, allowing divers to ascend and descend freely within these limits.

Figure 1
Illustration of the sequence of events of a bell run



- Post-excursion interval: the minimum time following an excursion before the next excursion can start.
- Pre-decompression hold time: the minimum time after the last excursion before an intermediate or final decompression can be initiated.

HISTORY OF SATURATION EXCURSIONS

The first excursion procedures were developed for underwater habitats in the early 1960s. At that time, the concept was to consider an excursion dive as a 'bounce dive' from the habitat. Scheiner and Kelly developed a matrix of M-values from symptom-free excursions based on habitat experiments. From this matrix, they designed a set of no-decompression dives from various storage depths that could be used along with repetitive dive interval procedures.[5] During the Hydrolab project (Bahamas, 1970–1985), the first undersea research habitat used by NOAA (US National Oceanic and Atmospheric Administration), divers used excursions requiring in-water decompression stops before they could return to the storage depth (Figure 2). Hamilton also developed a model for REPEX excursions (REPetitive EXposure) based on conventional perfusion-limited gas kinetics with eight compartments with half-times ranging from five to 640 minutes. Ascent criteria were defined with traditional M-values but with a reduced slope for storage depths deeper than 70 fsw. The procedure used the number of dives in the sequence and the time interval between dives to compute a decompression penalty.[6]

Miller compiled the experience gained with air and nitrox vertical excursions from habitat projects.[7] The NOAA OPS manual, published in 1975, included Hamilton's REPEX procedures computed for air and nitrox saturation excursions.[8]

In 1969, the diving company Comex performed its first saturation operations in the Gulf of Biscayne at a depth of 100 msw. The Comex excursion procedures provided varying bottom time limitations based on varying post-dive intervals, called Ludion N/M. The term Ludion refers to an ancient toy in which a figurine ascended and descended in a water-filled glass tube. The term N/M represented the combinations of a given bottom time and the minimum post-excursion intervals. For instance, a Ludion 6/8 was associated with six hours spent at the bottom depth, followed by eight hours at the storage depth. Various combinations of Ludions (6/8, 4/12, etc.) were listed for different storage depths (Figure 3).

In 1974, the US Navy Diving Operations Handbook included saturation excursions with no-decompression limits and repetitive groups designation tables for helium-oxygen dives.[9] The 1977 revision contained excursion procedures based on unlimited durations, which became the 'Bible' for many diving companies working in the North Sea oil and gas exploration.[10]

REFERENCE PROCEDURES

Most commercial saturation diving manuals are based on the US Navy and the Comex diving manuals. Other laboratories (Royal Navy, Institute for Environmental Medicine, Duke University, NUI) and past companies (Oceaneering, Taylor Diving) have contributed to these developments.

Figure 2
The dive slate of Dick Clarke, diver of Hydro-Lab, on 12 December 1974; he noted the information for an excursion dive from 42 fsw to 200 fsw for a 60 min bottom time. The slate indicates stops to be performed in water during the return to the habitat with a total decompression time of 42 min (Courtesy of Dick Clarke)

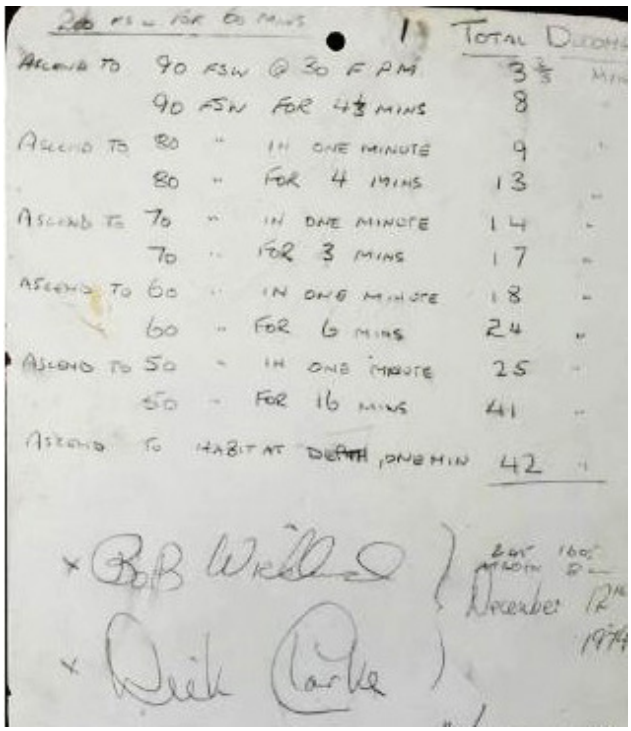
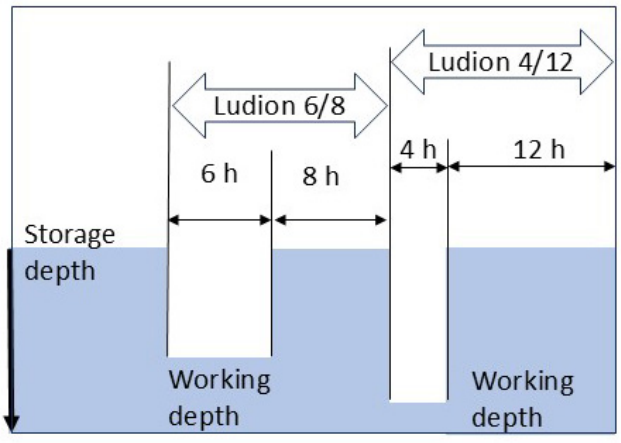


Figure 3
Example of 6/8 and 4/12 Comex Ludions excursions



US Navy excursion procedures

The USN Diving Manual has played a key role in the development of the offshore industry. It shaped minds and culture.

Bornmann computed the early US Navy helium oxygen saturation excursion tables.[11] The tables were tested by Summitt et al. at the Navy Experimental Diving Unit in 1969.[12,13] In these studies, no DCS was observed following 1,126 descending excursion dives ranging from 15 to 45 msw from storage depths ranging from 45 to 180 msw.

After the study of Barnard at the Royal Navy, the US Navy resumed its work on excursion tables.[14] The results were published after an exhaustive study of more than 240 excursion ascents ranging from 66 to 300 msw.[15] It formed the basis for the US Navy tables presented in the 1977 revision of the US Navy diving manual.[10] These tables provided unlimited-duration excursions and covered the depth range of 46 msw to 306 msw. They had significantly larger excursion distances when compared to today's commercial practices (Table 1).

The revised excursion procedures were published in the 1987 revision of the US Navy diving manual Volume 2, which included excursions defined up to the surface (Table 2). These procedures have remained unchanged since.

Comex excursion procedures

Comex was a leading diving company during the 1970s and 1980s. It conducted decompression research at its Marseille hyperbaric centre and used a database to monitor and validate its diving procedures until 1994.[16]

The 1986 Comex diving manual specified a fixed maximum 10 msw excursion distance, applicable to both downward and upward excursions, within a 40 to 300 msw storage depth range, with an eight-hour minimum post-excursion interval. To enhance operational flexibility, this manual also included Ludion excursions. They provided downward excursions, limited to 30 msw distance, and based on the same eight-hour post-excursion minimum interval (Table 3).

The 1994 Comex diving manual introduced standard and extended excursions (Table 4). Company evolutions, such as Stolt Comex Seaway and Acergy inherited Comex excursion procedures.

INTERNATIONAL STANDARDS AND REGULATIONS

Three countries, France, Norway, and Brazil, have regulated saturation diving with detailed specifications for ascent rates, hold times, chamber PO_2, etc.

French saturation procedures

The 1992 revision of the French diving regulations was associated with the publication of official air tables and saturation procedures known as 'MT92'.[17] These procedures are the same as those presented in the 1994 version of the Comex diving manual. The French diving regulations were revised in 2019, but the saturation procedures remained unchanged.[18] They have been used since in France and West Africa.

Norwegian saturation procedures

In 1984, the Norwegian Petroleum Directorate (NPD) contracted Dr Hempleman from the British Royal Navy

Table 1
Limits for descending excursions published in the 1977 US Navy diving manual; msw – metres of seawater

Storage depth (msw)	Excursion distance (msw)	Descending excursion depth (msw)
46	23	69
60	25	85
90	30	120
120	35	155
150	39	189
180	44	224
210	49	259
240	53	293

Table 2
Limits for descending excursions from a given storage depth published in the 2016 US Navy diving manual rev 7; msw – metres of seawater

Storage depth (msw)	Excursion distance (msw)	Descending excursion depth (msw)
15	14.1	29.1
30	17.8	47.8
45	20.5	65.5
60	23.3	83.3
90	27.9	117.9
120	31.6	151.6
150	35.2	185.2
180	38.6	218.6
210	41.4	251.4
240	44.1	284.1

Table 3

Comex 1986 Ludion N/M excursions; the excursions were only permitted deeper than 40 msw and limited to downward excursions. The minimum post-excursion interval was 8 hours; msw – metres of seawater

Storage depth (msw)	Maximum downward excursion depth (msw)			
	Maximum bottom time / minimum interval (hours)			
	2/8	4/8	6/8	8/8
45	70	63	60	58
60	87	79	75	74
90	120	110	106	105
120	150	142	138	136
150	180	174	169	167
180	210	207	202	200

Table 4

Comex 1994 standard and extended descending excursion limits from a given storage depth; the excursions are compared to those of the 2016 US Navy diving manual and expressed as fractions of the US Navy allowance; msw – metres of seawater; / – not defined

Storage depth (msw)	Comex standard excursions			Comex extended excursions		
	Excursion distance (msw)	Excursion depth (msw)	% of US Navy 2016	Excursion distance (msw)	Excursion depth (msw)	% of US Navy 2016
15	6	21	43	/	/	/
30	7	37	39	12	42	67
45	8	53	39	16	61	78
60	9	69	39	18	78	77
90	10	100	36	20	110	72
120	12	132	38	24	144	76
150	13	163	37	26	176	74
180	15	195	39	30	210	78

to evaluate the saturation procedures and organise an international conference.[19] The NPD then initiated a series of meetings with participants representing the diving contractors, unions, and employer representatives to agree on the environmental threshold/dive parameters for saturation diving. After assessing the practice of five diving contractors operating in the Norwegian sector, the participants proposed a common framework based on the most conservative features.[20] The excursion procedures appear similar to those outlined in the 1994 Comex standard excursions.

The work was published in an NPD report and referenced in the first edition of the Norsok U-100 standards for manned underwater interventions in 1999. Ascending and descending excursions were based on storage depths (Table 5). These limits have not been revised since and have remained in the 2023 revisions.[21]

Risberg and Segadal recently published a report on compression and excursion procedures in saturation diving, comparing NORSOK U-100:2023 to selected international reference procedures and a limited number of commercial procedures.[22] They concluded that empirical or experimental data could not support the narrow excursion distances that allowed for shallow saturation diving.

Brazilian saturation procedures

When deep operations began in the Campos field in the 1980s, Comex, which had completed two deep development contracts in Bergen (Statoil 3DP and Norsk Hydro Oseberg), brought along its Norwegian expertise and became highly influential.[23]

The first national diving legislation was published in 1988. It closely aligned with North Sea standards and was based on the 1994 Comex deep saturation procedures. The Brazilian Navy then built a hyperbaric centre and validated the procedures through a series of onshore dives before they were first published in 1999 (Table 6). Brazilian diving regulations ('Normam-15') are now available as Rev. 2, 2016.[24] Grounded in three decades of Brazilian deep diving experience, they have become an international reference.[25,26]

Table 5
Sample of the Norsok U100 2023 clause 13.4.2.4 listing maximum excursion distances from storage depth; msw – metres of seawater

Storage depth (msw)	Ascending distance (msw)	Descending distance (msw)
40 to 59	8	8
60 to 79	9	9
80 to 99	10	10
100 to 119	11	11
120 to 139	12	12
140 to 180	13	13

Table 6
Normam-15 2016 standard and extended excursion distances; the excursions are compared to those of the 2016 US Navy diving manual and expressed as fractions of the US Navy allowance; msw – metres of seawater; / – not defined

Storage depth (msw)	Brazil 2016 standard excursions			Brazil 2016 extended excursions		
	Excursion distance (msw)	Excursion depth (msw)	% of US Navy 2016	Excursion distance (msw)	Excursion depth (msw)	% of US Navy 2016
15	3	21	21	/	/	/
30	6	36	34	15	45	84
45	8	53	39	16	61	78
60	9	69	39	18	78	77
90	10	100	36	20	110	72
120	12	132	38	24	144	76
150	13	163	37	26	176	74
180	15	195	39	30	210	78

DESIGN

In addition to the constraints aiming at controlling the intrinsic DCS risk, we have identified five design concepts that influences how instructions are used.

Design 1: Ludion excursions

The first excursions were computed with knowledge of the 70s, which referred to Haldanian algorithms.[27] The concept was to consider excursions as a no-stop, repetitive bounce diving from the storage depth. According to these models, varying distances and bottom times required varying post-excursion intervals. This was the principle of the Ludion excursions of the 1986 Comex diving manual.

Design 2: Excursion distances defined from the deepest depth

The US Navy simplified the procedures by considering unlimited-duration excursions that assume saturation at excursion depth. The distance of the next excursion depends on the deepest depth previously reached by the divers, which the US Navy defined as the last 48 hours. This deepest depth becomes the entry point of the excursion table and sets the ascending excursion depth independently of the storage depth. This principle was first presented in the 1977 US Navy diving manual.

Design 3: Excursion distances defined from storage depth

The deepest depth concept was adapted to make it possible to define excursion directly from storage depth.

In 1986, Comex drastically reduced the excursion distances to authorise the definition of the deepest depth over the last eight hours. Since divers only perform one bell dive a day and stay at storage depth for the rest of the time, the storage depth becomes the deepest depth in all cases.

The storage depth replaced the deepest as the entry point of the excursion tables, from which the limits for descending or ascending excursion depths are listed. The Norwegian Norsok U-100 procedures are a typical example of this presentation (Figure 4).

Figure 4
Principle of downward and upward excursions defined from the storage depth

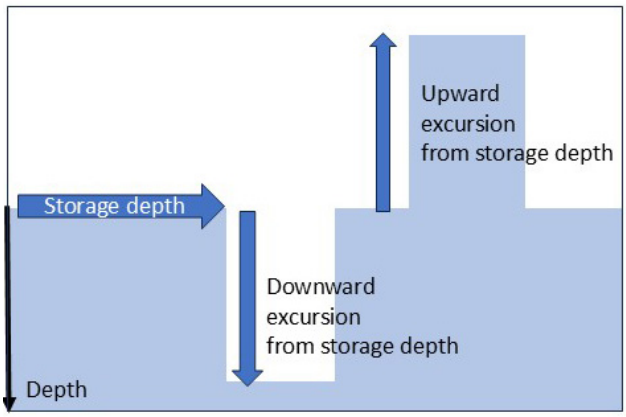


Figure 5
Principle of standard and extended excursions defined from storage depth

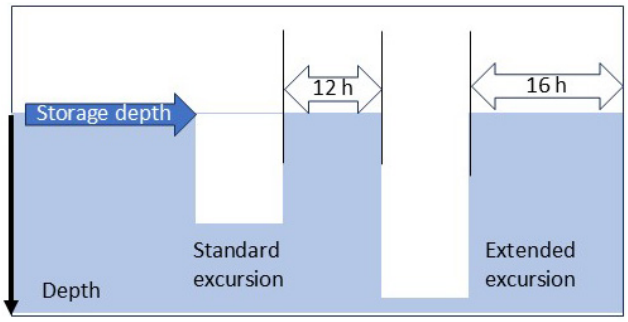
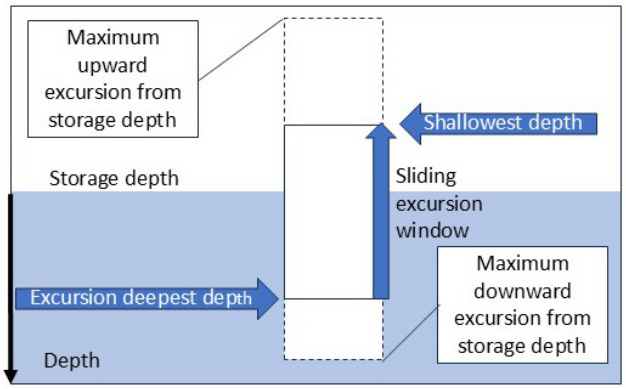


Figure 6
Design concept of excursions derived from the diver's deepest depth, showing the sliding excursion window



Design 4: Standard and extended excursion distances

The 1980s marked the development of inspection, maintenance, and repair jobs in the North Sea. Inspection work requires divers to move up and down the platform bracings, and the offshore construction managers discussed the possibility of using higher excursion windows for these specific projects. Comex revisited the concept of the Ludion N/M excursions and replaced them with standard and extended excursions (Figure 5):

- Standard excursions have moderate amplitudes (around 40% of the 1977 US Navy excursions). They can be used without restrictions for routine operations, based on a standard 12-hour post-excursion interval.
- Extended excursions provide higher amplitudes (around 75% of the 1977 US Navy excursion distance). They are only allowed for downward excursions and require a longer post-dive interval (16 h) to mitigate an increased DCS risk.

Standard and extended excursions were first used as special instructions onboard selected DSVs. Their safety performances were monitored using the Comex database.[28] As no DCS incidents were recorded after three years of evaluation, they were considered validated and finally accepted based on their measured safety track records. The Comex manual revision 1994 proposed standard and extended excursions as options for excursions from storage depth. The Brazilian Normam 15 procedures, derived from these procedures, provide a typical example of standard and extended excursions.

Design 5: Sliding excursion window

In the late 1990s, a new generation of large DSVs came to the North Sea. These expensive and efficient DSVs can operate on the spot market and move from one project to another. The divers had to change the storage depth accordingly. The diving companies requested flexible excursion limits to save on intermediate storage depth changes.

The idea was to change the table entry to the excursion deepest depth. Keeping the experience gained with standard and extended excursions, this allows the excursion window to slide between the downward and the upward limits of excursions from storage depth (Figure 6). The principle can be applied to both standard and extended excursions (Table 7) and allow the divers to work above and below the storage depth during the same bell dive.

COMPUTATION

The linear model

For the purpose of discussion, we have derived a simple equation to compute excursion distances based on Workmann's M-Value.[27] Considering a diver at pressure P_1,

Table 7
Sample of sliding excursion distances for standard and extended excursions; msw – metres of seawater

Deepest depth (msw)	Standard excursions		Extended excursions	
	Excursion distance (msw)	Shallowest depth (msw)	Excursion distance (msw)	Shallowest depth (msw)
125	16	109	22	103
126	17	109	23	103
127	17	110	23	104
128	17	111	23	105

we seek the minimum pressure P_2 that the diver can reach from this initial pressure. Assuming that:

- The diver is saturated at his initial pressure.
- One compartment is involved.
- The helium and oxygen gas tensions are equal to the inhaled gas partial pressures (P_{He} PO_2), thus ignoring the other metabolic gases and the effect of the oxygen window.[29]

We have:

E 1 $$P_1 = P_{He} + P_{O2}$$

Using a safe ascent condition similar to an M-Value, defined with coefficients A and B, it yields:

E 2 $$P_{He} = A * P_2 + B$$

Combining E 1 and E 2 gives:

E 3 $$P_1 = A * P_2 + B + P_{02}$$

This allows expressing the upward excursion distance (ΔP) as a linear function of P1:

E 4 $$\Delta P = P_1 - P_2 = \left(1 - \frac{1}{A}\right) P_1 + \frac{(B+P_{O2})}{A}$$

Asymmetry of ascending and descending excursions

According to Equation E4, the computation of excursion distances from a given storage depth gives different results for an upward or a downward excursion. The explanation for this asymmetry is that:

- The P_1 values are different. One corresponds to the excursion depth in a downward excursion, and the other to the storage depth in an upward excursion.
- The inhaled PO_2 are different. For a downward excursion, the starting PO_2 corresponds to the diving mix (0.60 to 0.80 bar). For an upward excursion, the starting PO_2 corresponds to the chamber atmosphere (0.40 to 0.45 bar).
- An upward excursion follows a full saturation excursion (divers have spent enough time to be saturated at the storage depth), when a downward excursion only lasts for 8 hours.

Asymmetrical excursions are presented in the US Navy 2016 manual. From a storage depth of 400 fsw (122.4 msw), the upward distance is 93 fsw (28.4 msw) and the downward distance is 105 fsw (32.1 msw).

Symmetrical excursion distances are sometimes proposed to simplify operations. The Norsok standards provide excursions from a 120 msw storage depth with symmetrical 12 msw distances above and below the storage depth. However, these procedures are known to be very conservative.

Computation of US Navy excursions

In 1989, Thalmann published a series of excursion tests that mentioned the historical development of the US Navy excursions.[30] The first excursion distances were initially computed from a linear relation to depth, as derived in the previous paragraph and illustrated in Figure 7. These excursions can be computed using the following expression, where UEXD is the upward excursion distance and D_1 is the deepest depth, defined over the range of excursions.

E 5 $$UEXD = 0.136\, D_1 + 13.8 \text{ in msw}$$

However, the extrapolation to greater depth proved to be hazardous. In 1976, during the Comex Janus IV onshore experiment, divers performed excursion dives from a 400 msw storage depth to 430, 445, 460, and 480 msw working depths. An excursion to 480 msw corresponded to the extrapolated US Navy excursion from 400 msw. One diver presented severe inner ear symptoms after his second excursion to 460 msw.

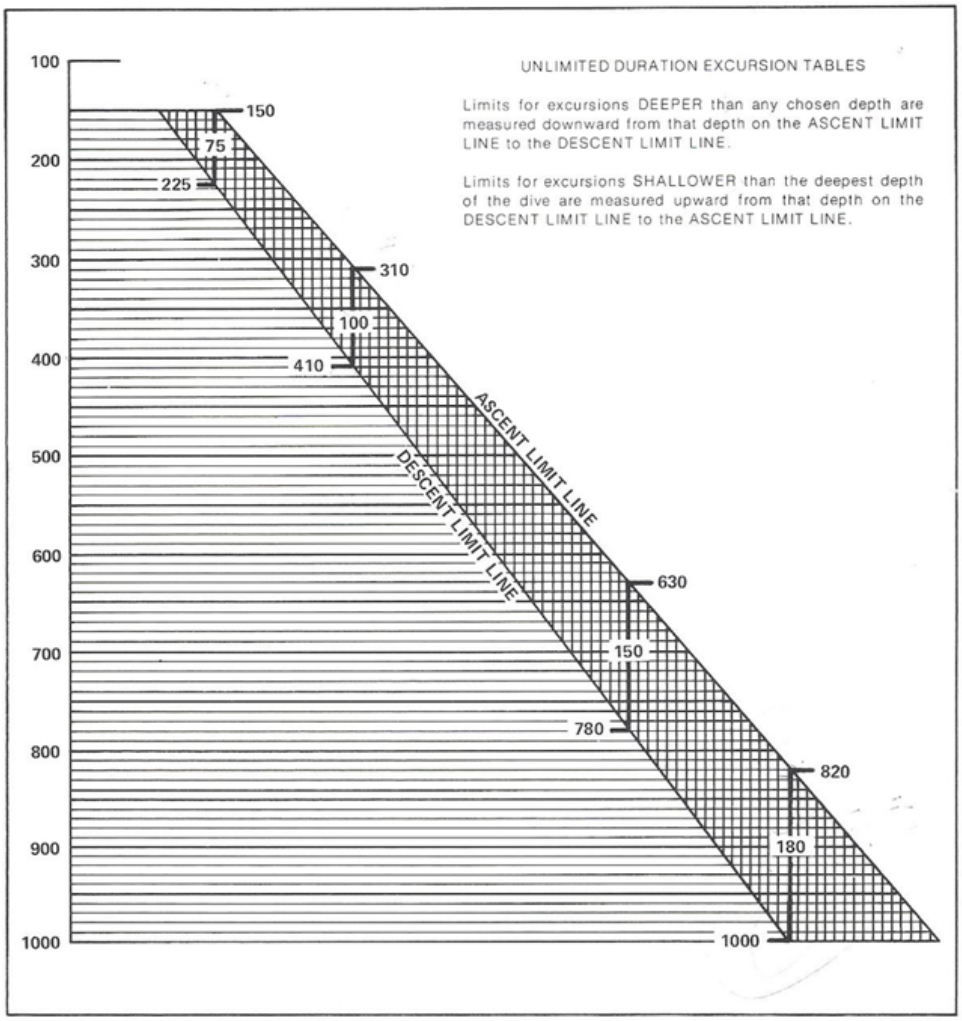
Thalmann reported that the excursions were later derived from an empirical equation proposed by Behnke in which the excursion distance is proportional to the square root of the absolute ambient pressure:[31] Thalmann further proposed the following formula (where, again, where UEXD is the upward excursion distance) that he used to generate the upward excursion published in the 1987 and 2016 US Navy diving manual revisions.[32]

E 6 $$UEXD = 0.5 \sqrt{(101.6\, D_1 + 3998)} - 12.7 \text{ in fsw}$$

Computation of Comex excursions

The 1994 Comex diving manual revision presented standard and extended excursions from storage depth, which were

Figure 7
Diagram 14-5 as per 1977 US Navy Diving Manual, which illustrates the linear algorithm used to calculate the first version of their unlimited-duration excursions in fsw



computed using two linear expressions defined from 15 to 200 msw. The expressions for upward excursions are:

E 7 *Standard excursions:* $UEXD = 0.050\,D_1 + 6$ in msw

E 8 *Extended excursions:* $UEXD = 0.100\,D_1 + 12$ in msw

Methods

We have contacted 15 leading international companies and invited them to participate in the study. The conditions for participation were defined in a memorandum of understanding, signed by the authors and each diving company representative, stating that:

- The procedures could be used scientifically without revealing the company name.
- The company could review the paper before submission and retain the right to withdraw from the publication.

A total of 13 diving companies accepted to participate in the study, which are presented below in alphabetical order along with review dates for their procedure manual:

- Boskalis, Aberdeen, UK, manual rev 2024.
- DCN Diving, The Netherlands, manual rev. 2024.
- DOF Subsea, Perth, WA, manual rev. 2022-6.05.
- Helix Well Ops, Aberdeen, UK, manual rev. 2024.
- K Subsea, Singapore, manual rev. 2021.
- McDermott, Houston, Texas, USA, manual rev. 2024
- Mermaid Subsea Services, Bangkok, Thailand, manual rev. 2024.
- NDE Offshore, Dubai, manual rev. 2023.
- POSH Subsea, Singapore, manual rev. 2024.
- RockSalt Subsea, UK, manual rev. 2022.
- Shelf Subsea, Perth, WA, manual rev. 2023.
- Subsea7, Aberdeen, UK, manual rev. 2024.
- TechnipFMC, Aberdeen, UK, manual rev. 2024.

The companies have been de-identified and randomly mentioned as company A, company B, etc., and their associated excursion procedures are designated as procedure

A, procedure B, etc. These company procedures have been compared to US Navy 2016, Comex 1994, France MT92, Brazil 2016, and Norsok 2023 saturation procedures, considered references. It should be noted that the authors only reviewed the diving manuals provided. Some information they considered missing or not documented could be elsewhere in the company documentation.

Results

The extraction of relevant data from US Navy 2016, Comex 1994, France MT92, Brazil 2016, and Norsok 2023 saturation procedures, and participating company manuals are presented in Tables 8–12.

Discussion

DCS INCIDENCE

Van Liew and Flynn stated that vertical excursions are associated with a threshold for clinical DCS, and this threshold depends on depth.[33] Companies do not share this information, and we did not request it from those participating in the study. It is thus difficult to evaluate the incidence of DCS associated with modern saturation excursion dives. What is known from various sources is presented below.

Comex database

Comex diving operations were recorded in the Comex database from 1977 to 1994.[16] Two DCS cases were reported immediately after returning from an excursion dive using the early versions of the Comex procedures (Table 13). At that time, the company averaged 1,000 men x saturation per year, corresponding to approximately 20,000 bell dives. The Comex database contained only two cases of DCS reported immediately after the bell excursion dive, presenting with typical inner ear symptoms. The database also established an overall incidence of DCS reported during or after final decompressions of 0.54% over the same period. They are all related to pain-only symptoms.[2, 34] It is difficult to evaluate the impact of excursion dives on the final decompression, but acute DCS symptoms presenting immediately after an excursion are rare.

Seaway Hades database

Seaway developed the Hades database to monitor their diving operations.[35] In 1978, the results published for saturation decompressions indicated an overall DCS incidence of 0.83% (2,662 exposures, 22 DCS). All cases presented as articular pain in the last part of the decompression. The publication of the Hades database did not document any DCS cases presented after an excursion dive.

Norwegian Ocean Industry database

The only diving database covering offshore commercial diving is maintained by Havtil (Norwegian Ocean Industry Authority), previously PSA (Norwegian Petroleum Safety Authority). This organisation has been collecting and publishing safety records since 1990.[36] The cases are all recorded in the Norwegian sector and, therefore, associated with diving procedures that comply with Norsok standards. The latest DCS reports in saturation diving were filed in 1993 and 2002. No case was identified as being directly related to an excursion dive.

North Sea incidents in the 1990s

During the 1990s, several DCS cases occurred in the North Sea following excursions compliant with US Navy procedures. The authors are aware of four of these cases (Table 14). Unfortunately, we have no further details about these incidents, such as the history of previous excursions, intervals, or other relevant information.

Due to these and possibly other incidents, the diving supervisors of some DSVs set rules to restrict excursions to a fraction of the maximum permitted US Navy distances. These rules were later implemented in diving manuals of North Sea companies as policies for selection of excursion distances (Table 15). These precautions have played an important role in reducing the DCS risk, as we have remained unaware of any similar incidents since.

Decompression stress

Today, DCS has become a rare event in saturation diving, and the incidence of DCS is no longer a relevant endpoint.[2] The concern has shifted to a broader approach based on the decompression stress mentioned by Brubakk et al.[37] This stress includes the effects of bubbles but also the cumulative effect of the oxidative stress associated with diving and decompression.[38] Saturation divers may perceive this decompression stress as 'decompression fatigue,' Diagnosing DCS remains difficult, potentially leading to underreporting in the commercial diving industry. The decompression stress related to saturation diving and its subsequent physiological effects can only be evaluated through comprehensive monitoring of the diver, both clinically and with non-invasive para-clinical methods.[39] Our experience is that divers' monitoring, which is part of the Undersea and Hyperbaric Medical Society recommendations, brings valuable support to the evolution of procedures.[40, 41]

VENOUS GAS EMBOLI

VGE are commonly observed after asymptomatic dives using ultrasound Doppler or cardiac imaging. Although VGE are not predictive of DCS for a given diver, there is a positive association between the occurrence of VGE and the incidence of DCS.[42]

Table 8
Excursion procedures design, options, and recommended use; msw – metres of seawater

Procedures	Source	Design concept	Working depth range (msw)	Allowance or extended excursions	Limitations of deep excursions
US Navy 2016		Deepest depth	0–306	No	No
Comex 1994		Storage depth	10–210	Yes	N/A
France MT92	Comex	Storage depth	9–210	Yes	N/A
Brazil 2016	Comex	Storage depth	14–350	N/A	No
Norsok 2023		Storage depth	14–180	No	N/A
Company A	Comex	Sliding window	14–200	Yes	N/A
Company B	US Navy	Deepest depth	0–305	N/A	N/A
Company C	Comex	Storage depth	15–300	Yes	Yes
Company D	US Navy	Deepest depth	12–305	No	No
Company E	US Navy	Deepest depth	18–305	No	No
Company F	Comex	Sliding window	10–350	Yes	Yes
Company G	US Navy	Deepest depth	14–300	No	No
Company H	US Navy	Storage depth	10–305	No	No
Company I	US Navy	Storage depth	14–300	Yes	No
Company J	US Navy	Storage depth	0–305	No	No
Company K	US Navy	Storage depth	0–306	No	No
Company L	Comex/US	Storage depth	8–200	Yes	N/A
Company M	US Navy	Deepest depth	14–306	No	No

Table 9
Excursion operational characteristics; (1) – diving mix defined as PO_2 0.60-0.80 bar for extended excursions; (2) – PO_2 0.9 bar accepted in exceptional situations; (3) – chamber PO_2 controlled between 360 and 400 mbar when deeper than 180 msw; / – not defined; min – minute; msw – metres of seawater

Procedures	Storage PO_2 (bar)	Diving mix PO_2 (bar)	Divers max ascent rate (msw·min^{-1})	Bell decomp rate (msw·min^{-1})
US Navy 2016	0.44–0.48	0.44–1.25	18	18
Comex 1994	0.40–0.42	0.50–0.80	15	10
France MT92	/	/	/	/
Brazil 2016	/	/	10	/
Norsok 2023	0.40–0.50	/	10	/
Company A	0.40–0.44	0.60–0.80	10	10
Company B	0.35–0.50	0.60–0.80	20	20
Company C	0.38–0.42	0.60–0.70 (1)	10	10
Company D	0.37–0.43	0.60–0.80	10	5
Company E	0.38–0.42	0.70–0.8 (2)	18	18
Company F	0.38–0.42 (3)	0.60–0.80	10	10
Company G	0.38–0.42	0.70–0.90	18	18
Company H	0.44–0.48	0.60–0.90	18	18
Company I	0.40–0.45	0.60–0.80	18	18
Company J	0.35–0.45	0.50–0.80	9	9
Company K	0.37–0.43	0.60–0.90	18	18
Company L	0.40–0.42	0.50–0.90	9	12
Company M	0.38–0.42	0.60–0.90	10	10

Table 10

Post-excursion minimum time intervals; (1) – 12 h after an extended excursion before a standard excursion, 24 h between two extended excursions; (2) – 0 h after a standard excursion, 12 h after an extended excursion; (3) – 15 h after a maximum descending excursion of a standard ascending excursion, 24 h after a maximum ascending excursion; (4) – 4 h when shallower than 80 msw storage depth, 8 h when deeper; (5) – 6 h for a final decompression, 2 h for an intermediate decompression; / – not defined; min – minute; msw – metres of seawater; N/A – not applicable

Procedures	Excursion post-interval (hours)	Standard excursion post-interval (hours)	Extended excursion post-interval (hours)	Deep excursion post-interval (hours)	Pre-decompression hold (hours)
US Navy 2016	48	N/A	N/A	N/A	0
Comex 1994	/	0	12–24 h (1)	N/A	0–12 (2)
France MT92	N/A	0	12	N/A	0 or 12
Brazil 2016	/	12	48	/	/
Norsok 2023	N/A	N/A	N/A	N/A	8
Company A	N/A	12	16	/	8
Company B	12	/	/	/	8
Company C	N/A	12	16	12	8
Company D	/	/	/	/	6
Company E	/	/	/	/	8
Company F	N/A	12	16	12	8
Company G	/	/	/	/	6
Company H	/	/	/	/	6–2 (5)
Company I	N/A	12	12	/	8
Company J	/	/	/	/	/
Company K	/	/	/	/	4 to 8 (4)
Company L	N/A	12	15–24 (3)	/	8
Company M	/	/	/	/	8

Table 11

The permitted standard descending excursion distance (msw) for typical storage depths for companies using standard and extended excursion tables; / – not defined; msw – metres of seawater

Organisation	Storage depth (msw)								
	15	30	60	90	120	150	180	210	240
US Navy 2016	14	18	24	28	32	35	39	42	44
Comex 1994	6	7	9	10	12	13	15	/	/
France MT92	6	7	9	10	12	13	15	/	/
Brazil 2016	3	6	9	10	12	13	15	15	15
Norsok 2023	1	6	9	10	12	13	13	/	/
Company A	6	9	12	15	18	20	20	/	/
Company C	/	8	10	13	15	18	20	15	15
Company F	6	9	12	15	18	20	20	15	15
Company I	/	14	18	21	24	27	29	31	33
Company L	3	6	8	13	15	17	/	/	/

Arterial and venous bubbles were observed in the six divers following ascending excursions from 300 msw to 250 msw during the NUI Deep Ex I experimental dive.[43,44] It must be noted that these detections were related to deep excursions largely exceeding the distances presently used in commercial diving. We recently reported findings from a study of commercial divers in the North Sea Danish sector, monitoring subclavian VGE one hour after descending excursions from 37 to 45 msw. No bubbles were detected.[39]

Based in large part on the strong association between inner ear DCS and patent foramen ovale (PFO), Doolette and Mitchell proposed a model of inner ear DCS based on shunted arterial bubbles reaching the inner at the time the

Table 12

The maximum permitted descending excursion distance (msw) for typical storage depths, for companies using extended or maximum excursion tables; companies using US Navy excursion procedures are listed as using maximum excursions. / – not defined; msw – metres of seawater

Organisation	Storage depth (msw)								
	15	30	60	90	120	150	180	210	240
US Navy 2016	14	18	24	28	32	35	39	41	44
Comex 1994	/	15	18	21	24	27	30	/	/
France MT92	/	15	18	21	24	27	30	/	/
Brazil 2016	/	15	18	20	24	26	30	30	30
Norsok 2023	/	/	/	/	/	/	/	/	/
Company A	6	9	12	15	18	20	/	/	/
Company B	14	18	23	28	31	35	38	41	44
Company C	/	10	13	17	20	24	27	/	/
Company D	/	17	23	28	31	35	38	41	44
Company E	/	14	17	21	24	26	29	31	33
Company F	9	11	16	21	25	30	/	/	/
Company G	14	18	23	28	31	35	38	41	44
Company H	14	18	23	28	31	35	38	41	44
Company I	/	18	23	28	31	35	38	41	44
Company J	/	18	24	28	32	35	38	41	44
Company K	14	17	23	28	31	35	38	41	44
Company L	6	12	17	21	26	30	35	/	/
Company M	0	18	24	28	32	35	39	41	44

Table 13

Decompression sickness (DCS) cases presenting immediately after returning from a bell excursion dive reported in the Comex database; msw – metres of seawater

Year	Working depth (msw)	Distance (msw)	Storage depth (msw)	DCS
1984	40	10	30	Inner ear
1985	137	20	117	Inner ear

Table 14

Decompression sickness (DCS) cases reported in the 1990s, in the North Sea, immediately after the return to storage depth from an excursion dive; msw – metres of seawater

Year	Working depth (msw)	Storage depth (msw)	Excursion distance (msw)	DCS
1992	146	126	20	Inner ear
1994	78	56	22	Inner ear
1997	131	114	17	Inner ear
2000	93	76	17	Inner ear

local tissues are supersaturated. They assumed that this situation causes inward gas diffusion and bubble growth.[45] In a second publication, the authors reviewed inner ear DCS cases observed during the US Navy excursion trials and various deep diving experiments.[46] They modelled the survival of microbubbles reaching the arterial side and concluded that arterial bubbles have longer survival times at higher pressures and are more likely to reach the inner ear in larger numbers and sizes. This was used to explain the differences observed in bubble measurements between deep excursions and standard commercial excursions.

The data listed in their paper indicate that VGE are detected during the excursion time in an upward excursion and during the post-excursion time in a downward excursion. It can be expected that a working diver (hyperventilation, muscular effort) is more likely to open a PFO or intrapulmonary arteriovenous anastomoses and shunt arterial microbubbles than a diver returning to storage depth for a shower and dinner. This could explain why upward excursions have a bad reputation. Companies sometimes recommend planning work with a downward excursion rather than an upward one in their diving manual. The authors admit that they have no data to support this sort of policy.

Table 15
Policies developed by companies referring to the US Navy excursion procedures

Company	Recommendation for the use of US Navy excursion distances
Company B	The maximum operating excursions should not be considered as a normal operational procedure.
Company D	An optimum operating range (50% of the excursion table values) for maximum descending and ascending distances is preferable wherever diving operations permit.
Company G	Maximum upward excursions to the limit of the tables shall not be carried out except for light inspection work.
Company H	Upward excursions should be limited to 75% of the distance.

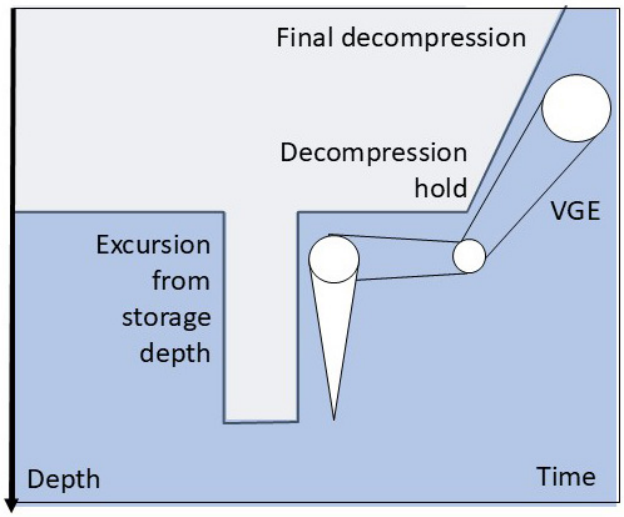
Modelling VGE during excursion dives

Van Liew and Burkard developed a model that Flook used to predict the volume of VGE gas produced after decompression in man.[47] This bubble growth model was calibrated using actual VGE measurements and allowed the estimation of the volume of the bubbles produced during a saturation profile.[48] The model confirmed that the duration of the post-excursion interval influences bubble growth during the following decompression, particularly after high-distance excursions. Flook concluded that the current excursion distances were unlikely to cause DCS but that combining excursions and the final decompression could generate a population of residual bubbles responsible for late DCS symptoms.

In 1989, Thalmann published the results of a series of tests that led to the revision of the US Navy excursion procedures.[30] Fifty divers performed 164 man-excursion dives during nine saturation experiments. During these tests, nine cases of joint pain occurred, which occurred eight hours or more into the saturation decompression. This seems to confirm Flook's theory, according to which bubbles remaining from the last bell excursion dive could provoke DCS symptoms during the final decompression (Figure 8).

Present commercial saturation diving procedures are not expected to cause DCS during or immediately following excursions. However, it is suspected that bubbles produced after the excursion dive could increase the DCS risk during the final decompression. The specification of a minimal post-excursion interval and pre-decompression hold is designed to mitigate this risk.

Figure 8
Schematic illustration of Flook's theory according to which bubbles produced after an excursion could interfere with the final decompression



OXYGEN TOXICITY

Role of oxygen in excursions

The inspired PO_2 sets the inert gas gradient, which in turn influences gas exchange. Although raised PO_2s allow larger excursion distances, high oxygen levels generate reactive oxygen species that interfere with cell functions. While central nervous system toxicity is usually not a concern in saturation diving, pulmonary toxicity (POT) can be a limiting factor.

The PO_2 during an excursion dive must be balanced between: A lower limit based on the physiological demand, safety, and permitted excursion distance (Equation 4).

An upper limit based on oxygen toxicity in general and POT in particular.

Pulmonary oxygen toxicity

Divers may experience POT if exposed to hyperoxic breathing gas for prolonged periods.[49] It is challenging to isolate the effects of hyperoxia from those caused by other mechanisms, such as immersion and high pressures, since many factors are known to affect pulmonary function after dives.[50] Most experimental studies on POT have focused on the effects of relatively short-lasting exposures to PO_2

exceeding 1 bar.[51] However, the effects of long-lasting exposure to low PO_2 ($PO_2 < 1$ bar) are less known. Thorsen et al. measured pulmonary function after a dry 28-day helium-nitrogen-oxygen saturation dive to 15 msw with a PO_2 of 0.4 bar in the bottom phase, followed by intermittent exposures to PO_2 = 0.75 bar. The PO_2 was 0.5 bar during the decompression phase.[52] They reported a temporary 10.6% reduction in transfer factor for carbon monoxide immediately after the dive, but a permanent 9.3% reduction in mid-expiratory flow volumes ($FEF_{25-75\%}$), persistent for three years after the dive. The low breathing gas density (1.6 $g \cdot L^{-1}$) and dry exposure suggest that hyperoxia rather than respiratory work or immersion caused the small-airway dysfunction. Suzuki reported a 4–13% decrease in pulmonary carbon monoxide diffusion capacity (DLCO) immediately after saturation dives to 300 and 320 msw lasting 14–16 days with an inspired PO_2 of 0.42 bar during the bottom phase and 0.5 bar during decompression.[53]

Thorsen et al. also demonstrated that cycling the inspired PO_2 between 0.3 and 0.5 bar during saturation decompression has a protective pulmonary effect, as no change in pulmonary function was observed following a 19-day experimental saturation dive with this decompression procedure, despite intermittent hyperoxic exposures to PO_2 = 0.7 bar in the bottom phase.[54]

These findings suggest that the increased constant PO_2 during saturation decompression, rather than the intermittent hyperoxic exposures during excursion dives, has the greatest impact on pulmonary function following saturation dives with PO_2 levels similar to those practiced in commercial saturation diving. From the data collected in Table 9 we would not expect the excursion PO_2 values used in the excursion procedures listed in this work to cause clinically relevant POT.

Evaluation of the oxygen toxicity dose

The divers' tolerance to pulmonary oxygen toxicity is difficult to measure and predict.[55] Because of their simplicity, the industry approach has traditionally managed exposures using the units of pulmonary toxic dose (UPTD) or oxygen toxicity unit (OTU).[56]

Recent advances suggest that divers' occupational hyperoxic exposure during surface-oriented diving is best monitored using the 'equivalent surface oxygen time' (ESOT) concept rather than the UPTD terms previously used.[57] However, the ESOT concept is not designed for saturation diving.

Arieli has proposed a hyperoxic exposure monitoring system applicable for saturation diving.[58] The model has not been validated, and the kinetics of POT development and recovery during and after saturation remain unresolved.

Oxygen in the diving mix

The current saturation procedures result from successive empirical adjustments that have progressively reduced the excursion distance while keeping the PO_2 specifications. The current oxygen specifications for the diving mix may exceed what is needed for the excursion distances.

We note that company C has restricted the diving PO_2 range to 0.60–0.70 bar for their standard excursions, which only authorise moderate excursion distances. Scientific work would be required to adjust the PO_2 levels in the current excursion procedures.

OPERATIONAL HAZARDS

The risk for a diver during a bell excursion dive is to exceed his permitted excursion envelope. We are aware of three typical incidents:

- A diving support vessel operating two bells back-to-back (continuous presence of divers at the bottom). A diver from the second bell locked out, and his umbilical was caught by the first bell when it started its ascent. The diver was pulled off his limits until the first bell ascent was finally stopped.
- A combined divers and ROV operations at shallow depths. The ROV caught the diver's umbilical in its tether and lifted him outside his excursion limits by a few metres.
- Divers lifted off the seabed by clump weight. Divers were at work at 42 msw with storage depth at 34 msw. The taut wire winch was activated to recover the system from the seabed and caught the divers' umbilicals. Divers were lifted to 13 msw (29 msw upward distance). No signs or symptoms were reported, but divers were given five cycles of therapeutic gas and rehydrated as a precaution.

The potential consequences of these degraded conditions must be evaluated on a case-by-case basis. Divers may not present immediate and detectable DCS symptoms. The contingency procedure is generally to abort the bell run and keep the diver under observation. Severe violations of the excursion limits may require additional hyperbaric oxygen breathing. In such situations, the 1977 US Navy excursion limits provide practical guidelines because they indicate 'what has been done before,' which helps 'calibrate' the situation.

TRENDS

We have observed discrepancies between procedures, primarily due to their historical development. However, as discussed during the DMAC 2014 meeting in Aberdeen, we do have sufficient data today to conclude the consequences of these differences on the divers' health.[59] We also observe the harmonisation of the procedures.

Figure 9
Plot of the excursion distance versus the excursion start depth using the standard descending excursion tables; msw – metres of seawater

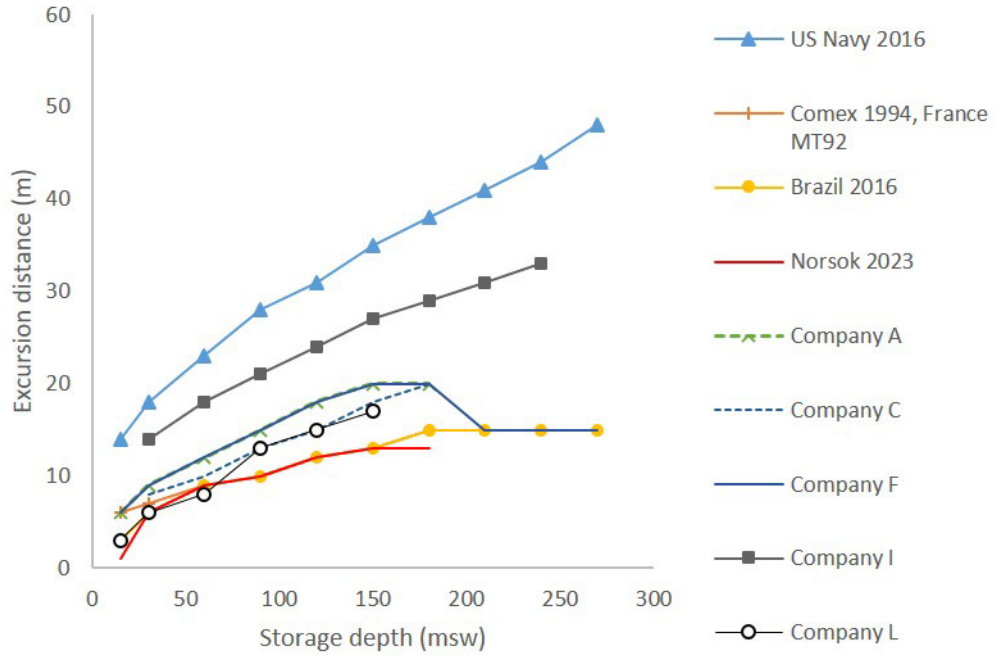
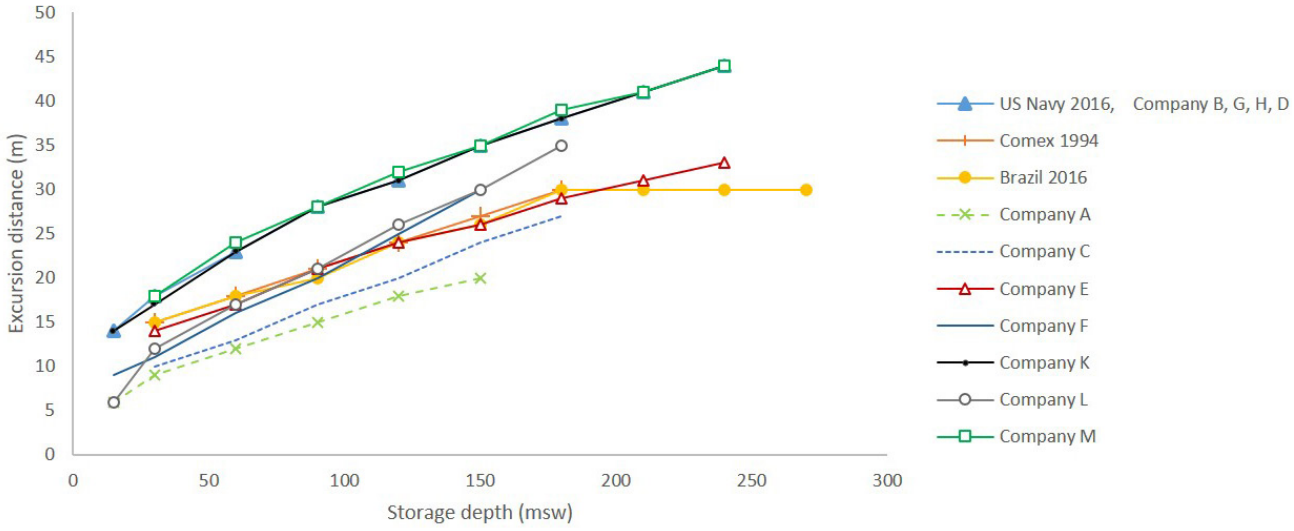


Figure 10
Plot of the excursion distance versus the excursion start depth using the extended or maximum descending excursion tables; msw – metres of seawater



Reduction of excursion distances

The US Navy excursion procedures that once ruled the offshore diving industry are now considered the upper limit of what can be done.

A consensus seems to have emerged on using moderate excursion distance (40–60% of the 1977 US Navy distances) for routine operations and keeping Extended excursion (70–75% of the 1977 US Navy distances) for exceptional situations (Figure 9 and Figure 10).

Another mitigating procedure has been the introduction of standard excursions, which further reduced the excursion distances for routine operations (Table 16).

Table 16
Standard excursion distances expressed as fractions of US Navy diving manual 2016

Company	% of 2016 US Navy distances
Comex	39–43%
Norsok	37–38%
A	43–57%
C	44–52%
F	43–57%
L	21–49%

Extension to shallower depths

The performance of modern diving DSVs has permitted saturation divers to operate at depths that once were the domain of air diving. The excursion procedures have been extended to shallow waters, up to 14 msw storage depth, or even shallower (Table 8). The US Navy diving manual 2016 rev. 7 proposes a direct excursion ascent from 29 fsw (8.9 msw) to the surface.

On the one hand, shallow excursions allow adapting to emerging markets, such as wind farm installations, and permit filling the planning of DSV with saturation projects. On the other hand, excursion dives from shallow storage depths are challenging to plan because of operational issues. The bell standoff frame distance or even the hull clearance limits the access. Swim lines must be installed to help the diver stay within his narrow excursion window (4 msw at 14 msw). The influence of swell and waves perturbs the operations.

The problem is to define a computational algorithm that could optimise these shallow excursions. It must be noted that saturation excursions cannot be extrapolated to hypobaric exposures or space extra-vehicular activity. It can be assumed that at low ambient pressures, Boyle's law becomes predominant and activates more complex bubble scenarios. The analysis of new experiences and the review of new theoretical models are required.

Extension to deeper depths

In the 1990s, Brazilian diving operations in the Campos field provided the industry with a large-scale deep-diving experience.[23] It was then observed that deeper than 200 msw, the rapid pressure change associated with excursion dives could induce high pressure neurological syndrome (HPNS) symptoms, essentially hand tremors. As a precaution, the excursion distances were reduced to 15 msw to control HPNS when diving deeper than 200 msw. This feature was later incorporated into the Brazilian diving regulations Normam-15/DPC edition.[24]

Deep diving has remained limited outside the Brazilian Campos field. However, there have been few occasions for diving deeper than 200 msw in Libya and the eastern Mediterranean over the last decade. Companies A, C, and F have designed original deep excursion procedures with reduced excursion distances to control HPNS.

Harmonisation of the minimum post-excursion interval

The companies have different practices regarding the post-excursion interval. Several diving manuals reviewed (Companies D, G, H, J, K, M) did not specify a minimum interval between bell excursion dives. Their operations are based on one team performing one daily excursion, which implicitly ensures a minimum 12-hour interval between dives. All the other diving manuals stipulate a minimum 12 hours post-excursion interval for a standard excursion.

For extended or maximum excursions, this post-dive interval is set to 16 hours for three companies (Companies A, C, F). Considering an eight-hour bell run time, this pattern still fits into a 24-hour cycle. Company L uses longer post-dive intervals for maximum excursion (15–24 h).

Harmonisation of the minimum pre-decompression hold

The Norsok standards first introduced the pre-decompression hold as a minimum time interval defined after the last excursion dive before the divers can start a final or intermediate decompression. As documented in a previous publication, this hold is now harmonised to eight hours.[2] However, one company does not specify this hold (Company J). Two others use six hours (Company G) or two hours (Company H). This last value is used as an extension to the US Navy diving manual rev. 7 rule (paragraph 13.23.3), which specifies a two-hour hold after an upward excursion at a depth shallower than 60 msw.

Conclusions

We have reviewed the history of excursion diving and the procedures of 13 companies involved in heliox saturation diving.

The comparison of these excursion procedures shows that:
- Current saturation procedures are derived from the US Navy and the Comex procedures.
- Diving companies have since empirically modified these procedures according to their needs. This explains the differences observed in the excursion distances and presentations.
- DCS associated with bell excursion dives has become a rare event.

The review reveals that:
- Companies are moving towards reduced excursion distances for routine operations.
- Companies seek higher flexibility to manage modern DSVs. This is illustrated by the recent introduction of sliding excursion windows or shallow excursions.

We believe that saturation excursion procedures will continue to evolve. Scientific research must support this evolution. Scientific monitoring of saturation divers permits measuring the decompression stress and supporting further excursion evolution. We recommend that companies document their procedural developments to record and thus keep the lessons learned.

References

1 Cadieux C. Description of a saturation diving system, Diving and ROV Specialist, 2021. [cited 2025 September 30]. Available from: https://diving-rov-specialists.com/index_htm_files/div-rov_description-saturation-system.pdf.

2 Imbert JP, Matity L, Massimelli JY, Bryson P. Review of saturation decompression procedures used in commercial diving. Diving Hyperb Med. 2024;54:23–38. doi: 10.28920/dhm54.1.23-38. PMID: 38507907. PMCID: PMC11065503.

3 EN 13319:2000 – Diving accessories – Depth gauges and combined depth and time measuring devices – Functional and safety requirements, test methods, European Standards, 2000. [cited 2025 Sep 30]. Available from: https://www.en-standard.eu/search/?q=EN+13319%3A2000.

4 IMCA. D 022 rev.1.3 Guidance for Diving Supervisors, The International Maritime Contractors Association, 2024. [cited 2025 Sep 30]. Available from: https://www.imca-int.com/resources/technical-library/document/1a4b165f-c55b-ee11-8def-6045bdd2c9bc/.

5 Schreiner HR, Kelley PL. Computation of decompression schedules for repetitive saturation excursion dives. Aerosp Med. 1970;41:491–4. PMID: 5430675.

6 Hamilton RW, Kenyon D, Peterson R. Repex habitat diving procedures: Repetitive vertical excursions, oxygen limits, and surfacing techniques, 1988. [cited 2025 Sep 30]. Available from: https://repository.library.noaa.gov/view/noaa/60671/noaa_60671_DS1.pdf.

7 Miller JW. Vertical excursions breathing air from nitrogen-oxygen or air saturation exposures: US Department of Commerce, National Oceanic and Atmospheric Administration. 1976. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/scient-a_106-vertical-excursions-breathing-air-from-nitrogen-oxygen-or-air-sat%20.pdf.

8 Joiner JT. NOAA diving manual: Diving for science and technology: National Oceanic and Atmospheric Administration; 2001.

9 US Navy diving operations handbook, US Navy Department, 1974. Report: NAVSHIP 0994-009-6010. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/history-56-handbook-us-navy-diving-operations-1974.pdf.

10 US Navy diving manual, volume 2, Change 1. Mixed gas diving. NAVSEA 0994-LP-001-9010. US Department of the Navy. Washington (DC); 1977. [cited 2025 Sep 30]. Available from: https://apps.dtic.mil/sti/tr/pdf/ADA112710.pdf.

11 Bornmann RC. Helium-Oxygen saturation-excursion diving for US Navy. In: Lambertsen CJ, editor. Underwater physiology. Proceedings of the fourth symposium on underwater physiology. New York: Academic Press; 1971. p. 529–36.

12 Summitt JK, Herron JM, Flynn ET. Repetitive excursion dives from saturated depths on helium-oxygen. Phase III. Saturation depth 300 Feet, Navy Experimental Diving Unit, Report: 2-70. 1970. [cited 2025 Sep 30]. Available from: https://apps.dtic.mil/sti/citations/AD0723172.

13 Summitt JK, Alexander JM, Flynn ET, Edward T, Kuly JW. Repetitive excursion dives from saturated depths on helium-oxygen mixtures. Phase IV. Saturation depth 500 feet, saturation depth 600 feet, Navy Experimental Diving Unit, Report: 7-70. 1970. [cited 2025 Sep 30]. Available from: https://apps.dtic.mil/sti/citations/AD0723173.

14 Barnard EP. Fundamental studies in decompression from steady-state exposures. In: Lambertsen CJ, editor. Proceedings of the fifth symposium on underwater physiology. Bethesda: Federation of American Societies for Experimental Biology; 1976. p. 263–71.

15 Spaur W, Thalmann E, Flynn E, Zumrick J, Reedy T, Ringelberg J. Development of unlimited duration excursion tables and procedures for helium-oxygen saturation diving. Undersea Biomed Res. 1978;5:159–77. PMID: 675881.

16 Imbert JP, Montbarbon S. Presentation of the Comex database. In: Sterk W, Hamilton, RW, editor. EUBS workshop on operational dives and decompression data: collection and analysis, 11-18th August. Amsterdam, The Netherlands; 1990. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/scient-b_120-presentation-comex-diving-database.pdf.

17 Ministère du Travail. Travaux en Milieu Hyperbare. Mesures particulières de prévention. Imprimerie du Journal Officiel, 26 rue Desaix, 75732 Paris cedex 15: Bulletin Officiel de la République Francaise. 1992. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/history-27-french-decree-30-october-2012.pdf.

18 Ministère du Travail. Arreté du 14 mai 2019 définissant les procédures d'accès, de séjour, de sortie et d'organisation du travail pour les interventions en milieu hyperbare, Bulletin Officiel de la République Francaise, 2019. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/docs-16-tables-mt2019.pdf.

19 Hempleman V. The safety evaluation of saturation decompression tables, Report: I82-7527-203.6. Norwegian Petroleum Directorate; 1986. [cited 2025 Sep 30]. Available from: https://www.ptil.no/contentassets/350fcc45128449329b7b92c78f6100a4/hempelman---safety-evaluation-of-saturation-decompression-tables-1986.pdf.

20 Oljedirektoratet [Norwegian Petroleum Directorate]. Rapport om sammenligning av metningsdykketabeller og utarbeidelse av rammebetingelser for standardisering [Report on comparison of saturation diving tables and preparation of frame conditions for standardization], Report: OD-91-12. 1991.

21 NORSOK. U-100 Manned underwater operations rev. 6, NORSOK, 2023. [cited 2025 Sep 30]. Available from: https://standard.no/en/sectors/petroleum/norsok-standards/u-underwater-op/u-100manned-underwater-operations/.

22 Risberg J, Segadal K. Compression and excursion parameters for saturation dives 0-250 msw, NUI AS, Report: 2023-69. Norway; 2023. [cited 2025 Sep 30]. Available from: https://www.havtil.no/contentassets/04882bf9c4054c0989f0fd70fc8c05e6/2022_1121-prosjektrapport-compression-and-excursion-parameters-for-saturation-diving.pdf.

23 Imbert JP. Deep diving: the Comex experience. In: Hope A, Risberg J, editors. Long-term health effects of diving The Godøysund 1993 consensus conference revisited; September 15-17th, Bergen, Norway: NUI AS; 2005. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/scient-c_12-deep-diving-comex-experience-JP.pdf.

24 Normam-15 DPC. Atividades Subaquáticas, Capitulo 11 Tabelas de mergulho, rev 2, 2016. [cited 2025 Sep 30]. Available from: https://www.marinha.mil.br/dpc/normas.

25 Vivacqua R. Practical experience of the use of deep heliox tables with specific focus on medical, physical and psychological aspects – Fugro Brasil. Proceedings of the annual IMCA diving seminar and DMAC workshop; 25-26th September 2017; London, UK; 2017.

26 Cadieux C. Diving management study no 5: Implement Normam 15/DPC saturation diving procedures, 2019. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/cco-study-5-implement-normam-15-saturation-07-aug-25.pdf.

27 Workman RD. Calculation of decompression schedules for nitrogen-oxygen and helium-oxygen dives, US Navy Exp Diving Unit, Report: Res Rep 6-65. 1965. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/scient-a_102-calculation-deco-schedules-nitrogen-oxy-and-helium-oxy.pdf.

28 Imbert JP, Bontoux M. A method for introducing new decompression procedures. Proceedings of the Undersea Medical Workshop on validation of decompression schedules; 13-14th February; Bethesda, Maryland: Undersea and Hyperbaric Medical Society; 1987. p. 13–4. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/scient-b_94-a-method-for-introducing-new-deco.pdf.

29 Kot J, Sicko Z, Doboszynski T. The extended oxygen window concept for programming saturation decompressions using air and nitrox. PLoS One. 2015;10(6):e0130835. doi: 10.1371/journal.pone.0130835. PMID: 26111113. PMCID: PMC4482426.

30 Thalmann ED. Testing of revised unlimited-duration upward excursions during helium-oxygen saturation dives. Undersea Biomed Res. 1989;16:195–218. PMID: 2741254.

31 Behnke AR. The square-root principle in the calculation of one-stage (no-stop) decompression tables. Undersea Biomed Res. 1979;6:357–65. PMID: 538864.

32 US Navy diving manual, Revision 7. NAVSEA 0910-LP-115-1921. US Department of the Navy ed. Washington, DC, 20350. 2016. [cited 2025 Sep 30]. Available from: https://diving-rov-specialists.com/index_htm_files/docs-14-usn-manual-rev7.pdf.

33 Van Liew HD, Flynn ET. Direct ascent from air and N_2-O_2 saturation dives in humans: DCS risk and evidence of a threshold. Undersea Hyperb Med. 2005;32:409–19. PMID: 16509283.

34 Imbert JP, Bontoux M. Diving data bank: a unique tool for diving procedures development. 20th Annual offshore technology conference; May 2nd-5th Houston, Texas, USA; 1988. [cited 2025 September 30]. Available from: https://diving-rov-specialists.com/index_htm_files/scient-b_17-diving-data-bank-a-tool-for-diving-procedrues-development.pdf.

35 Jacobsen G, Jacobsen JE, Peterson RE, McLellan JH, Brooke ST, Nome T, et al. Decompression sickness from saturation diving: a case control study of some diving exposure characteristics. Undersea Hyperb Med. 1997;24:73–80. PMID: 9171466.

36 Rapport fra ptil's dykkedataabse dsy, PSA; 2022. [cited 2025 Sep 30]. Available from: https://www.ptil.no/contentassets/7284426234ae40cdaa62e2037ed2bf35/dsys_2022-rapport.pdf.

37 Brubakk AO, Ross JA, Thom SR. Saturation diving; physiology and pathophysiology. Compr Physiol. 2014;4:1229–72. doi: 10.1002/cphy.c130048. PMID: 24944036.

38 Mrakic-Sposta S, Vezzoli A, D'Alessandro F, Paganini M, Dellanoce C, Cialoni D, et al. Change in oxidative stress biomarkers during 30 days in saturation dive: a pilot study. Int J Environ Res Public Health. 2020;17(19):7718. doi: 10.3390/ijerph17197118. PMID: 32998440. PMCID: PMC7579105.

39 Imbert JP, Barbaud A, Stevens S, Miller C, Peace H, Rossin H, et al. Evaluation of North Sea saturation procedures through divers monitoring. Int Marit Health. 2024;75:89–102. doi: 10.5603/imh.99606. PMID: 38949219.

40 Wekre SL, Landsverk HD, Lautridou J, Hjelde A, Imbert JP, Balestra C, et al. Hydration status during commercial saturation diving measured by bioimpedance and urine specific gravity. Front Physiol. 2022;13:971757. doi: 10.3389/fphys.2022.971757. PMID: 36246118. PMCID: PMC9559868.

41 Imbert JP, Balestra C, Kiboub FZ, Loennechen Ø, Eftedal I. Commercial divers' subjective evaluation of saturation. Front Psychol. 2018;9:2774. doi: 10.3389/fpsyg.2018.02774. PMID: 30692957. PMCID: PMC6340096.

42 Nishi RY, Brubakk AO, Eftedal OS. Bubble detection. In: Brubakk AO, Neumann TS, editors. Physiology and medicine of diving. 5th ed. London, UK: Saunders; 2003. p. 501–29.

43 Brubakk AO, Peterson R, Grip A, Holand B, Onarheim J, Segadal K, et al. Gas bubbles in the circulation of divers after ascending excursions from 300 to 250 msw. J Appl Physiol (1985). 1986;60:45–51. doi: 10.1152/jappl.1986.60.1.45. PMID: 3511026.

44 Tønjum S. Norwegian deep diving trials. Philos Trans R Soc Lond B Biol Sci. 1984;304(1118):143–9. doi: 10.1098/rstb.1984.0015.

45 Doolette DJ, Mitchell SJ. Biophysical basis for inner ear decompression sickness. J Appl Physiol (1985). 2003;94:2145–50. doi: 10.1152/japplphysiol.01090.2002. PMID: 12562679.

46 Doolette DJ, Mitchell SJ. Extended lifetimes of bubbles at hyperbaric pressure may contribute to inner ear decompression sickness during saturation diving. J Appl Physiol (1985). 2022;133:517–23. doi: 10.1152/japplphysiol.00121.2022. PMID: 35834629.

47 Van Liew HD, Burkard ME. Density of decompression bubbles and competition for gas among bubbles, tissue, and blood. J Appl Physiol (1985). 1993;75:2293–301. doi: 10.1152/jappl.1993.75.5.2293. PMID: 8307888.

48 Flook V. Excursion tables in saturation diving - decompression implications of current UK practice, Unimed Scientific Limited, Report: 244. 2004. [cited 2025 Sep 30]. Available from: https://webarchive.nationalarchives.gov.uk/ukgwa/20241208030054/https://www.hse.gov.uk/research/rrhtm/rr244.htm.

49 van Ooij PJ, Hollmann MW, van Hulst RA, Sterk PJ. Assessment of pulmonary oxygen toxicity: relevance to professional diving; a review. Respir Physiol Neurobiol. 2013;189:117–28. doi: 10.1016/j.resp.2013.07.014. PMID: 23886638.

50 Tetzlaff K, Thomas PS. Short- and long-term effects of diving on pulmonary function. Eur Respir Rev. 2017;26(143):160097. doi: 10.1183/16000617.0097-2016. PMID: 28356403. PMCID: PMC9489140.

51 Risberg J, van Ooij PJ. Hyperoxic exposure monitoring in diving: A farewell to the UPTD. Undersea Hyperb Med. 2022;49:395–413. doi: 10.22462/07.08.2022.1. PMID: 36446287.

52 Thorsen E, Kambestad BK. Persistent small-airways

dysfunction after exposure to hyperoxia. J Appl Physiol (1985). 1995;78:1421–4. doi: 10.1152/jappl.1995.78.4.1421. PMID: 7615450.
53 Suzuki S, Ikeda T, Hashimoto A. Decrease in the single-breath diffusing capacity after saturation dives. Undersea Biomed Res. 1991;18:103–9. PMID: 2042261.
54 Thorsen E, Segadal K, Stuhr LE, Troland K, Grønning M, Marstein S, et al. No changes in lung function after a saturation dive to 2.5 MPa with intermittent reduction in PO_2 during decompression. Eur J Appl Physiol. 2006;98:270–5. doi: 10.1007/s00421-006-0276-8. PMID: 16969641.
55 Shykoff BE, Lee RL. Risks from breathing elevated oxygen. Aerosp Med Hum Perform. 2019;90:1041–9. doi: 10.3357/amhp.5393.2019. PMID: 31748001.
56 Bardin H, Lambertsen CJ. A quantitative method for calculating pulmonary oxygen toxicity. use of the unit pulmonary toxicity dose (UPTD). Institute for Environmental Medicine, University of Pennsylvania, Pennsylvania, USA; 1971.
57 Risberg J, van Ooij PJ, Mátity L. Recovery from pulmonary oxygen toxicity: a new (ESOT) model. Undersea Hyperb Med. 2024;51:407–23. PMID: 39821770.
58 Arieli R. Pulmonary oxygen toxicity in saturation dives with PO_2 close to the lower end of the toxic range – A quantitative approach. Respir Physiol Neurobiol. 2019;68:103243. doi: 10.1016/j.resp.2019.05.017. PMID: 31158523.
59 DMAC. Improving diver safety – current medical issues. Report of a workshop held in October 2014. Aberdeen, UK; 2014. [cited 2025 Sep 30]. Available from: https://www.dmac-diving.org/guidance/DMAC-Workshop-20141008.pdf.

Acknowledgments

The authors thank the companies participating in this study for their support, and their representatives who reviewed the paper. In alphabetic order: Andy Butler (TechnipFMC), Cyrus Cama (POSH Subsea), Hadyn Stark (DCN Diving), Jeremy Starling (K Subsea), Tony French (RockSalt), Mark Hamilton (Boskalis), Michel Plutarque (Club des Anciens de Comex), Sean Brunton (Mc Dermott), Shane Ford (Shelf Subsea), Steve Ginn (DOF Subsea), Simon Binsted (Subsea7), Steve Sheppard (Helix Well Ops), Tomas Kristofferson (NDE Offshore), Torsten Lechler (Mermaid).

Conflict of interest and funding

The authors work for the offshore industry and sometimes for the participating companies. However, the study received no funding, and the review process remained independent.

Submitted: 22 July 2025
Accepted after revision: 25 November 2025

Treatment success in relation to timing of hyperbaric oxygen therapy in idiopathic sudden sensorineural hearing loss

Cheuk-Yin Lun[1], Kwan-Leong Au Yeung[1], Yuk-Fai Lau[2], Wing-Wa Yan[3], Kin-Bong Tang[3]

[1] *Accident and Emergency Department, Queen Elizabeth Hospital, Hong Kong SAR, China*
[2] *Department of Ear, Nose and Throat, Pamela Youde Nethersole Eastern Hospital, Hong Kong SAR, China*
[3] *Hyperbaric Oxygen Therapy Centre, Pamela Youde Nethersole Eastern Hospital, Hong Kong SAR, China*

Corresponding author: *Dr Cheuk-Yin Lun, Accident and Emergency Department, Queen Elizabeth Hospital, 30 Gascoigne Road, Kowloon, Hong Kong SAR, China*
cylun1006@gmail.com

Keywords
Hearing loss, sudden; Hyperbaric oxygen treatment; Otologic emergency; Outcomes; Treatment latency; Pure-tone audiometry

Abstract
(Lun C-Y, Au Yeung K-L, Lau Y-F, Yan W-W, Tang K-B. Treatment success in relation to timing of hyperbaric oxygen therapy in idiopathic sudden sensorineural hearing loss. Diving and Hyperbaric Medicine. 2026 31 March;56(1):41–47. doi: 10.28920/dhm56.1.41-47. PMID: 41875440.)

Introduction: Idiopathic sudden sensorineural hearing loss (ISSNHL) is an otologic emergency for which hyperbaric oxygen therapy (HBOT) is a potential treatment. This study aimed to evaluate the effectiveness of HBOT in treating ISSNHL, with a focus on the timing of treatment and its impact on hearing outcomes, while also considering other factors such as demographic characteristics, clinical parameters, and treatment methods.

Methods: This retrospective cohort study analysed 70 ISSNHL patients (April 2019 to August 2024) who received steroid treatment (oral, intratympanic or both). Patients were divided into early HBOT (< 12 days), late HBOT (13–22 days), salvage HBOT (> 22 days), and no HBOT groups. Hearing improvement, measured by pure-tone audiometry (PTA), defined the treatment outcome.

Results: Significant PTA improvements were observed in most groups (median changes: early HBOT 33.8 dB [n = 15], late HBOT 6.9 dB [n = 16], salvage HBOT 0.0 dB [n = 5], no HBOT 11.9 dB [n = 34]), with early HBOT showing greater gains than late HBOT ($P < 0.001$), salvage HBOT ($P = 0.001$), and no HBOT ($P = 0.002$). Receiver operating characteristic (ROC) analysis indicated that treatment within 10.5 days predicted marked improvement (AUC = 0.883, $P < 0.001$), and linear regression showed that each day's delay reduced PTA improvement by 0.832 dB ($P < 0.001$).

Conclusions: HBOT is effective in restoring hearing in patients suffering from ISSNHL and early treatment is associated with better outcome.

Introduction

Idiopathic sudden sensorineural hearing loss (ISSNHL) is an otologic condition characterised by rapid hearing loss of at least 30 decibels (dB) over at least three contiguous frequencies within 72 hours.[1] With an incidence of 5–20 cases per 100,000 people per year in the United States, ISSNHL poses a substantial clinical challenge owing to its unknown aetiology.[2]

Vascular events, viral or inflammatory responses, and immune-mediated mechanisms are the potential causes of ISSNHL.[3] Steroid treatment and hyperbaric oxygen therapy (HBOT) have been suggested as treatment options for ISSNHL according to existing clinical guidelines. Evidence supporting other treatments, including antivirals or vasodilators, remains limited.[1]

Hyperbaric oxygen therapy (HBOT) has been recognised for its potential benefit in ISSNHL, especially after the Undersea and Hyperbaric Medical Society endorsed it in 2011.[4] A 2005 Cochrane review revealed considerable hearing progress with HBOT for ISSNHL, a finding reaffirmed by subsequent Cochrane reviews in 2007 and 2012.[5–7] The most up-to-date systematic review (late 2025) is also positive.[8] Earlier treatments have been suggested to improve outcomes; however, the ideal therapeutic window remains elusive.[9–11] Current guidelines, such as those from the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) and the European Committee for Hyperbaric Medicine (ECHM), recommend initiating HBOT within 14 days of symptom onset, often combined with steroids, to maximise hearing recovery by enhancing oxygen delivery to the cochlea during the reversible phase of damage.[1,12] For salvage therapy, HBOT may be offered up to one month post-onset, particularly for severe or

profound hearing loss, though efficacy diminishes over time, with ECHM guidelines advising against its use after six months due to potential irreversible damage.[12] Despite these recommendations, variability in patient responses and the lack of consensus on the cutoff for optimal benefit necessitate further research. Furthermore, most HBOT studies were conducted in Western populations, with limited data on Asian cohorts, where genetic and environmental differences may influence treatment efficacy. This study aimed to examine the efficacy of HBOT in ISSNHL and the effect of timing of initiation of HBOT on hearing outcomes, to facilitate its management and future protocols.

Methods

STUDY DESIGN AND STUDY POPULATION

This single-center, retrospective cohort study was conducted at Pamela Youde Nethersole Eastern Hospital in Hong Kong to assess the treatment efficacy of HBOT in patients with ISSNHL and effect of the timing of HBOT administration on clinical outcomes. This study was approved by the Hospital Authority Central Institutional Review Board (no. CIRB-2024-519-3, approved on 28th December 2024), and informed consent was waived.

The medical records of 70 patients diagnosed with ISSNHL between April 2019 and August 2024 were reviewed. Demographic information, clinical characteristics, treatment details, and pure-tone audiometry (PTA) results were collected before and after treatment. Inclusion criteria encompassed adult patients aged ≥ 18 years of both sexes, diagnosed with ISSNHL, and treated between April 2019 and August 2024. ISSNHL was diagnosed based on a sensorineural hearing loss of at least 30 dB over at least three contiguous frequencies occurring within a 72-hour period, with no identifiable cause after clinical evaluation.[1] Exclusion criteria included paediatric patients aged < 18 years, those with sensorineural hearing loss due to identifiable causes, and patients with incomplete PTA records before or after treatment. (Figure 1)

HYPERBARIC OXYGEN THERAPY

HBOT treatments were conducted daily at 243 kPa (2.4 atmospheres absolute), providing 80–90 minutes of oxygen time with two air breaks. Each patient received up to 20 HBOT sessions, with the number determined by otolaryngologist evaluation, including patient feedback on hearing recovery and symptoms. After the diagnosis of ISSNHL was made, patients were referred to the HBOT centre at the discretion of the otolaryngologists. 'Early HBOT' was defined as starting within 12 days of symptom onset, 'Late HBOT' as starting between 13 and 22 days, 'Salvage HBOT' as starting after 22 days, and 'No HBOT' as no HBOT administered during treatment. These cut-off times were determined based on current evidence and existing clinical guidelines to facilitate group comparisons.[1,9,12]

AUDIOGRAM EVALUATION

Hearing thresholds were measured by certified audiologists in a soundproof booth within the ENT clinic, using a pure tone audiometer to test air and bone conduction at 500, 1,000, 2,000, and 4,000 Hz in decibels hearing level (dB HL). For each patient, the pure tone audiogram (PTA) average was calculated as the mean of the thresholds at these four frequencies. PTA scores before the first HBOT session and after completing all sessions were recorded. 'Significant improvement' was defined as a gain of > 20 dB or a return to normal hearing. 'Moderate improvement' was defined by a gain of 10–20 dB, whereas 'No improvement' was defined as a gain of < 10 dB.

DATA ANALYSIS

Demographic and clinical characteristics are summarised using descriptive statistics; differences between groups were assessed using the Mann-Whitney U test for age and Chi-square or Fisher's exact test for categorical variables. The Shapiro-Wilk test was used to evaluate the normality of age and distribution of the PTA scores. Mann-Whitney U and Wilcoxon signed-rank tests were used to compare the baseline and post-treatment PTA scores. To account for multiple comparisons, the Bonferroni correction was applied to *P*-values from Mann-Whitney U tests and Wilcoxon signed-rank tests to control the family-wise error rate at $\alpha = 0.05$. Where appropriate, Cohen's d was calculated to

Figure 1
Patient selection process for idiopathic sudden sensorineural hearing loss (ISSNHL) patients; HBOT – hyperbaric oxygen therapy; PTA – pure-tone audiometry

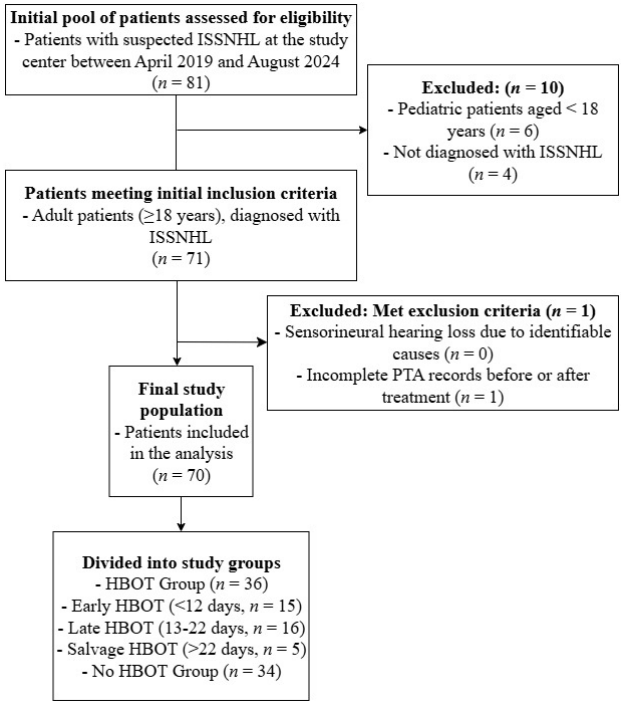


Table 1

Demographic and clinical characteristics of HBOT vs. no HBOT groups; age is presented as median (IQR), data are otherwise *n* (%) based on group totals. HBOT – hyperbaric oxygen therapy; ISSNHL – idiopathic sudden sensorineural hearing loss

Characteristic	HBOT (*n* = 36)	No HBOT (*n* = 34)	*P*
Age (years)	56.5 (41.8, 65.3)	66.0 (58.0, 72.0)	0.002
Sex			
Male	20 (55.6%)	22 (64.7%)	0.435
Female	16 (44.4%)	12 (35.3%)	
Side of ISSNHL			
Right	18 (50.0%)	18 (52.9%)	0.719
Left	18 (50.0%)	15 (44.1%)	
Bilateral	0 (0.0%)	1 (2.9%)	
Recurrence of ISSNHL			
Yes	8 (22.2%)	9 (26.5%)	0.679
No	28 (77.8%)	25 (73.5%)	
Presence of tinnitus			
Yes	20 (55.6%)	19 (55.9%)	0.978
No	16 (44.4%)	15 (44.1%)	
Oral steroid use			
Yes	34 (94.4%)	30 (88.2%)	0.422
No	2 (5.6%)	4 (11.8%)	
Intratympanic steroid use			
Yes	34 (94.4%)	25 (73.5%)	0.022
No	2 (5.6%)	9 (26.5%)	
Pre-treatment severity			
Mild	2 (5.6%)	0 (0.0%)	0.649
Moderate	11 (30.6%)	11 (32.4%)	
Severe	10 (27.8%)	8 (23.5%)	
Profound	13 (36.1%)	15 (44.1%)	

standardise mean differences in PTA changes. Multiple linear regression was applied to assess the influence of age and categorical predictors on square root-transformed PTA alterations to address non-normal residuals. Receiver operating characteristic (ROC) curve analysis was conducted to predict treatment outcomes based on the duration from onset to treatment. Linear regression was used to evaluate the relationship between onset-to-treatment days and PTA alterations. A significance level of $\alpha = 0.05$ was used for all statistical tests in this study. Statistical analyses were performed using IBM SPSS Statistics version 29.

Results

A total of 70 patients were included in this study. Thirty-six patients received HBOT and 34 patients did not receive HBOT (Table 1). Baseline demographics, including sex distribution, side of ISSNHL, recurrence rates, presence of tinnitus, and pre-treatment ISSNHL severity, were similar between the groups. However, the HBOT group was younger, with a median age of 56.5 years (interquartile range [IQR]: 41.8, 65.3), compared with a median of 66.0 years in the No HBOT group (IQR: 58.0, 72.0; $P = 0.002$). All 70 patients in either group received some form of steroid treatment (oral, intratympanic, or both). Intratympanic steroid use was more prevalent in the HBOT group (94.4%) than in the No HBOT group (73.5%; $P = 0.022$). Oral steroid use was comparable between groups, with 94.4% of the HBOT group and 88.2% of the No HBOT group receiving oral steroids ($P = 0.422$).

Baseline hearing comparisons using Mann–Whitney U tests showed no significant differences in all pre-treatment PTA scores between the HBOT and No HBOT groups ($P_{adj} > 0.05$). The HBOT and No HBOT groups exhibited significant improvements in PTA scores after treatment ($P_{adj} \leq 0.004$ for all comparisons) (Table 2). A multiple linear regression analysis showed that age, side of ISSNHL, recurrence of ISSNHL, presence of tinnitus, and steroid use were not significant predictors of square root-transformed PTA improvement ($P > 0.05$ for all).

The impact of HBOT on ISSNHL varied by treatment timing (Table 3). The Early HBOT group ($n = 15$) exhibited significant improvement, with median PTA score decreasing

Table 2

Comparison of the PTA measurements between the HBOT and no HBOT groups; PTA 500/1,000/2,000/4,000 represent specific frequency hearing thresholds; PTA average is the mean of thresholds at 500, 1,000, 2,000, and 4,000 Hz per patient. Lower post-treatment PTA values indicate better hearing. Data are presented as median and interquartile range (Q1, Q3). Adjusted *P*-values (P_{adj}) were determined using the Bonferroni correction (m = 10). HBOT – hyperbaric oxygen therapy; PTA – pure-tone audiometry

Group	Measure	Pre-treatment	Post-treatment	P_{adj}
HBOT (*n* = 36)	PTA 500	82.5 (56.3, 95.0)	62.5 (26.3, 73.8)	< 0.001
	PTA 1,000	85.0 (60.0, 100.0)	67.5 (36.3, 85.0)	< 0.001
	PTA 2,000	80.0 (55.0, 103.8)	62.5 (45.0, 80.0)	0.001
	PTA 4,000	80.0 (60.0, 117.5)	70.0 (45.0, 80.0)	0.001
	PTA average	80.0 (58.8, 102.5)	63.1 (45.6, 79.7)	< 0.001
No HBOT (*n* = 34)	PTA 500	77.5 (53.8, 105.0)	62.5 (35.0, 75.0)	< 0.001
	PTA 1,000	87.5 (60.0, 110.0)	67.5 (45.0, 85.0)	< 0.001
	PTA 2,000	87.5 (63.8, 111.3)	75.0 (48.8, 91.3)	0.004
	PTA 4,000	90.0 (75.0, 111.3)	77.5 (60.0, 91.3)	< 0.001
	PTA average	87.5 (61.3, 106.6)	70.0 (50.3, 82.5)	< 0.001

Table 3

Changes in PTA in different treatment groups; HBOT – hyperbaric oxygen therapy; PTA – pure-tone audiometry

Outcome	Min	Max	Q1	Median	Q3
Early HBOT (*n* = 15)					
Pre-treatment PTA average	45.00	120.00	77.5	91.3	103.8
Post-treatment PTA average	20.00	101.25	45.0	57.5	78.8
PTA change	11.25	58.75	20.0	33.8	40.0
Late HBOT (*n* = 16)					
Pre-treatment PTA average	32.50	120.00	52.2	75.0	97.8
Post-treatment PTA average	20.00	115.00	36.3	73.1	86.9
PTA change	−13.75	36.25	-2.5	6.9	19.4
Salvage HBOT (*n* = 5)					
Pre-treatment PTA average	30.00	112.50	35.6	58.8	89.4
Post-treatment PTA average	30.00	112.50	39.4	62.5	88.1
PTA change	−7.50	2.50	−5.6	0.0	1.3
No HBOT (*n* = 34)					
Pre-treatment PTA average	45.00	120.00	61.3	87.5	106.6
Post-treatment PTA average	25.00	118.75	50.3	70.0	82.5
PTA change	−2.50	66.25	1.3	11.9	26.3

from 91.3 to 57.5 dB, a change of 33.8 dB. The Late HBOT group (*n* = 16) demonstrated a change of 6.9 dB. The Salvage HBOT group (*n* = 5) revealed no significant improvement. The No HBOT group (*n* = 34) showed a moderate improvement of 11.9 dB. The mean number of HBOT sessions administered was 18.5 (standard deviation [SD] 3.7) for the Early HBOT group, 16.6 (SD 5.4) for the Late HBOT group, and 16.6 (SD 4.8) for the Salvage HBOT group. No significant correlation was observed between the number of sessions and PTA improvement overall (Spearman's rho = −0.117, *P* = 0.496).

Our study highlighted significant variations in PTA improvement based on the timing of HBOT initiation (Figure 2). The Mann-Whitney U test revealed greater improvement with early HBOT than with late HBOT (*P* < 0.001, rank-biserial correlation [rrb] = 0.763), salvage HBOT (*P* = 0.001, rrb = 1.000), and No HBOT (*P* = 0.002, rrb = 0.549) (Table 4).

ROC curve analysis evaluated the predictive capability of onset to treatment (day) for marked improvement in the average PTA score (Figure 3). The area under the

Figure 2
Pre- to post-treatment change in pure-tone audiometry (PTA) in different treatment groups (early HBOT started within 12 days of symptom onset, late HBOT started between 13 and 22 days, salvage HBOT started after 22 days); boxplots show median (centre line), interquartile range (IQR) (box), whiskers to 1.5 × IQR, with outliers shown as points; ISSNHL – idiopathic sudden sensorineural hearing loss; HBOT – hyperbaric oxygen therapy

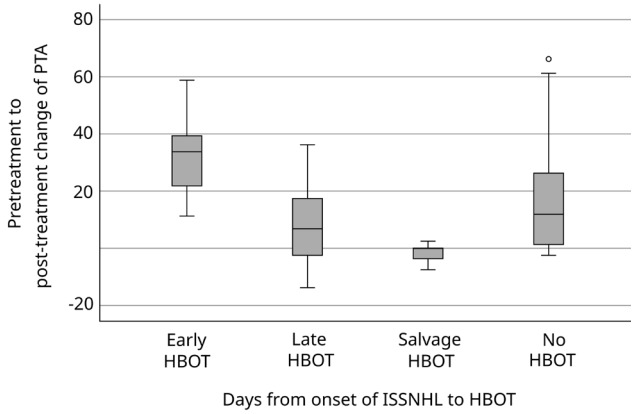


Figure 3
Receiver operating characteristic (ROC) curve analysis of the onset to treatment days in predicting marked improvement in the pure-tone audiometry (PTA) scores

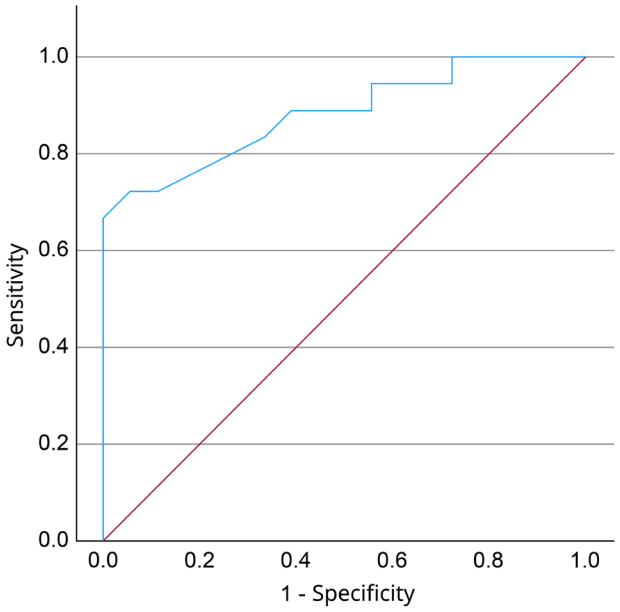
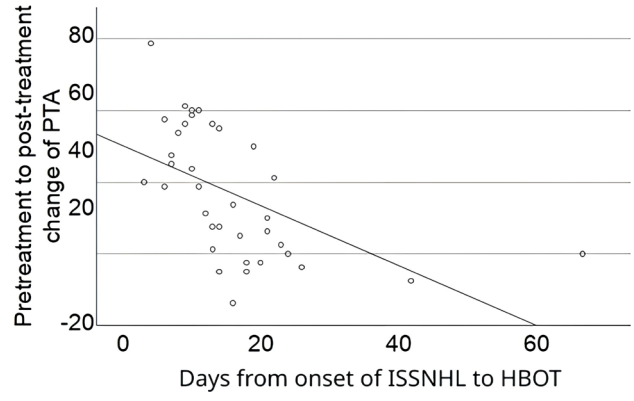


Table 4
The results of the Mann-Whitney U test comparing Early HBOT with Late HBOT, Salvage HBOT, and No HBOT; HBOT – hyperbaric oxygen therapy; Rrb – rank-biserial correlation

Comparison groups	Mann–Whitney U	Z-value	P_{adj}	r_{rb}	Cohen's d
Early HBOT vs. Late HBOT	28.50	-3.619	0.003	0.763	1.64
Early HBOT vs. Salvage HBOT	0.00	-3.277	0.003	1.000	3.04
Early HBOT vs. No HBOT	115.00	-3.039	0.006	0.549	0.86

Figure 4
Relationship between hyperbaric oxygen therapy (HBOT) timing and pure-tone audiometry (PTA) improvement; ISSNHL – Idiopathic sudden sensorineural hearing loss; PTA – pure-tone audiometry



curve was 0.883 (95% CI 0.771–0.995), indicating strong discriminative ability ($P < 0.001$).

A moderate negative correlation (r = -0.534, $P < 0.001$) was observed between the onset to treatment days and PTA change (Figure 4). Linear regression analysis revealed that treatment delay significantly reduced PTA improvement, with each additional day decreasing PTA improvement by 0.832 dB (95% CI -1.291, -0.373, $P < 0.001$).

Discussion

The inner ear's cochlea appears to be the main site of damage in ISSNHL, with potential contributing factors being thrombosis and viral infection.[13] The rationale for administering HBOT is predicated on the hypothesis that HBOT may mitigate a postulated oxygen deficit, aiding auditory recovery.[14]

Both HBOT and No HBOT groups demonstrated improvements in hearing post-treatment. While these

suggest potential benefits from HBOT, the improvement observed in No HBOT group may reflect spontaneous recovery or steroid effects. Statistical comparisons showed no significant differences in hearing improvement between the groups, consistent with the findings of Skarzynski et al.[15] Baseline differences were observed in age ($P = 0.002$) and intratympanic steroid use ($P = 0.022$) between the HBOT and No HBOT groups; however, multiple linear regression analysis indicated that age, side of ISSNHL, recurrence of ISSNHL, presence of tinnitus, oral and intratympanic steroid use were not significant predictors of PTA improvement, indicating that other factors may play crucial roles in recovery.

All patients received steroids in this study regardless of whether HBOT was administered, and clinical improvement was seen in both groups. However, the degree of clinical improvement was significantly higher among patients who received early HBOT in addition to the steroid therapy. Patients who received HBOT early showed a markedly enhanced PTA improvement compared to delayed or no HBOT. This finding is consistent with other studies.[9–11] Our analysis showed that the best outcome would be expected if HBOT was initiated within 10.5 days from symptom onset. In addition, this study showed a linear relationship in decrease in clinical efficacy for each day's treatment delay. The emphasis on early intervention remains a crucial takeaway for maximising the efficacy of ISSNHL treatments.

This study's strengths include a robust dataset spanning five years with 70 patients, the use of objective PTA measurements for reliable evaluation of hearing improvement, and statistical techniques such as ROC and linear regression analyses. These methods confirmed the critical timing window for HBOT, offering actionable insights for ISSNHL treatment optimisation. However, the retrospective design introduces potential selection biases, and the single-center setting limits generalisability. Moreover, non-random patient allocation and small subgroup sizes may influence results. The study's short-term focus calls for future research with extended follow-up to evaluate long-term outcomes.

Conclusions

Early HBOT initiation improves hearing recovery in patients with ISSNHL. The HBOT and No HBOT groups exhibited improvements in PTA scores; however, early HBOT patients demonstrated significantly greater clinical improvement compared to those who received late, salvage, or No HBOT. The study highlights the importance of prompt HBOT intervention to optimise auditory outcomes.

References

1 Chandrasekhar SS, Tsai Do B, Schwartz SR, Bontempo LJ, Faucett EA, Finestone SA, et al. Clinical practice guideline: sudden hearing loss (update). Otolaryngol Head Neck Surg. 2019;161(1_suppl):S1–S45. doi: 10.1177/0194599819859885. PMID: 31369359.

2 O'Malley MR, Haynes DS. Sudden hearing loss. Otolaryngol Clin North Am. 2008;41:633–49. doi: 10.1016/j.otc.2008.01.009. PMID: 18436003.

3 Rauch SD. Clinical practice. Idiopathic sudden sensorineural hearing loss. N Engl J Med. 2008;359:833–40. doi: 10.1056/NEJMcp0802129. PMID: 18716300.

4 Undersea & Hyperbaric Medical Society. Idiopathic sudden sensorineural hearing loss (New! Approved on October 8, 2011 by the UHMS Board of Directors). Published October 8, 2011. [cited 2024 Nov 27]. Available from: https://www.uhms.org/14-idiopathic-sudden-sensorineural-hearing-loss-new-approved-on-october-8-2011-by-the-uhms-board-of-directors.html.

5 Bennett MH, Kertesz T, Yeung P. Hyperbaric oxygen for idiopathic sudden sensorineural hearing loss and tinnitus. Cochrane Database Syst Rev. 2005;CD004739. doi: 10.1002/14651858.CD004739.pub2. PMID: 15674964.

6 Bennett MH, Kertesz T, Yeung P. Hyperbaric oxygen for idiopathic sudden sensorineural hearing loss and tinnitus. Cochrane Database Syst Rev. 2007;CD004739. doi: 10.1002/14651858.CD004739.pub3. PMID: 17253520.

7 Bennett MH, Kertesz T, Perleth M, Yeung P, Lehm JP. Hyperbaric oxygen for idiopathic sudden sensorineural hearing loss and tinnitus. Cochrane Database Syst Rev. 2012;10:CD004739. doi: 10.1002/14651858.CD004739.pub4. PMID: 23076907. PMCID: PMC11561530.

8 Newth A, Perleth M, Sherlock S, Romero L, Bennett MH. Hyperbaric oxygen therapy for acute idiopathic sudden sensorineural hearing loss; a systematic review with meta-analysis. Diving Hyperb Med. 2025;55:398–406. doi: 10.28920/dhm55.4.398-406. PMID: 41364864.

9 Chin CS, Lee TY, Chen YW, Wu MF. Idiopathic sudden sensorineural hearing loss: is hyperbaric oxygen treatment the sooner and longer, the better? J Pers Med. 2022;12:1652. doi: 10.3390/jpm12101652. PMID: 36294791. PMCID: PMC9605195.

10 Cavaliere M, De Luca P, Scarpa A, Strzalkowski AM, Ralli M, Calvanese M, et al. Combination of hyperbaric oxygen therapy and oral steroids for the treatment of sudden sensorineural hearing loss: early or late? Medicina (Kaunas). 2022;58:1421. doi: 10.3390/medicina58101421. PMID: 36295581. PMCID: PMC9611781.

11 Wang HH, Chen YT, Chou SF, Lee LC, Wang JH, Lai WY, et al. Effect of the timing of hyperbaric oxygen therapy on the prognosis of patients with idiopathic sudden sensorineural hearing loss. Biomedicines. 2023;11:2670. doi: 10.3390/biomedicines11102670. PMID: 37893044. PMCID: PMC10604466.

12 Mathieu D, Marroni A, Kot J. Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. Diving Hyperb Med. 2017;47:24–32. doi: 10.28920/dhm47.1.24-32. PMID: 28357821. PMCID: PMC6147240.

13 Yamada S, Kita J, Shinmura D, Nakamura Y, Sahara S, Misawa K, et al. Update on findings about sudden sensorineural hearing loss and insight into its pathogenesis. J Clin Med. 2022;11:6387. doi: 10.3390/jcm11216387. PMID: 36362614. PMCID: PMC9653771.

14 Bayoumy AB, de Ru JA. The use of hyperbaric oxygen therapy in acute hearing loss: a narrative review. Eur Arch

Otorhinolaryngol. 2019;276:1859–80. PMID: 31111252. PMCID: PMC6581929.

15 Skarzynski PH, Kolodziejak A, Gos E, Skarzynska MB, Czajka N, Skarzynski H. Hyperbaric oxygen therapy as an adjunct to corticosteroid treatment in sudden sensorineural hearing loss: a retrospective study. Front Neurol. 2023;14:1225135. doi: 10.3389/fneur.2023.1225135. PMID: 37475734. PMCID: PMC10354245.

Conflicts of interest and funding: nil

Submitted: 7 July 2025
Accepted after revision: 26 October 2025

Scuba tank fill survey in Victoria, Australia, 1 July 2024 to 30 June 2025

John Lippmann[1]

[1] *Australian Diving Safety Foundation, Canterbury, Victoria, Australia*

Corresponding author: *Dr John Lippmann, Australasian Diving Safety Foundation, PO Box 478, Canterbury VIC 3126, Australia*
johnl@adsf.org.au

Keywords
Compressors; Cylinder fills; Decompression illness; Dive numbers; Diving deaths; Diving industry

Abstract
(Lippmann J. Scuba tank fill survey in Victoria, Australia, 1 July 2024 to 30 June 2025. Diving and Hyperbaric Medicine. 2026 31 March;56(1):48–51. doi: 10.28920/dhm56.1.48-51. PMID: 41875441.)
Introduction: This study's aim was to determine the number of scuba tank fills done in Victoria, Australia from 1 July 2024 to 30 June 2025 to provide an estimate of the number of scuba dives conducted during that period and, from that, estimates of the fatality and decompression illness rates.
Methods: Suppliers of compressed gas for scuba diving in Victoria were identified through internet searches, industry liaison and the Australasian Diving Safety Foundation records. Those identified were emailed an invitation to participate in the tank fill survey and provided with dedicated spreadsheets. Email reminders were sent to collect monthly data on air, nitrox and 'other' fills. Data were compiled and, at the end of the survey period, non-regular participants were approached to provide actual numbers or estimates of the year's fills.
Results: Overall, 38/40 (95%) identified current suppliers participated in the survey, with 27 submitting regular monthly data and the remainder providing actual or estimated annual fills. There were 46,720 reported fills, including 39,386 air, 6,758 nitrox, and 576 others, with proportions of 84%, 15% and 1%, respectively. During that period, 11 scuba divers were treated for decompression illness (DCI) (eight of whom had dived locally) and there were two fatalities.
Conclusions: It is estimated that around 50,000 scuba tank fills were provided, equating to approximately 50,000 dives conducted in Victorian waters during from 1 July 2024 to 30 June 2025. During that period, there were eight open circuit divers who had dived in Victoria treated for DCI and two scuba diving fatalities, yielding estimates of 16 DCI cases and four deaths per 100,000 dives.

Introduction

Diving activity data provides valuable insights into the health of the dive industry and assists planning. Importantly, it also provides a denominator for determining the risk, indicating obvious problems to be identified and addressed, where necessary.

It is very difficult to obtain reliable estimates of scuba diving activity in most places. Entry-level certification numbers provide insights into industry growth but not the level of activity of divers overall. Sporting surveys can provide some insights, but the samples used may be too small to provide accurate data after extrapolation. Activity surveys are also subject to reporting bias.

Scuba tank fill data have been used to provide estimates in some places.[1,2] Although a single tank fill may sometimes be used for several shallow, relatively short dives (e.g., in a pool) and multiple cylinders are used on technical dives, a tank fill most often represents a single dive. Therefore, the number of tank fills can provide a reasonable estimate of the number of dives.

A tank fill survey was conducted in Victoria, Australia in 1993 to gauge the level of activity and size of the Victorian dive industry.[2] Australian entry-level certification data has waned since the early 1990s,[3] and anecdotal reports suggest a decline in diving in Victoria. To this end, it appeared timely to conduct another survey to assess the current level of activity and the accident rate.

The aim of this study was to determine the number of scuba tank fills done in Victoria from 1 July 2024 to 30 June 2025, to provide an estimate of the number of scuba dives conducted during that period and, from that, estimates of the fatality and decompression illness rates.

Methods

An internet search and discussions with industry sources were conducted to identify dive shops, charter operators, dive clubs and certain government agencies involved in diving throughout Victoria. The results were compared to the internal Australasian Diving Safety Foundation (ADSF) diving industry database and any discrepancies investigated. Separate email groups for dive shops, clubs and others were created and invitations to participate in the survey were

distributed, along with dedicated spreadsheets on which to record cylinder fills, if desired. Potential participants were assured by the investigator (who was known to most of them) that their individual data would be kept confidential with only totals reported. Participants were asked to record and report the number of air, nitrox and 'other' (i.e., other breathing gas mixtures). At the beginning of each month, emails were sent requesting participants to report their data for the preceding month. Late submitters were followed up by email and/or telephone and asked to provide actual, or a realistic estimate of their fills. In this way, data were collected from 1 July 2024 to 30 June 2025. At the end of the period, participants were asked to report whether the tank fills during the survey period were lower, similar or higher than recent years in order to gauge whether the survey data was typical, or otherwise.

Ninety-five percent confidence intervals (CI) were calculated based on an exact binomial method as implemented in the binomial test in the R statistical package.[4]

Results

Thirty-three shops (including dedicated dive shops, sports stores and other compressed gas suppliers), 11 dive clubs and three government agencies involved in diving were identified, and, of these, four shops and one club were no longer operating. Although two of the government agencies had their own compressors, these were not used, and tank fills were obtained from one of the other survey participants.

Of the 29 operating shops, 28 agreed to participate, as did ten of the dive clubs, the overall participation rate being 95%. Twenty-one shops and six clubs provided regular monthly data, and the remainder provided annual data, albeit sometimes an estimate. The total number of tank fills for the period is shown in Table 1. Monthly totals from 27 regular participants are shown in Figure 1.

During the period of this survey, were eight open circuit divers (all used air or nitrox) who had dived in Victoria and were treated for decompression illness (DCI) at The Alfred Hyperbaric Service, the sole local recompression facility treating divers in Victoria. In addition, there were two scuba fatalities (both of whom were diving on air or nitrox).[5] The two fatalities that occurred during the survey period are consistent with the long-term average of 1.6 scuba deaths per year in Victoria[6] and, based on an estimate of 50,000 dives over the period (to allow for some missing data), this yields a fatality rate for the year of four deaths per 100,000 dives (95% CI 0.40–14.45). Similarly, based on an estimate of 50,000 dives over the period, the DCI rate for this survey period was 16/100,000 dives (95% CI 6.91–31.52).

Table 1
Total air, nitrox and 'other' tank fills reported in Victoria from 1 July 2024 to 30 June 2025; note – the shops alone reported a total of 43,812 fills and clubs the balance of 2,908

Gas	*n* (%)
Air	39,386 (84)
Nitrox	6,758 (14)
Other	576 (1)
Total	46,720 (100)

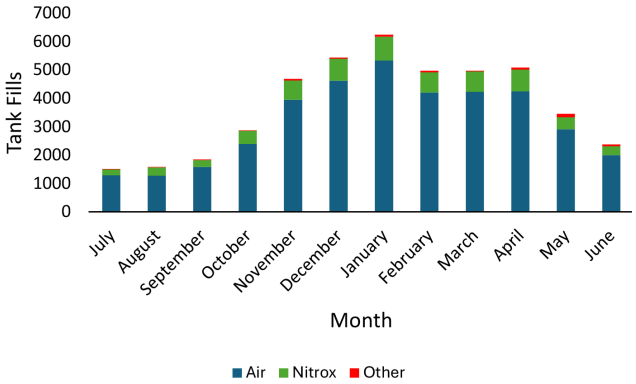
Discussion

Keeping a good record of tank fills provides a variety of benefits to the dive operator or club, as well as enabling some industry-wide benefits. First, it can provide a measure against the running cost of the compressor on which to base the fill price, as well as an indication of when maintenance is likely to be required. It also provides an indicator of the level of activity of customers or club members.

Although fatalities in scuba divers from carbon monoxide toxicity are rare, they do occur,[7,8] and anecdotal reports suggest that there are many more non-fatal incidents associated with breathing gas contamination in scuba divers. If cylinder filling dates and recipient details are recorded, these can provide a necessary record in the event of a mishap involving gas contamination. If a diver becomes incapacitated from contaminated gas, the date when their tank was filled can be found and, if other tanks were likely affected, the recipients can be tracked and notified of the potential for contamination. Workplace authorities in some jurisdictions, require this information to be available upon request.

On an industry level, periodic tank fill surveys help to track the health of the industry and can be used to guide individual business and local industry planning and marketing campaigns. For example, the 1993 Victorian tank fill survey[2] included 46 respondents (dive shops only) and yielded an estimate of 77,706 fills for that year, although

Figure 1
Monthly air, nitrox and 'other' fills, 1 July 2024–30 June 2025



if dive clubs and other compressed gas suppliers had been included the number would have been higher (McDonald, personal communication, 2025). By comparison, this later and broader-based survey suggests a reduction of around 35%, confirming beliefs of lower diving activity.

An important benefit of obtaining a reasonable estimate of activity is to provide a denominator for accident risk estimates. Based on the 1993 survey data the fatality rate at that time was 2.5 deaths per 100,000 dives (95% CI 0.3–9.03).[9] Although the current rate is higher, the two estimates lie within each other's 95% confidence intervals so there may be no significant difference in the underlying risk. In the year that the 1993 survey was conducted, 88 divers were treated for DCI in Victoria, although it is unknown how many of these dived locally so a meaningful DCI rate cannot be estimated. The DCI rate for this recent survey period was 16/100,000 dives (95% CI 6.91–31.52). The greatly reduced number of DCI cases treated is unsurprising given the substantial reduction in treated DCI Australia-wide over the past two decades.[10] This is likely partly from reduced activity, but also a result of improved decompression management, including the introduction of slower ascents and routine safety stops, as well as some changes in diagnostic and treatment criteria. The latter is likely driven in part by changes in the management of mild and marginal DCI, especially in remote locations, which is largely focused on the appropriate delivery of oxygen first aid in consultation with diving medical expertise.[11,12]

By way of comparison, some other DCI and fatality rate estimates based on hard numerator and denominator data include 4.1 DCI cases/100,000 dives (95% CI 1.12–10.50) for an operator in Tutukaka, New Zealand[13] (based on charter dives from 2008 to 2014) and 9.6/100,000 dives (95% CI 5.23–16.05) in British Columbia, Canada (based on tank fills in 2000).[1] Compared to these estimates and despite the decrease over the years, the DCI rate in Victoria appears higher, suggesting closer scrutiny of potential preventative measures may be appropriate.

On the other hand, the fatality estimates for Tutukaka and British Columbia were 1.03 (95% CI 0.03–5.70) and 2.05 (95% CI 0.42–6.0) deaths/100,000 dives, respectively. In addition, hard data from a large Victorian dive operator from 2007–2014 gave an estimate of 1.64 deaths/100,000 dives (95% CI 0.20–5.93) for its customers.[14] These estimates suggest that there may be no significant difference in the fatality risk between these and Victoria generally, when measured.

LIMITATIONS

Limitations to this study included the absence of data from an operator and a club and the likelihood that some individual compressor owners were not included, although an allowance was made for this. It also relies on the accuracy of record keeping by participants, and in particular, the accuracy of estimates of annual fills offered by some who did not provide monthly data. The decompression illness rate is based on treated DCI and it is likely there were many more cases (especially mild cases) which remained untreated.[15] The fatality estimates are based on very small numerators and can vary greatly with small changes in these.

Conclusions

Based on data provided by known Victorian compressed gas providers, it is estimated that around 50,000 scuba tank fills were provided, which equates to approximately 50,000 dives conducted in Victorian waters from 1 July 2024 to 30 June 2025. During that period, there were eight local divers treated for DCI and two scuba diving fatalities, yielding estimates of 16 DCI cases and four deaths per 100,000 open circuit dives.

References

1 Ladd G, Stepan V, Stevens L. The Abacus Project: establishing the risk of recreational scuba death and decompression illness. SPUMS Journal. 2002;32:124–8. [cited 2025 Aug 20]. Available from: https://www.dhmjournal.com/images/IndividArticles/32Sept/Ladd_SPUMSJ.32.3.124-128.pdf.

2 McDonald W. Victorian air fill survey 1993–1994. SPUMS Journal. 1994;24:194–6. [cited 2025 Aug 20]. Available from: https://www.dhmjournal.com/images/IndividArticles/24Dec/McDonald_SPUMSJ.24.4.194-196.pdf.

3 Lippmann J. Analysis of scuba diving-related fatalities in Australia. PhD thesis. [cited 2025 Aug 20]. Available from: https://dro.deakin.edu.au/articles/thesis/Analysis_of_scuba_diving-related_fatalities_in_Australia/21112966.

4 Ihaka R, Gentleman R. R: A language for data analysis and graphics. J Comp Graph Stat. 1996;5:299–314.

5 Australasian Diving Safety Foundation. Diving-related fatality database and cumulative register. [cited 2025 Aug 20]. Available from: http://www.adsf.org.au. (data available only to authorised internal researchers).

6 Lippmann J. Diving-related fatalities in Victoria, Australia, 2000 to 2022. Diving Hyperb Med. 2025;55:35–43. doi: 10.28920/dhm55.1.35-43. PMID: 40090024.

7 Lippmann J, Millar I. Severe carbon monoxide poisonings of scuba divers in the Asia-Pacific region - Cases and review of causation. Undersea Hyperb Med. 2022;49:341–53. PMID: 36001567.

8 Hampson NB. Carbon monoxide poisoning while scuba diving: a rare event? Undersea Hyperb Med. 2020;47:487–90. doi: 10.22462/03.07.2020.10. PMID: 32931677.

9 Lippmann J. Review of scuba diving fatalities and decompression illness in Australia. Diving Hyperb Med. 2008;38:71–8. PMID: 22692688. [cited 2025 Aug 20]. Available from: https://www.dhmjournal.com/images/IndividArticles/38June/Lippmann_dhm.38.2.71-78.pdf.

10 ADSF data repository. [cited 2025 Aug 27]. Available from: https://images.prismic.io/adsf/Z0Kpk68jQArT1PLH_DCI-Aust_95-24.jpg.

11 Mitchell SJ, Doolette DJ, Wachholz CJ, Vann RD, editors. Management of mild or marginal decompression illness in remote locations workshop proceedings. Durham NC:

Divers Alert Network; 2005. [cited 2025 Aug 20]. Available from: https://world.dan.org/wp-content/uploads/2021/06/remotewrkshpfinal05-1.pdf.

12 Mitchell SJ, Bennett MH, Bryson P, Butler FK, Doolette DJ, Holm JR et al. Consensus guideline: Prehospital management of decompression illness: expert review of key principles and controversies. Undersea Hyperb Med. 2018;45:273–86. PMID: 30028914.

13 Hubbard M, Davis FM, Malcolm K, Mitchell SJ. Decompression illness and other injuries in a recreational dive charter operation. Diving Hyperb Med. 2018;48:218–23. doi: 10.28920/dhm48.4.218-223. PMID: 30517953. PMCID: 6355312.

14 Lippmann J, Stevenson C, Taylor D McD, Williams J. Estimating the risk of a diving fatality in Australia. Diving Hyperb Med. 2016;46:241–6. PMID: 27966203. [cited 2025 Aug 20]. Available from: https://www.dhmjournal.com/images/IndividArticles/46Dec/Lippmann_dhm.46.4.241-246.pdf.

15 Tuominen LJ, Sokolowski S, Lundell RV, Räisänen-Sokolowski AK. Decompression illness in Finnish technical divers: a follow-up study on incidence and self treatment. Diving Hyperb Med. 2022;52:78–84. doi: 10.28920/dhm52.2.78-84. PMID: 35732278. PMCID: PMC9527095.

Acknowledgements

Many thanks to the dive operators, clubs and other compressed gas suppliers who contributed to this survey.

Conflicts of interest and funding

This study was funded by the Australian Diving Safety Foundation. No conflicts of interest were declared.

Submitted: 29 August 2025
Accepted after revision: 25 November 2025

Decision regret and shared decision-making in patients undergoing hyperbaric oxygen therapy

Joost R Meijering[1,2,*], Nurseda Risvanoglu[3,*], Julia D van Waard[3], Johanna H Nederhoed[1], Rigo Hoencamp[2,4,5], Robert A van Hulst[3], Dirk T Ubbink[1]

[1] *Surgery, Amsterdam University Medical Center, Amsterdam, the Netherlands*
[2] *Surgery, Alrijne, Leiderdorp, the Netherlands*
[3] *Anaesthesiology, Amsterdam University Medical Center, Amsterdam, the Netherlands*
[4] *Department of Surgery, Leiden University Medical Center, Leiden, the Netherlands*
[5] *Department of Surgery, Erasmus University, Rotterdam, the Netherlands*
[*] *Drs Meijering and Risvanoglu contributed equally to this study*

Corresponding author: *Dr Joost Meijering, Amsterdam University Medical Center, Amsterdam, the Netherlands*
ORCiD: *0009-0004-3667-0353*
j.r.meijering@amsterdamumc.nl

Keywords
Communication; Health surveys; Personalised medicine; Questionnaire; Side effects; Treatment sequelae

Abstract
(Meijering JR, Risvanoglu N, van Waard JD, Nederhoed JH, Hoencamp R, van Hulst RA, Ubbink DT. Decision regret and shared decision-making in patients undergoing hyperbaric oxygen therapy. Diving and Hyperbaric Medicine. 2026 31 March;56(1):52–58. doi: 10.28920/dhm56.1.52-58. PMID: 41875442.)
Introduction: Hyperbaric oxygen therapy (HBOT) is used for various medical conditions. HBOT is demanding and varies in effectiveness. This intensity combined with logistical challenges may lead to patients regretting undergoing HBOT. Therefore, shared decision-making (SDM) seems applicable when considering HBOT. The goal of this study was to assess the level of SDM as perceived by HBOT patients and relate this to post-hoc regret about choosing HBOT.
Methods: Patients referred for ≥ 10 sessions HBOT, were recruited for this prospective cohort study. Participants completed the SDM-Q-9 and SDM-K-Q questionnaires within one week of HBOT initiation. At least six weeks after HBOT completion or discontinuation participants completed the Decision Regret Scale (DRS) questionnaire. Multivariable linear regression analysis was applied to find factors influencing decision regret and SDM.
Results: Sixty-two patients (mean age 61.5 years; 36 female), primarily treated for radiation-related injuries, were included. Minor complications, including fatigue and temporary visual changes, were common. Mean SDM-Q-9 and SDM-K-Q scores were 61.9% and 72.1%, respectively. Among 54 patients completing the DRS, mean regret score was 13.4%. Lower regret correlated with symptom improvement (B = −16.56, $P = 0.036$) and more side effects (B = −6.81, $P = 0.014$). Males tended to report more regret (B = 8.26, $P = 0.081$), while age and SDM-Q-9 scores were not significant predictors. No factors significantly affected SDM-Q-9 scores.
Conclusions: HBOT patients reported limited involvement in decision-making and low levels of regret. Interestingly, minor complications were associated with less regret, suggesting complex dynamics in patient experience and treatment justification. These findings highlight the importance of individualised shared decision-making and patient education in the context of HBOT to ensure treatment choice aligns with patient values and expectations.

Introduction

Hyperbaric oxygen therapy (HBOT) is a medical treatment that has shown to be beneficial for a wide array of medical conditions, such as post-radiation injuries, sudden sensorineural hearing loss, and (ischaemic) diabetic foot ulcers.[1–7] While there is evidence regarding the effectiveness of HBOT for various (chronic) disorders, the therapy is intensive. It consists of daily treatment sessions, in which patients are confined to a pressurised chamber in which they breathe 100% for 1.5 to 2 hours. These sessions are repeated for four to eight weeks. Because HBOT-facilities are often not in the immediate proximity, there is also an additional travel burden. Given the demanding nature and logistical challenges of HBOT, as well as the sometimes poor health condition of the patient, not all have the endurance to complete the treatment. Additionally, temporary minor complications such as ear barotrauma, sinus discomfort, transient myopia, fatigue, and claustrophobia during HBOT-sessions can further hinder patients' ability or willingness to continue therapy.

Shared decision-making (SDM) is an increasingly important principle in healthcare, in which patients and healthcare providers work together to make informed decisions about treatment options in a collaborative approach. This leads

to improved treatment experience and patient-reported outcomes.[8–10] SDM may therefore be vital to manage patient expectations and to improve motivation for patients entering HBOT. Conversely, it may dissuade patients who may not be up to the challenge. While medical professionals are increasingly aware of the importance of SDM, patients may not always be aware of their right to be involved in this decision-making process or even what SDM entails.[11]

Some patients who have undergone HBOT may regret this decision afterwards, because it is a demanding treatment with possible (albeit temporary) side-effects, while its effectiveness is not guaranteed. Decision regret is a mostly negative emotional response following (healthcare) decisions. Decision regret analysis (DRA) helps identify areas where communication and decision support may need improvement, ultimately enhancing patient outcomes.[12] The theory of regret regulation proposes that regret can be experienced both retrospectively and prospectively and can arise from both actions and inactions.[13] The temporal nature of regret is particularly important, as the emotional impact of a decision may evolve over time. Initially, the regret following a choice, like the intense treatment of HBOT, may be acute. However, if positive outcomes, such as healing or recovery, become apparent over time, initial regret may diminish or transform into a sense of acceptance or even satisfaction. Therefore, DRA should be conducted only after an appropriate follow-up period and with a clear definition of the type of regret being investigated. DRA has already been applied in other medical areas,[14] confirming that collaborative and detailed discussion should take place to minimise regret when counselling patients regarding the treatment.

This study aimed to explore to what extent patients knew about, and perceived SDM when HBOT was decided, and the level of post-decision regret after having undergone HBOT for various medical indications. Furthermore, we studied factors influencing decision regret and SDM and the relation between the decision-making process and the patients' eventual regret with the choice for HBOT.

Methods

This prospective cohort study was conducted among patients undergoing HBOT to evaluate their knowledge about, and perceived level of SDM before treatment and the level of decision regret at least six weeks after treatment. The study was reported along the STROBE guidelines for observational studies.[15] The study protocol was approved by the Institutional Review Board of the Amsterdam University Medical Center (number 2023.0947).

PATIENTS

Patients were considered for recruitment while in their first week of HBOT, as provided by the Department of Hyperbaric Medicine of the Amsterdam University Medical Center between November 2023 and November 2024. To be eligible, participants had to be adults (18 years or older) and referred for at least ten sessions of HBOT to treat a chronic medical condition for which HBOT has been approved.[6] Patients were excluded if they had been treated with HBOT before, were undergoing pre-operative optimisation, or were being treated for an acute indication, such as crush injury. All participants provided written informed consent prior to entering the study.

STUDY CONDUCT

After enrolment, baseline characteristics of participants were extracted from their medical files by the research team. Participants were then asked to complete two questionnaires in Dutch: the Shared Decision-Making Knowledge Questionnaire (SDM-K-Q) (reproduced at *Appendix A), assessing their understanding of SDM principles, and the Shared Decision-Making Questionnaire (SDM-Q-9) (reproduced at *Appendix B), measuring their perceived level of involvement when facing the decision to undergo HBOT.[16,17]

At least six weeks after completing the HBOT, participants were contacted by phone to assess the level of decision regret by means of the Decision Regret Scale in Dutch (DRS) (reproduced at *Appendix C).[18] This time interval was chosen to allow any temporary side effects of HBOT to subside. Patients were given the option to either digitally receive the questionnaire to fill out at their leisure, or to go through the questionnaire on the phone with one of the researchers. Patients typically also received a consultation over the phone two months after cessation of HBOT from their treating physician. This instance was used to analyse improvement of complaints, side effects and complications from HBOT, as perceived by patients or caregivers. Data confidentiality and participant anonymity were strictly maintained throughout the study.

QUESTIONNAIRES

Three validated instruments were used to assess participants' knowledge and experiences related to shared decision-making, and level of decision regret regarding the choice for HBOT.

The SDM-K-Q measures participants' factual understanding of shared decision-making principles. It consists of 24 multiple-choice items addressing core concepts such

***Footnote:** Appendix A–C are available online on our website https://www.dhmjournal.com/index.php/journals?id=397

as patient involvement, communication, and weighing treatment options. Higher scores, expressed as a percentage of the maximum score, indicate greater knowledge of shared decision-making. In a validation study among healthy citizens a mean knowledge score of 73.8% was found.[11]

The nine-item SDM-Q-9 assesses participants' perception of their involvement in the decision-making process during their consultation.[16] Each item is rated on a six-point Likert scale ranging from zero ("*completely disagree*") to five ("*completely agree*"), yielding a total score between zero and 45. The total score is then converted into a percentage of the maximum score, with higher scores indicating a stronger perception of involvement in the decision-making process. In previous studies among various outpatient groups a mean SDM-Q-9 score of 80% was found.[18]

The Decision Regret Scale (DRS) evaluates participants' level of regret regarding their decision to undergo HBOT.[19] This tool includes five items rated on a five-point Likert scale, which are then transformed into a total score, ranging from zero (no regret) to 100 (highest level of regret). It captures feelings such as whether the decision was right and whether the participant would make the same choice again. In a systematic review of studies among individuals making non-hypothetical health decisions an overall mean regret score of 16.5 was found.[20]

DATA ANALYSIS

Collected data was encoded and securely stored in a password-protected electronic database using Castor Electronic Data Capturing system, version 2025.1.0.1 (Castor EDC, Amsterdam, The Netherlands), a validated platform for clinical data management. To ensure data integrity, all entries were independently verified for accuracy and completeness by two members of the research team.

Sample size was calculated to be 58 patients to obtain a precision (i.e., the 95% confidence interval [CI]) of ± 5% around the expected mean values of the questionnaire results, based on previous literature.[11,18,20] Taking into account a possible 10% loss to follow-up, a total of 65 patients were to be recruited.

Continuous variables were summarised as means with standard deviations or medians with interquartile ranges, depending on the distribution of the data.

Possible associations between key factors and DRS or SDM-Q-9 were analysed using multivariable linear regression modelling. Key factors, based on theoretical relevance and prior literature, included age, sex, SDM-Q-9 scores, occurrence of adverse events, and perceived benefits from therapy. Similarly, a multivariable regression was performed for SDM-Q-9, using age, sex and SDM-Q-K scores as possibly influencing factors. The proportion of variance in scores explained by the model was to be reported using the coefficient of determination (R^2).

All statistical analyses were conducted using SPSS version 28 (IBM Corp., Armonk, NY, USA), and statistical significance was set at $P < 0.05$.

Results

PARTICIPANT CHARACTERISTICS

Sixty-two patients were enrolled in the study between November 2023 and November 2024. The mean age of the participants was 61.5 years (range 39–81), comprising 36 females and 26 males. The majority of patients received HBOT for radiation-related injuries. Other patient and treatment characteristics are shown in Table 1.

A total of nine (14.5%) patients did not reach their predefined number of treatment sessions. Three patients discontinued HBOT because the desired therapeutic effect was reached sooner than anticipated. Two patients stopped treatment due to logistical or personal reasons and four patients due to other

Table 1
Participants' characteristics at baseline; DRS – Decision Regret Scale; F – female; HBOT – hyperbaric oxygen therapy; M – male; SD – standard deviation

Characteristic	Total (*n* = 62)
Age; mean (range), in years	61.5 (39–81)
Sex; M/F, *n* (%)	26/36 (41.9/58.1)
Indication, *n* (%) Radiation-related Osteomyelitis Diabetic wound Impaired wound healing Other	 53 (85.5) 3 (4.8) 2 (3.2) 1 (1.6) 3 (4.8)
Number of HBOT sessions; mean (SD), range	37.3 (8.7), 14–60
Time to DRS; mean (SD), in days	74.1 (30.3)

Table 2
Side-effects reported at follow-up; HBOT – hyperbaric oxygen therapy

HBOT side-effects	*n* (%)
None	12 (19.4)
Myopia	27 (43.5)
Fatigue	45 (72.6)
Other	2 (3.2)

Table 3
Questionnaire scores: DRS – Decision Regret Scale; SDM-K-Q – Shared Decision-Making Knowledge Questionnaire; SDM-Q-9 – Shared Decision-Making Questionnaire; SD – Standard Deviation

Questionnaire	*n*	Score % (SD)	Range	Reference score
SDM-Q-9 score	58	61.9 (24.9)	5–100	80.0 [18]
SDM-K-Q knowledge score	52	72.1 (15.5)	8.3–91.7	73.8 [11]
DRS score	54	13.4 (19.0)	0–95	16.5 [20]

Table 4
Multiple regression for Decision Regret Scale (DRS) scores; statistically significant effects in bold; CI – confidence interval; HBOT – hyperbaric oxygen therapy; SDM-Q-9 – Shared Decision-Making Questionnaire

Variable	B	SE	β	*P*	95% CI
Age (years)	0.332	0.229	0.188	0.153	-0.128 to 0.792
Sex (male)	8.264	4.636	0.234	0.081	-1.073 to 17.602
SDM-Q-9 score	0.086	0.081	0.138	0.296	-0.077 to 0.249
HBOT side-effects	-6.812	2.661	-0.330	**0.014**	-12.173 to -1.452
Improvement of complaints	-16.555	7.654	-0.281	**0.036**	-31.970 to -1.139

medical issues: diagnosed malignancy (n = 2), amputation of target limb (n = 1), or hospitalisation (n = 1).

SIDE-EFFECTS OF HBOT

At follow-up, 50 participants (80.6%) reported experiencing minor and reversible side effects from HBOT, including fatigue and temporary myopia (Table 2). During treatment, 13 patients experienced complaints unrelated to HBOT, seven of which were related to the disease for which they were referred to HBOT. Five other patients experienced flu-like symptoms, and one patient was admitted to the hospital with an unrelated infection.

SHARED DECISION-MAKING QUESTIONNAIRES

The SDM-K-Q was completed by 52 patients (84%), with a mean score of 72.1% (17.3 out of 24 answers correct; SD 15.5%; range 8.3–91.7%). The SDM-Q-K was not filled out by the initial ten participants due to logistical errors in the questionnaire availability.

The SDM-Q-9 questionnaire was completed by 61 patients (98%), yielding a mean score of 61.9% (SD 24.9%; range 5–100%). Three participants were excluded from the SDM analysis because they reported a score of zero. According to these participants, they had not discussed the therapy with their treating physician, but had requested themselves to be referred for HBOT.

DECISION REGRET SCORE

The DRS was completed by 54 patients (87%), yielding a mean regret score of 13.4 (SD 19.0). Participants completed the questionnaire after a median of 62 days (range 42–166).

REGRESSION ANALYSIS

Multivariable linear regression analysis (Table 4) showed that improvement of complaints was strongly associated with decision regret. Participants who reported improvement had, on average, a 16.6-point lower regret score (95% CI -31.97 to -1.14, P = 0.036). The presence of complications was also significantly associated with lower regret, with participants reporting 6.8 points lower regret scores per complication they experienced (B = -6.81, 95%CI -12.17 to -1.45, P = 0.014). Male participants tended to report higher regret scores than females, with an average increase of 8.26 points, although this did not reach statistical significance (95% CI -1.07 to 17.60, P = 0.081). No significant associations were observed between decision regret and age or SDM-Q-9 scores. This model explained 28% of the variance in decision regret (R^2 = 0.282).

In a separate regression model with the SDM-Q-9 score as the dependent variable, none of the factors (knowledge, age, sex) were significantly associated with perceived shared decision-making (P > 0.2 for all).

Discussion

This study investigated the role of decision regret and the level of SDM among patients with a chronic disorder for which they underwent HBOT, providing new insights into patient experiences and treatment satisfaction in this context. The majority of participants received HBOT for radiation-related conditions, mostly accompanied by temporary and minor side-effects, such as fatigue or myopia. Decision regret levels were slightly lower than reported in previous studies of similarly intensive interventions. A possible explanation for this limited level of regret may be that HBOT

is commonly considered as a last-resort treatment.[21] Patients are often referred for HBOT when other options have failed, which may cause patients to have less regret as they no longer have anything to lose and have no alternatives.

Perceived involvement in decision-making was lower than that reported in general populations, while the participants' knowledge about SDM was fairly good and similar to healthy populations.[11,18] Apparently, the participants were well aware their involvement in the decision-making process towards HBOT had been limited. Although decisional regret may hypothetically be more likely to occur when patients are less involved in the treatment decision, neither the perceived SDM nor the SDM knowledge was significantly associated with decision regret in the multivariable model. This is likely because decisional regret is a different construct than SDM and was measured sometime after completion of HBOT, while the level of SDM was gauged shortly after the start of the treatment. A measurement of decisional regret earlier during HBOT might have better reflected a relationship with the level of shared decision-making.

Unexpectedly, patients who experienced side-effects during HBOT reported less decision regret. One explanation may be that side-effects provide tangible evidence that 'something happened', reinforcing the perception that treatment was active. This paradox has been noted in surgical literature as well: regret is not consistently higher in patients who experience complications, particularly when outcomes are still satisfactory.[22] In this way, mild complications may act almost like a confirmation, reassuring patients of treatment activity and strengthening decision confidence.

The men participating in this study trended toward higher regret scores. Besides, participants who experienced relief of their complaints during the course of HBOT reported lower regret. These findings suggest that various personal and contextual factors play a role in shaping patient satisfaction in the HBOT setting.

STUDY LIMITATIONS

Potential limitations of this study include in the first place its single-centre design, in which the HBOT facility is accommodated within the hospital. This may limit the generalisability of the findings to broader patient populations or other HBOT settings. Multicentre studies often capture a more diverse range of clinical practices and patient demographics, potentially yielding results that are more widely applicable.

Second, the study relied heavily on self-reported measures, such as patient questionnaires assessing SDM knowledge, perceived involvement, and decision regret. Self-report data are inherently subject to response biases, including social desirability bias, recall bias, and differences in individual interpretation of questionnaire items, which may affect the accuracy and reliability of the findings.

Third, the response rate for the DRS and SDM-K-Q questionnaires was approximately 85%. The 15% who did not complete the questionnaires may have introduced attrition bias.

Fourth, if decisional regret had been recorded in more instances, changes could have been detected in regret during HBOT and possible correlations with other factors might have been found. Also the severity of disease of the participants was hardly taken into account, while only patients were included who were sufficiently able to comply. This could have influenced the level of regret, given the burden of HBOT, which would especially have affected those with a poor condition.

STUDY STRENGTHS

Despite these limitations, this study contributes valuable insights by systematically evaluating SDM and decision regret in patients undergoing HBOT. Understanding the patient experience in this context is crucial, as HBOT is a demanding treatment, both physically and mentally, often requiring daily commitment over several weeks. However, even this taxing treatment may be perceived differently, as the indications for HBOT cover a wide spectrum of patients, from relatively healthy, working-age individuals receiving HBOT after radiation therapy for oncology, to older patients with multiple comorbidities undergoing treatment for chronic wounds. By highlighting patient perspectives, the study identifies critical areas where patient-centred care can be improved through SDM, including enhancing communication, setting realistic expectations, and providing structured decision support. SDM is widely recommended as a method of care in modern healthcare.[23] However, this method is not practiced ubiquitously, neither in the clinical nor in the primary healthcare setting.[24] This is particularly true in the realm of hyperbaric medicine, where evidence remains scarce.[25]

Although our results did not show a direct association between perceived shared decision-making or SDM knowledge and decision regret, patient involvement remains an essential component of care. In HBOT, which often requires a long-term commitment, engaging patients in treatment decisions can help ensure that therapy aligns with their goals, preferences, and expectations. Structured decision-making tools and clearer communication strategies may still enhance patients' sense of support, potentially reducing regret and improving overall satisfaction and clinical outcomes.

Future research should focus on developing and evaluating targeted interventions, such as decision aids or structured

counselling protocols, to enhance SDM in the hyperbaric medicine setting. A different line of research that would be valuable to pursue would be evaluating and promoting SDM among the referring specialties to get a better sense of patients who decide to undergo HBOT versus those who do not, and to what extent SDM influences this decision.

Conclusions

This study found relatively low levels of decision regret among patients undergoing HBOT, while patients perceived moderate involvement in decision-making and showed to have generally adequate SDM knowledge. Neither SDM perception nor knowledge was directly associated with regret, whereas patient characteristics and complications appeared to play a more influential role. These findings highlight the complexity of patient experiences in HBOT and underscore the importance of tailored, patient-centred approaches, particularly given the heterogeneity of this population. Structured communication and decision support may help to further reduce regret and enhance satisfaction. Further research may be performed with larger, multi-centre cohorts to explore other potential determinants of decision regret in HBOT patients, as well as further research into the temporal alterations in decision regret during and after HBOT.

References

1 Bennett MH, Kertesz T, Perleth M, Yeung P, Lehm JP. Hyperbaric oxygen for idiopathic sudden sensorineural hearing loss and tinnitus. Cochrane Database Syst Rev. 2012;(10):CD004739. doi: 10.1002/14651858.CD004739.pub4. PMID: 23076907. PMCID: PMC11561530.

2 Brouwer RJ, Lalieu RC, Hoencamp R, van Hulst RA, Ubbink DT. A systematic review and meta-analysis of hyperbaric oxygen therapy for diabetic foot ulcers with arterial insufficiency. J Vasc Surg. 2020;71:682–92.e1. doi: 10.1016/j.jvs.2019.07.082. PMID: 32040434.

3 de Ru JA, Bayoumy AB. Sudden deafness: hyperbaric oxygen therapy should be discussed. BMJ. 2019;364:l758. doi: 10.1136/bmj.l758. PMID: 30787000.

4 Chandrasekhar SS, Do BST, Schwartz SR, Bontempo LJ, Faucett EA, Finestone SA, et al. Clinical practice guideline: sudden hearing loss (update) executive summary. Otolaryngol Head Neck Surg. 2019;161:195–210. doi: 10.1177/0194599819859885. PMID: 31369359.

5 Huang ET, editor. Hyperbaric medicine indications manual. 15th ed. North Palm Beach (FL): Best Publishing Company; 2024.

6 Mathieu D, Marroni A, Kot J. Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. Diving Hyperb Med. 2017;47:24–32. doi: 10.28920/dhm47.1.24-32. PMID: 28357821. PMCID: PMC6147240.

7 Lin ZC, Bennett MH, Hawkins GC, Azzopardi CP, Feldmeier J, Smee R, et al. Hyperbaric oxygen therapy for late radiation tissue injury. Cochrane Database Syst Rev. 2023;(8):CD005005. doi: 10.1002/14651858.CD005005.pub5. PMID: 37585677. PMCID: PMC10426260.

8 Niburski K, Guadagno E, Abbasgholizadeh-Rahimi S, Poenaru D. Shared decision making in surgery: a meta-analysis of existing literature. Patient. 2020;13:667–81. doi: 10.1007/s40271-020-00443-6. PMID: 32880820.

9 Mitropoulou P, Grüner-Hegge N, Reinhold J, Papadopoulou C. Shared decision making in cardiology: a systematic review and meta-analysis. Heart. 2023;109:34–9. doi: 10.1136/heartjnl-2022-321050. PMID: 36007938.

10 Wyatt KD, List B, Brinkman WB, Prutsky Lopez G, Asi N, Erwin P, et al. Shared decision making in pediatrics: a systematic review and meta-analysis. Acad Pediatr. 2015;15:573–83. doi: 10.1016/j.acap.2015.08.004. PMID: 25983006.

11 Thijs JB, Peters LJ, Lindeboom R, Somai P, Ubbink DT. What do people really know about shared decision-making? Developing and validating a questionnaire. Patient Educ Couns. 2025;138:109182. doi: 10.1016/j.pec.2024.109182. PMID: 40435661.

12 Brera AS, Arrigoni C, Magon A, Conte G, Belloni S, Bonavina L. A scoping review of decision regret in non-communicable diseases: The emerging roles of patient-clinician communication, psychological aspects, and medical outcomes. Patient Educ Couns. 2025;130:108478. doi: 10.1016/j.pec.2024.108478. PMID: 39437462.

13 Zeelenberg M, Pieters R. A theory of regret regulation 1.0. J Consum Psychol. 2007;17:3–18. doi: 10.1207/s15327663jcp1701_3.

14 Lindsay J, Uribe S, Moschonas D, Pavlakis P, Perry M, Patil K, et al. Patient satisfaction and regret after robot-assisted radical prostatectomy: a decision regret analysis. Urology. 2021;149:122–8. doi: 10.1016/j.urology.2020.12.015. PMID: 33359493.

15 von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The STROBE statement: guidelines for reporting observational studies. J Clin Epidemiol. 2008;61:344–9. doi: 10.1016/j.jclinepi.2007.11.008. PMID: 18313558.

16 Rodenburg-Vandenbussche S, Pieterse AH, Kroonenberg PM, Scholl I, van der Weijden T, Luyten GP, et al. Dutch translation and psychometric testing of the SDM-Q-9 and SDM-Q-doc in primary and secondary care. PLoS One. 2015;10(7):e0132158. doi: 10.1371/journal.pone.0132158. PMID: 26151946. PMCID: PMC4494856.

17 Kriston L, Scholl I, Hölzel L, Simon D, Loh A, Härter M. The 9-item shared decision making questionnaire (SDM-Q-9): development and psychometric properties in a primary care sample. Patient Educ Couns. 2010;80:94–9. doi: 10.1016/j.pec.2009.09.034. PMID: 19879711.

18 Ubbink DT, van Asbeck EV, Aarts JWM, Stubenrouch FE, Geerts PAF, Atsma F, et al. Comparison of the CollaboRATE and SDM-Q-9 questionnaires to appreciate the patient-reported level of shared decision-making. Patient Educ Couns. 2022;105:2475–9. doi: 10.1016/j.pec.2022.03.012. PMID: 35331573.

19 Brehaut JC, O'Connor AM, Wood TJ, Hack TF, Siminoff L, Gordon E, et al. Validation of a decision regret scale. Med Decis Making. 2003;23:281–92. doi: 10.1177/0272989X03256005. PMID: 12926578.

20 Becerra Pérez MM, Menear M, Brehaut JC, Légaré F. Extent and predictors of decision regret about health care decisions: a

systematic review. Med Decis Making. 2016;36:777–90. doi: 10.1177/0272989X16636113. PMID: 26975351.

21 Katarina H, Magnus L, Per K, Jan A. Diabetic persons with foot ulcers and their perceptions of hyperbaric oxygen chamber therapy. J Clin Nurs. 2009;18:1975–85. doi: 10.1111/j.1365-2702.2008.02769.x. PMID: 19638057.

22 Bartosiak K, Janik MR, Walędziak M, Paśnik K, Kwiatkowski A. Effect of significant postoperative complications on decision regret after laparoscopic sleeve gastrectomy: a case-control study. Obes Surg. 2022;32:2591–7. doi: 10.1007/s11695-022-06084-3. PMID: 35619046. PMCID: PMC9273554.

23 Ubbink DT, Geerts PAF, Gosens T, Brand PLP. [Updated Dutch law demands shared decision-making]. Ned Tijdschr Geneeskd. 2021;165:D5831. PMID: 34346637.

24 Ubbink DT, Shamoun F, Heuvelsland S, van Etten-Jamaludin FS, Bolt EE. To what extent do general practitioners involve patients in decision-making? A systematic review of studies using the OPTION-instrument. Prim Health Care Res Dev. 2025;26:e67. doi: 10.1017/S1463423625000674. PMID: 40740110. PMCID: PMC12455353.

25 Meijering JR, Risvanoglu N, Nederhoed JH, Hoencamp R, van Hulst RA, Ubbink DT. Shared decision-making when considering hyperbaric oxygen therapy: a systematic review. Diving Hyperb Med. 2025;55:180–185. doi: 10.28920/dhm55.2.180-185. PMID: 40544146. PMCID: PMC12520998.

Conflicts of interest and funding: This work is supported by the Dutch organisation for healthcare research (ZonMw), grant number 852002123. No conflicts of interest were declared.

Submitted: 22 October 2025
Accepted: 31 January 2026

Review articles

Transgender people and occupational diving: a new challenge for diving physicians?

Pieter-Jan AM van Ooij[1,2], Annemarije R Bek[1], Robert A van Hulst[3]

[1] *Diving Medical Centre, Royal Netherlands Navy, Den Helder, the Netherlands*
[2] *Department of Respiratory Medicine, Amsterdam University Medical Centre (AUMC), University of Amsterdam, Amsterdam, the Netherlands*
[3] *Department of Anesthesiology and Hyperbaric Medicine, Amsterdam University Medical Centre (AUMC), University of Amsterdam, Amsterdam, the Netherlands*

Corresponding author: *Pieter-Jan van Ooij, Diving Medical Centre, Royal Netherlands Navy. PO Box 10,000 1780 CA Den Helder, the Netherlands*
ORCiD: *0000-0002-2108-320X*
pjam.v.ooij.01@mindef.nl

Keywords
Fitness to dive; Gender affirming hormone therapy; Medical conditions; Review article; Risk factors

Abstract

(van Ooij PJAM, Bek AR, van Hulst RA. Transgender people and occupational diving: a new challenge for diving physicians? Diving and Hyperbaric Medicine. 2026 31 March;56(1):59–70. doi: 10.28920/dhm56.1.59-70. PMID: 41875443.)
The gender identity of transgender people is not fully aligned with their sex assigned at birth. It has been estimated that approximately 355 of 100,000 people in the general population consider themselves transgender. Transgender people are increasingly choosing to transition through gender-affirming hormone therapy, including treatment with testosterone or oestrogens and gender-affirming surgeries. Occupational diving is performed in a unique, highly hostile physiological environment. An occupational diver should be free of pulmonary, cardiovascular, neurological, and psychological risk factors that could increase the risk of diving-associated adverse events. Dive medical assessments can identify these risk factors. The increasing number of people openly identifying as transgender raises the likelihood that more will want to participate in occupational diving. To date, however, no guidelines have been specifically designed for safe occupational diving by transgender individuals. This review, involving 43 systematic reviews and/or meta-analyses, was therefore designed to assess the long-term health effects in transgender individuals and how these influence occupational diving. Although transgender people face some additional health risks that could affect occupational diving, these risks can be managed by adhering to regular occupational fitness-to-dive guidelines.

Introduction

In contrast to cisgender individuals, the gender of transgender individuals does not fully align with their sex assigned at birth.[1] A transgender man is an individual assigned female at birth who identifies as male, whereas a transgender woman is an individual assigned male at birth who identifies as female.[2] A 2016 meta-analysis assessing self-reported transgender identity, primarily in the United States, Europe, and Southeast Asia, estimated that 355 per 100,000 people in the general population identify as transgender.[3] In recent decades, the number of people openly identifying as transgender has increased markedly,[4] with a recent Canadian census reporting that the prevalence of transgender and non-binary individuals was five-fold higher in Generation Z, born between 1997 and 2006, than in the baby boomer generation, born between 1946 and 1965.[5] This increase may result from the greater social acceptance of people wishing to change gender and their increased opportunities for more appropriate medical care.[6]

Transgender people are increasingly choosing to transition through gender-affirming hormone therapy (GAHT) and gender-affirming surgeries (GAS). Although rates vary worldwide, it has been estimated that 9.2 per 100,000 people in the general population seek GAS or GAHT.[3] GAHT in transgender females consists of treatment with anti-androgens and oestrogens, whereas GAHT in transgender males consists of treatment with testosterone, possibly supplemented with progestins.[7] GAS also varies widely and can include gynaecological, urological, dermatological, plastic, and ear, nose, and throat (ENT) surgery.[7]

Diving involves work or recreation in a unique physiological environment. The human body is not adapted to an aquatic habitat and requires special equipment, such as diving gear,

to function in this environment. Some individuals, however, are unable to dive. For example, individuals with pulmonary or cardiovascular diseases (CVD) are more likely to be found unfit to dive.[8] Individuals are subjected to a dive medical assessment to identify physical factors or conditions that increase the risk of developing underwater problems or divers' diseases. If this risk is deemed too high, the candidate will be rejected. The European Diving Technology Committee (EDTC) 2024 fitness-to-dive guidelines are considered the most current.[9] These guidelines, however, do not include assessments of transgender individuals.

The increasing prevalence of transgender people increases the likelihood that more of these individuals will wish to participate in diving, both professionally and recreationally. Dive medical physicians seek to offer all occupational divers a reliable dive medical assessment. These tests are limited by the lack of guidelines for the assessment of transgender divers. Because reference values are based on biological sex, it is essential to differentiate between 'gender,' based on self-identification as male or female, and 'sex,' based on the physical and genetic attributes of that person. The 'gender' values providing the lowest risk have not been determined, and the effects of undergoing hormonal therapy and / or gender reassignment surgery on the risk of developing diving diseases such as decompression illness have not been evaluated.

To date, there are no guidelines for safe occupational diving tailored to the transgender population. This review aims to provide recommendations for assessing diving medical fitness among transgender individuals based on an exhaustive survey of the relevant literature.

Methods

SEARCH STRATEGY

The current review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 checklist to find articles regarding long-term health effects in adult transgender people.[10] A search was initially performed in February 2024, but due to a new search strategy, it was repeated in February 2025. The PubMed, Embase, and Web of Science databases were searched for articles published between January 1, 2000, and December 31, 2024. The search strategy was customised for each database, combining search terms using Boolean operators such as 'OR', 'AND' and 'NOT.' The detailed search strategies are available in *Supplemental Table 1. The Rayyan web application (rayyan.ai) was utilised for the screening process.

DATA EXTRACTION

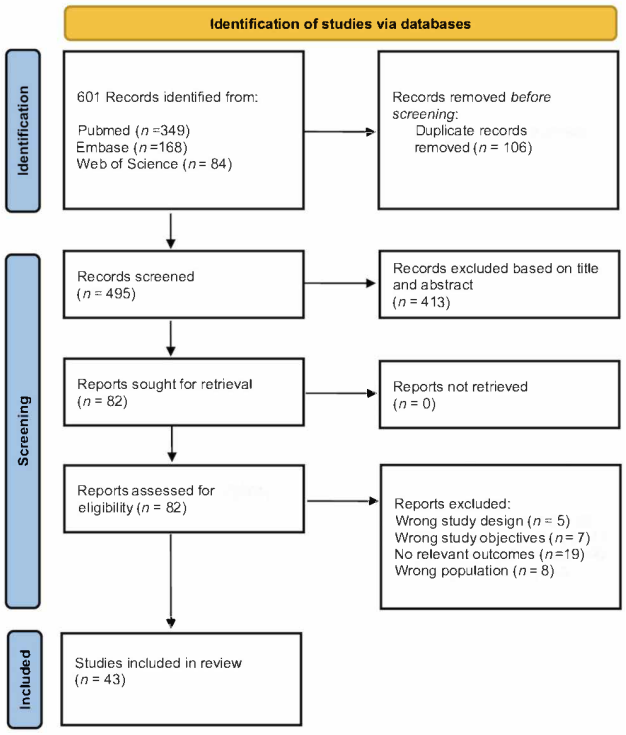
Two independent reviewers (PJVO and AB) were involved in the study selection. In case of uncertainty, decisions were made through discussion with a third reviewer (RVH). Systematic reviews and/or meta-analyses in English regarding the long-term health effects on transgender individuals were included. Other types of reviews, studies involving populations other than transgender individuals, and studies published in languages other than English were excluded.

Results

SEARCH AND ARTICLE INCLUSION

Figure 1 illustrates the inclusion and exclusion process. An electronic database search identified 601 studies. After removing duplicates, 495 studies were screened. A review of titles and abstracts excluded 413 of these studies, leaving 82 for further assessment of eligibility. A full reading of these articles resulted in the exclusion of 39 due to inadequate study design, seven for irrelevant study objectives, 19 for study outcomes unrelated to this review, and 14 for other reasons. Ultimately, 43 articles were included for further assessment.

Figure 1
PRISMA flow diagram showing an overview of the study selection process



*Footnote: Supplemental Table 1 is available online on our website https://www.dhmjournal.com/index.php/journals?id=399

CHARACTERISTICS OF INCLUDED STUDIES

The characteristics of the included articles are summarised in Table 1. Of these 43 included articles, 23 were systematic reviews, four were meta-analyses, and 16 were combined systematic reviews and meta-analyses (SRMAs). The 23 systematic reviews included six cardiovascular,[11–16] five psychosocial,[17–21] one locomotor,[22] one neurological,[23] and two endocrinological[24,25] reviews, as well as eight reviews on miscellaneous topics,[26–33] including breast cancer, sport performance, and changes in haemoglobin concentrations. The four meta-analyses included two cardiovascular,[34,35] one psychosocial[36] and one body composition[37] meta-analysis. The 16 combined SRMAs included seven cardiovascular,[38–44] one psychological,[45] three locomotor,[46–48] and one neurological[49] SRMA, as well as four SMRAs on miscellaneous topics,[50–53] including breast cancer and blood testing.

Assessing diving medical fitness among transgender individuals

Guidelines for the assessment of divers are criteria used to determine whether a diver is fit or unfit to dive, regardless of the diver's gender. The application of these guidelines to transgender divers, however, remains undetermined. The outcomes of the included studies were compared with the EDTC 2024 guidelines[9] to determine whether adjustments of these guidelines are required for transgender individuals.

PSYCHOSOCIAL

According to the EDTC 2024 guidelines, divers should have good mental stability. Any condition that causes mental instability might render these persons unfit to dive. Evaluations of a diver's mental fitness should not only consider the risk to the diver and those around them, but also the chance of recurrence of any psychiatric or psychological disorder or symptoms that could affect them. Special attention should be paid to the type of work, remote locations, and associated risks involved.[9]

The results of systematic reviews and meta-analyses on psychological functioning and quality of life in transgender individuals are inconsistent. Some studies showed that psychosocial functioning and quality of life improved after GAHT or GAS,[17,20,45] whereas one study found no improvements in quality of life, anxiety, and depression.[19]

Transgender individuals were found to use significantly more tobacco (odds ratio [OR] 1.58; 95% confidence interval [CI] 1.44–1.73) and specific substances such as cocaine, amphetamines or inhalants (OR 2.11; 95% CI 1.77–2.51).[36] Indeed, the rates of binge drinking and illicit drug use were observed to be higher in transgender than in cisgender individuals, indicating that transgender individuals are more at risk for problem drinking.[18]

Although the risks of tobacco use, alcohol consumption and illicit drug use, as well as rates of psychological disorders, such as depression and anxiety, are higher in transgender than in cisgender individuals, a person-by-person approach is essential when assessing a transgender individual. An additional in-depth psychological or psychiatric evaluation by a specialist with expertise in diving medicine might be necessary to decide whether a candidate is fit to dive.

PULMONOLOGY

In dive medical assessments, evaluating the pulmonary tract is paramount, as it is one of the main organ systems that must adapt to immersion.[9] Decreases in forced vital capacity (FVC), forced exhaled volume in one second (FEV_1), and the FEV_1/FVC ratio increase the risk of barotrauma. Unsurprisingly, pulmonary function testing (PFT) is essential in assessing medical fitness to dive. To exclude subjects with 'unfit lungs', PFT results are compared with a reference set, such as those of the Global Lung Function Initiative.[54] This reference set is, among other criteria, based on the gender of the subject.

The literature search did not identify any articles evaluating the long-term effects on the respiratory health of transgender individuals, suggesting that special adjustments are unnecessary for evaluating transgender divers. However, the European Respiratory Society recommends using the sex assigned at birth as the reference in evaluating PFT results, thereby avoiding underestimating risks in a female-to-male transgender person (FtM) or overestimating risks in a male-to-female transgender person (MtF).[55]

CARDIOVASCULAR

The EDTC 2024 guidelines regard all organic heart diseases, such as coronary heart disease and dysrhythmia, as potential reasons for rejection unless a cardiologist with a dive medical background decides otherwise.[9] Cardiac issues are a leading factor in diving accidents.[56] Older age, obesity and hypertension are factors associated with a higher risk of developing decompression sickness (DCS), and hypertension is also associated with an increased risk of developing immersion pulmonary oedema (IPO).[57] It is therefore vital to examine the cardiovascular system for potential cardiovascular diseases (CVD) in all divers, regardless of gender. Assessing cardiovascular risk factors should be included in the dive medical assessments of individuals aged over 35 years.[9]

Most systematic reviews and meta-analyses evaluating the cardiovascular system in FtM individuals have reported increases in the concentrations of low-density lipoproteins (LDL),[11,35,38,42,44] total cholesterol (TC)[35,42,44] and triglycerides (TG),[38] and a decrease in the concentration of high-density lipoproteins (HDL),[11,12,15,35,38,42] indicating a heightened risk of CVD.

Table 1

Summary of the characteristics of the included papers; BMD – bone mass density; BMI – body mass index; CI – confidence interval; CVD – cardiovascular disease; FtM – female-to-male transgender person; GAHT – gender-affirming hormone therapy; HDL – high-density lipoprotein; Hb – haemoglobin; Hct – haemocrit; INR – international normalised ratio test; LDL – low-density lipoprotein; MA – meta-analysis; MtF – male-to-female transgender person; NR – not reported; OR – odds ratio; QoL – quality of life; SIR – standardised incidence ratio; SR – systematic review; TC – total cholesterol; TG – transgender persons; TGL – triglycerides; VTE – venous thromboembolism; ↑ – increase; ↓ – decrease; ↔ – no increase/decrease

Ref	Type of study	Studies included	Population (*n*)	Primary findings/conclusion	Quality control	
					Risk of bias	Heterogeneity
Cardiology						
11	SR	13	499 (FtM)	BMI↑, LDL↑, Hb↑, Hct↑, HDL↓	NR	NR
38	SR/ MA	29	3,231 (MtF) 1,500 (FtM)	FtM: TGL↑, LDL↑ MtF: TGL↑	Moderate	Low-considerable
12	SR	77	5,866 (MtF) 1,501 (FtM)	MtF: cardiometabolic morbity↑, thromboembolic morbidity↑ compared to cisgender females, ↔ compared to cisgender males. MtF/FtM: hypertension ↔, DM ↔ cisgender peers	NR	NR
39	SR/ MA	12	2,518 (MtF)	VTE risk = 2.3 per 1000 person-years	NR	Substantial
34	MA	18	11,542 (MtF)	MtF > 37.5 years or > 53 months GAHT: VTE risk is 3.0% and 1% respectively. MtF < 37.5 years or < 53 months GAHT: VTE risk is neglectable	Low	Considerable
13	SR	14	648 (MtF) 661 (FtM)	FtM: blood pressure ↔. MtF: ambiguous result regarding blood pressure	Moderate-serious	NR
14	SR	11	6,068 (MtF) 3,112 (FtM)	MtF: VTE risk 42.6:10.000 patients, ↑ than cisgender females FtM: VTE risk 10.8:10.000 patients equal to cisgender males	Moderate-serious	Substantial
15	SR	11	471 (FtM)	HDL↓, LDL inconsistent results	Serious	NR
40	SR/ MA	22	19,893 (MtF) 14,840 (FtM)	Transgender people have a 40% higher risk of CVD compared with cisgender peers	Serious-critical	Substantial (MtF) Moderate (FtM)
41	SR/ MA	7	312 (FtM)	FtM: Hct ↑ (4.39 [3.25–5.26]), Hb ↑ (1.48 [1.17–1.78]), INR ↑ (0.02 [0.01–0.03]).	Moderate	Low-moderate
42	SR/ MA	35	1,305 (MtF) 1,336 (FtM)	FtM: LDL↑ (26.2mg·dl^{-1}), TC ↑ (26.1mg·dl^{-1}), TGL ↑ (30.7mg·dl^{-1}), HDL ↓ (-9.4mg·dl^{-1}) MtF: HDL ↔, TGL ↔, LDL and TC inconsistent results	Moderate-serious	Low-considerable
16	SR	18	2,080 (MtF)	Hct ↑. Smoking, higher age at initiation of testosterone therapy, higher BMI, and a predisposing medical history associated with increased Hct	Low-moderate	NR
43	SR/ MA	35	2,752 (MtF)	BMI ↑ (0.46 kg·m^{-2}), LDL ↓ (6.67 mg·dl^{-1}), systolic blood pressure ↓ (-3.69 mmHg)	Low-moderate	Low
44	SR/ MA	24	992 (MtF) 1,241 (FtM)	FtM: LDL ↑ (0.28 mg·dl^{-1}), TGL ↑ (0.42 mg·dl^{-1}), TC ↑ (0.17 mg·dl^{-1}), HDL ↓ (-0.50 mg·dl^{-1}), BMI ↑ (0.24 kg·m^{-2}), blood pressure ↔ MtF: TGL ↑ (0.64 mg·dl^{-1}), LDL ↔, HDL ↔, TC ↔, blood pressure ↔, BMI ↔	Serious	Considerable
35	MA	39	1,949 (FtM)	FtM: BMI ↑ (0.78 kg·m^{-2}), weight ↑ (2.20 kg), body fat ↓ (-1.29 kg), TC ↑ (4.95 mg·dl^{-1}), HDL ↓ (-7.52 mg·dl^{-1}), LDL ↑ (11.15 mg·dl^{-1}), TGL↑ (9.49 mg·dl^{-1}), blood glucose ↓ (-2.06 mg·dl^{-1})	Moderate	Low

Table 1 continued.

Psychosocial						
17	SR	3	237 (TG)	3–12 months after hormone therapy psychosocial functioning and QoL improved in both FtM and MtF transgender individuals	Moderate-serious	Low
18	SR	41	23,191 (TG)	Transgender people are more likely to engage in binge drinking and are at increased risk for problematic drinking and illicit drug use than cisgender individuals	Low-moderate	Substantial
45	SR/ MA	29	421 (MtF) 164 (FtM)	TG mental QoL ↓ (-0.78) compared with the general population. Post-treatment mental QoL ↔ compared with the general population	Moderate-high	Substantial
19	SR	7	552 (TG)	QoL ↔, anxiety ↔, depression ↔	Low-moderate	NR
20	SR	33	2,253 (MtF) 8,095 (FtM)	Gender-affirming surgery may lead to multiple psychological benefits	NR	NR
36	MA	20	18,329 (TG)	Compared with cisgender individuals, tobacco↑ (OR) = 1.65), previous substances use ↑ (OR = 1.48), present specific substances use ↑ (OR = 1.79)	Low-moderate	Low
21	SR	19	NR	Transgender veterans and service members experience worse mental health outcomes than their cisgender counterparts	NR	NR
Locomotor						
46	SR/ MA	13	392 (MtF) 247 (FtM)	FtM: BMD lumbar spine ↔, femoral neck ↔, total hip ↔ MtF: BMD lumbar spine ↑ (0.06 g·cm2), femoral neck↔, total hip ↔, fracture rates ↔	Moderate	Low (FtM) Low-substantial (MtF)
47	SR/ MA	19	812 (MtF) 487 (FtM)	GAHT did not affect bone density in FtM and affected bone density only at the lumbar spine in MtF	Low-moderate	Low-considerable (control studies)
22	SR	9	912 (MtF) 719 (FtM)	Longterm effect: BMD MtF ↓, FtM ↔. MtF and FtM: Calcium ↔, phosphate ↔, alkine phosphate ↔, osteocalcin ↔	Moderate	NR
48	SR/ MA	14	1,484 (FtM)	No significant changes were observed in BMD, calcium, phosphate, vitamin D, parathyroid hormone, or other analysed bone turnover markers	Moderate	Low – substantial
Neurology						
49	SR/ MA	14	8,014 (MtF)	Incidence of 2% for cerebrovascular events	Low-moderate	Substantial
23	SR	9	47 (MtF)	Increased intracranial meningioma risk when using > 25 mg/day cyproterone acetate	Moderate	NR
Endocrinology						
24	SR	26	689 (MtF) 751 (FtM)	FtM: lean body mass ↑, fat ↓ , insulin resistance ↔ MtF: lean mass ↓, fat ↑, insulin resistance ↑	NR	NR
25	SR	11	6,211 (MtF) 4,838 (FtM)	TG: BMI ↑, insulin resistance ↑ (more in MtF than FtM)	Low	NR
Physical performance						
26	SR	8	147 (TG)	One-year post-cross hormone therapy FtM are likely to compete without an athletic advantage. This also applies to MtF who also take testosterone blockers, although they still may have greater muscle mass	NR	NR

Table 1 continued.

37	MA	10	171 (MtF) 354 (FtM)	MtF: body weight ↑ (1.8 kg), body fat ↑ (3.0 kg), lean body mass ↓ (-2.4 kg) FtM: body weight ↑ (1.7 kg), body fat ↓ (-2.6 kg), lean body mass ↑ (3.9 kg)	Low	Substantial – considerable
32	SR	24	1,829 (MtF)	MtF: Hb decreased but ended equal to cisgender females. Lean body mass, total body fat, and muscle strengths higher than in cisgender females	Moderate	NR
Cancer						
27	SR	26	22 (MtF)	The risk of breast cancer is low, but when present occurs in younger patients	Moderate	NR
28	SR	8	17 (FtM)	FtM transgender individuals have a lower risk of breast cancer than cisgender females (44.5 yrs vs. 62 yrs)	Moderate-high	NR
29	SR	43	31 (MtF) 28 (FtM)	FtM: breast cancer comparable to cis-males (5.9 vs. 1.2 per 100,000 person-years), lower than cis-females (170 per 100,000 person-years). Ovarian, vaginal, uterine and cervical cancer not found. MtF: breast cancer comparable to cis-males (4.3 per 100,000 person-years). Prostate cancers lower (0.04%) than in cis-males. GAHT has not been shown to affect cancer risk	Serious	NR
30	SR	43	8,384 (MtF) 3,028 (FtM)	GAHT not significantly related to risk of cancer or cancer related deaths although mortality lower in MtF individuals	NR	NR
31	SR	22	23 (FtM)	FtM: lower risk of breast cancer than in cisgender females but higher than that in cisgender males.	Low-moderate	NR
33	SR	76	31 (FtM)	FtM: breast cancer risk ↑ than in cisgender men ↓ than in cisgender women. Breast cancers been diagnosed at a younger age than in cisgender women and cisgender men	Low-Serious	NR
51	SR/ MA	41	6,166 (MtF) 6,604 (FtM)	FtM (SIR = 63.4) and MtF (SIR = 22.5) individuals are at higher risk of developing breast cancer than cisgender men, but lower risk than in cisgender women (SIR = 0.42 vs. 0.30)	NR	Low-substantial
52	SR/ MA	14	1,864 (MtF)	MtF: breast augmentation is overall a safe procedure but higher risk of early (haematoma 0.63%) and longer term (implant malposition 3.89%) complications than in cisgender females	Low	Low-substantial
Miscellaneous						
50	SR/ MA	26	1,455 (MtF) 1,386 (FtM)	FtM: creatinine ↑ (0.15 $mg \cdot dl^{-1}$) MtF: creatinine ↔	Moderate-high	Low
53	SR/ MA	16	2,758 (FtM)	Alanine-aminotransferase initially increases (OR 2.31; 95% CI 1.41–3.21), but stabilises as early as 24 months (OR 1.71; 95% CI -0.02–3.44)	Moderate	Low-substantial

Indeed, a recent study analysing 22 articles showed that FtM individuals are at higher risks of venous thromboembolism (VTE; OR 1.4) and myocardial infarction (OR 1.7) than cisgender individuals.[40] More importantly, the risk of CVD death was more than two-fold higher in FtM than in cisgender individuals (OR 2.2).[40]

Several systematic reviews and meta-analyses in MtF individuals have shown increases in the concentrations of HDL,[12] TC,[42] and TG,[12,38,44] and a reduction in the concentration of LDL,[12,43] indicating that MtF individuals have a more protective lipid profile than FtM persons. However, the risk of VTE was more than two-fold higher in MtF that in cisgender individuals (OR 2.2),[40] especially in those aged > 37.5 years or using GAHT for > 53 months.[34] Moreover, the risk of CVD death was found to be higher in MtF than in cisgender individuals (OR 1.5).[40]

Only six studies to date have reported the effect of GAHT on blood pressure.[11–13,15,43,44] Although systolic and diastolic blood pressure tended to increase in FtM and decrease in MtF individuals, no definitive conclusions could be drawn, either because the differences were not statistically significant or because the studies were of low to moderate quality.

Taken together, these findings suggest that transgender individuals may be at higher risk for CVDs, particularly after age 37 years. Because the EDTC recommends that divers aged ≥ 35 years undergo cardiovascular risk management (CVRM), there is no need for additional screening of a transgender occupational diver. Although CVRM risk score calculators like QRISK3 may be useful,[58] these risk calculators were designed for cisgender individuals. It is therefore unclear whether the reference for transgender individuals should be based on their cisgender or transgender peers.

NEUROLOGY

Because neurological diseases can imitate decompression illnesses or compromise diver safety, a thorough assessment of the neurological system is crucial. A diver's medical history, combined with a neurological examination, should be part of the initial and annual evaluations. Any neurological disease that affects a diver's consciousness or leads to a sudden impairment might have an impact on their fitness to dive. Divers with pre-existing neurological disorders, therefore, require careful evaluation.[9]

Only two of the 43 included papers examined the long-term neurological health effects on transgender individuals. One study reported that the prevalence of cerebrovascular events in MtF individuals was 2%, which is lower than the worldwide stroke risk.[49] The second study examined the long-term effects of cyproterone acetate on neurological pathway. MtF individuals who used high doses of cyproterone acetate were found to have a higher risk of intracranial meningiomas. Although the overall risk of meningiomas in transgender people was very low, multiple meningiomas occurred more often than in the cisgender population. At its recommended dose of 10 mg, however, cyproterone acetate did not increase the risk of meningiomas.[23]

These findings suggest that transgender individuals are not at a higher risk of neurological diseases that could affect their ability to dive. Therefore, the neurologic recommendations in the EDTC guidelines are sufficient for assessing transgender divers.[9]

EAR, NOSE AND THROAT (ENT)

ENT-related diving diseases are by far the most common injuries in diving, with most associated with dis-equalisation of the middle ear or sinuses. Thus, a suitable working equalisation technique is important.

Besides hormones, gender-affirmation surgery often plays a role in the transition to the desired gender. ENT-related gender-affirmation surgery (ERGAS) can include rhinoplasty, bone and soft-tissue reconstruction, forehead contouring, hairline adjustment, brow lift, lip lift, mandibular shaping, genioplasty, vocal cord surgery, and chondrolaryngoplasty.[59]

The search of the relevant literature did not identify any systematic review or meta-analysis on the long-term health effects of ERGAS on the ENT tract. Although some aspects of ERGAS may have consequences for diving, these problems are unlikely to occur. The EDTC guidelines should therefore be sufficient for assessing transgender divers.[9]

INTERNAL ORGANS

Depending on the signs or symptoms, endocrine disorders can pose a risk to the diver. For examples, disturbances of consciousness, cardiac arrhythmias and decreased exercise capacity can incapacitate a diver, and diseases such as phaeochromocytoma, Addison's disease, and diabetes mellitus may be incompatible with occupational diving. Dive medical physicians should therefore consult specialists for advice before determining whether an individual is fit to dive.[9]

To date, three systematic reviews and one meta-analysis have evaluated the effects of GAHT on insulin resistance and the prevalence of diabetes mellitus. One study found no significant differences in insulin resistance between transgender and cisgender individuals,[12] whereas a second study found that rates of insulin resistance did not differ in FtM and cisgender individuals, whereas the results were inconclusive in MtF individuals.[24] Insulin levels did not differ significantly in FtM and cisgender individuals,[35] and no differences were observed in the prevalence of type 2 diabetes mellitus in transgender and cisgender populations.[25]

The concentration of alanine-aminotransferase in FtM individuals was found to increase during the first two years of GAHT (OR 1.71, 95% CI -0.02–3.44). Although statistically significant, this increase was not clinically significant, indicating that GAHT does not impair liver function during the first 24 months of treatment.[53] GAHT for 12 months was associated with an increase in serum creatinine in FtM, but not in MtF individuals, suggesting a decrease in kidney function in the former.[50] None of the included systematic reviews and/or meta-analyses reported that GAHT had any other long-term health effects on internal organs. Taken together, these findings indicate that the EDTC guidelines on internal organs are sufficient for transgender divers, with no additional specific tests being necessary.

PHYSICAL PERFORMANCE AND MUSCULOSKELETAL TRACT

According to the EDTC guidelines, the physical demands for occupational diving range from 3 to 13 METs, where one MET equals 3.5 ml $O_2.kg^{-1}.min^{-1}$ for males and 3.2 ml $O_2.kg^{-1}.min^{-1}$ for females. Although different tasks require varying physical demands, the EDTC guidelines recommend a minimum physical capacity of 12 METs. Divers with a physical capacity between 8 and 11 METs may, however, be deemed fit to dive if this capacity is compatible with the demands of the task.[9] Moreover, strength may be more important than physical endurance in underwater construction work, emphasising the fit-for-the-job principle. Finally, the EDTC guidelines do not differentiate between genders.

To date, only one systematic review has examined the effects of GAHT on physical performance in transgender individuals. Muscle mass in FtM individuals using GAHT was found to be comparable to that in cisgender males.[26] Although muscle mass decreased in MtF individuals using GAHT, it was significantly higher than that in cisgender females.[26] Because no review has assessed the impact of GAHT on athletic performance levels, it is difficult to compare physical endurance in the transgender and cisgender populations.

Physical performance and strength are also influenced by body composition, haemoglobin (Hb) and haematocrit (Hct) levels. High body weight resulting from a high percentage of body fat or a lower lean body mass can reduce maximal oxygen uptake (VO_2-max). GAHT, particularly in MtF individuals, can result in increased body weight and/or reduced lean body mass.[37] Lower Hb and Hct levels can result in reduced physical endurance, as observed after whole blood donation.[60] FtM individuals have shown increases in Hb and Hct, to levels similar to those of cisgender males, likely resulting in improved physical endurance.[11,16,41] By contrast, MtF individuals have shown reductions in Hb and Hct, with Hct levels close to those of cisgender females.[32] GAHT did not significantly affect bone mass density in either FtM or MtF individuals.[22,46–48]

Although physical strength and performance are vital for an occupational diver, and GAHT might influence both in various ways, there is no reason to deviate from the current EDTC guidelines.[9] Regardless of gender, individuals must meet the minimum requirements.

CANCER

Any form of cancer can lead to temporary or permanent disqualification from diving. Depending on the type of cancer, the treatment received, and the presence of disability, the dive medical physician must determine whether an individual is fit to continue occupational diving. These decisions are made on a case-by-case basis.[9]

Seven systematic reviews have assessed the effect of GAHT on cancer development. Generally, GAHT does not influence cancer risk.[29] The risk of breast cancer in MtF individuals has been reported to range from 4.1–20 per 100,000, roughly similar to the risk in cisgender males but lower than in cisgender females.[27,29,33,51] Breast cancer, however, occurred at a younger age in MtF (approximately 51 years) than in cisgender individuals.[27,33] The risk of breast cancer in FtM individuals was similar to that in cisgender males but lower than that in cisgender females.[28,29,31,51] Ovarian and uterine cancers have not been observed to date in FtM individuals,[29] whereas the risk of prostate cancer was lower in MtF individuals than in cisgender males.[29]

Because many factors affect the fitness to dive after a cancer diagnosis, each person must be assessed individually. The EDTC guidelines do not require modification when assessing a transgender diver who was diagnosed with cancer.

Discussion

To our knowledge, this is the first review evaluating transgender occupational divers. Although these individuals may face some increased health risks, there is no need to modify the current fitness-to-dive guidelines. These additional health risks can be addressed by following the proper guidelines.

To date, only one case report has evaluated a transgender diver, an MtF person who transitioned during her career as a diver.[61] Although the potential DCI risk was discussed, the lack of data on DCI risk among transgender divers required application of the risk for female divers to this MtF diver. Based on French law, the company employing the MtF diver was advised to restrict her diving activities to those permitted by French legislation, such as wearing weights of no more than 25 kg. Because of a possible increased risk of CVD, blood tests, including measurements of Hb and glucose concentrations and evaluation of lipidaemia, were recommended every three months. By contrast, the EDTC guidelines regarding the risk of CVRM do not recommend quarterly blood tests.[9]

Although there is no need to modify the EDTC guidelines when assessing a transgender diver, dive medical physicians should be aware of other issues not related to assessment. The psychosocial aspect of being transgender in a predominantly male world of occupational diving should be considered. Employers are required to create a physically and psychologically safe working environment. Dive medical physicians, in close cooperation with occupational physicians, should therefore provide diving companies with recommendations on this aspect of diving.

This review has several strengths, such as being the first to evaluate the assessment of occupational transgender divers, the systematised search protocol and its relevance to occupational diving. However, this review also had several limitations. First, the quality of the included papers varied markedly. Most of the reviews and meta-analyses included showed a moderate to considerable level of heterogeneity, indicating that the data within these studies were inconsistent. Therefore, even statistically significant outcomes may not have been clinically meaningful. Additionally, the quality of the included articles was not evaluated systematically, leading to the inclusion of studies with low to moderate quality. This may have limited the validity of some outcomes and the potential for selective reporting of long-term health effects in transgender individuals. More importantly, some studies lacked detailed information regarding the characteristics of the population. Nonetheless, comparisons of the results of the included systematic reviews and meta-analyses by topic showed insubstantial differences in the reported outcomes. Thus, although the risks of bias and heterogeneity may have influenced the results, they did not significantly affect the overall conclusion.

Second, the search included only systematic reviews and meta-analyses, excluding other types of reviews and non-review articles. This search strategy may therefore have been too narrow, missing important information from other publications. However, based on the methodological approach of conducting systematic reviews and/or meta-analyses, the key papers for this review were likely included. Examination of the references cited in the included reviews and meta-analyses showed substantial overlaps, suggesting that important information from other, non-included literature sources was not overlooked.

Thirdly, the search was limited to systematic reviews and meta-analyses written in English, which may have led to omission of relevant studies published in other languages and influenced the results of this review. English, however, is the primary language used in scientific publications, suggesting that significant findings would likely have been published in English. Although this publication bias could not be entirely eliminated, it likely had no effect on the results of this analysis.

Finally, this review was concentrated on occupational diving, which has more stringent fitness-to-dive guidelines than recreational diving. Therefore, the present findings cannot be directly applied to fitness-to-dive guidelines for recreational diving. However, diving medicine physicians who assess recreational divers might adapt the results of this review to recreational divers.

The present study found that current fitness-to-dive guidelines are adequate for assessing transgender divers involved in occupational underwater or caisson work. Further research focused on occupational diving is required, however, to ensure that transgender divers can continue to dive safely. Outcomes of these studies may result in alterations to current fitness to dive guidelines.

Conclusions

Worldwide, the number of people openly identifying as transgender is increasing. This may result in an increase in the number of transgender occupational divers asking dive medical physicians for fitness-to-dive assessments. To date, specific fitness to dive guidelines have not been formulated for transgender persons. The results of this systematic review suggest that, although transgender divers are at higher risk of long-term health effects from GAHT, such as cardiovascular issues, the likelihood that these health effects have an impact on diving can largely be reduced by adhering to regular fitness-to-dive guidelines, such as the EDTC guidelines.

References

1 American Psychological Association. Guidelines for psychological practice with transgender and gender nonconforming people. Am Psychol. 2015;70:832–64. doi: 10.1037/a0039906. PMID: 26653312.

2 Winter S, Diamond M, Green J, Karasic D, Reed T, Whittle S, et al. Transgender people: Health at the margins of society. Lancet. 2016;388:390–400. doi: 10.1016/S0140-6736(16)00683-8. PMID: 27323925.

3 Collin L, Reisner SL, Tangpricha V, Goodman M. Prevalence of transgender depends on the "case" definition: A systematic review. J Sex Med. 2016;13:613–26. doi: 10.1016/j.jsxm.2016.02.001. PMID: 27045261. PMCID: PMC4823815.

4 Wiepjes CM, Nota NM, de Blok CJM, Klaver M, de Vries ALC, Wensing-Kruger SA, et al. The Amsterdam cohort of gender dysphoria study (1972–2015): Trends in prevalence, treatment, and regrets. J Sex Med. 2018;15:582–90. doi: 10.1016/j.jsxm.2018.01.016. PMID: 29463477.

5 Statistic Canada. Filling gaps in gender diversity data in Canada [Internet]; 2022. [cited 2023 Sep 15]. Available from: https://www150.statcan.gc.ca/n1/daily-quotidien/220427/dq220427b-eng.htm?HPA=1.

6 De Cuypere G, Van Hemelrijck M, Michel A, Carael B, Heylens G, Rubens R, et al. Prevalence and demography of transsexualism in Belgium. Eur Psychiatry. 2007;22:137–41. doi: 10.1016/j.eurpsy.2006.10.002. PMID: 17188846.

7 Coleman E, Radix AE, Bouman WP, Brown GR, de Vries ALC, Deutsch MB, et al. Standards of care for the health of transgender and gender diverse people, Version 8. Int J Transgend Health. 2022;23(Suppl 1):S1–S259. doi: 10.1080/26895269.2022.2100644. PMID: 36238954. PMCID: PMC9553112.

8 Pendergast DR, Lundgren CEG. The underwater environment: cardiopulmonary, thermal, and energetic demands. J Appl Physiol (1985). 2009;106:276–83. doi: 10.1152/japplphysiol.90984.2008. PMID: 19036887.

9 Wendling J, vanden Eede R, Elliott D, Meintjes J, Meliet JL, Nome T, editors. Medical assessment for work under pressure. 2nd ed. Biel-Bienne: Hyperbaric Editions; 2024. p. 1–350.

10 Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi: 10.1136/bmj.n71. PMID: 33782057. PMCID: PMC8005924.

11 Velho I, Fighera TM, Ziegelmann PK, Spritzer PM. Effects of testosterone therapy on BMI, blood pressure, and laboratory profile of transgender men: A systematic review. Andrology. 2017;5:881–8. doi: 10.1111/andr.12382. PMID: 28709177.

12 Defreyne J, Van de Bruaene LDL, Rietzschel E, Van Schuylenbergh J, T'Sjoen GGR. Effects of gender-affirming hormones on lipid, metabolic, and cardiac surrogate blood markers in transgender persons. Clin Chem. 2019;65:119–34. doi: 10.1373/clinchem.2018.288241. PMID: 30602477.

13 Connelly PJ, Clark A, Touyz RM, Delles C. Transgender adults, gender-affirming hormone therapy and blood pressure: a systematic review. J Hypertens. 2021;39:223–30. doi: 10.1097/HJH.0000000000002632. PMID: 32809982. PMCID: PMC7810409.

14 Kotamarti VS, Greige N, Heiman AJ, Patel A, Ricci JA. Risk for venous thromboembolism in transgender patients undergoing cross-sex hormone treatment: A systematic review. J Sex Med. 2021;18:1280–91. doi: 10.1016/j.jsxm.2021.04.006. PMID: 34140253.

15 Quintela-Castro FCA, Pereira TSS, Alves DB, Chiepe L, Nascimento LS, Chiepe KCMB, et al. Lipid profile and risk of cardiovascular disease in adult transgender men receiving cross-sex hormone therapy: A systematic review. Nutr Rev. 2023;81:1310–20. doi: 10.1093/nutrit/nuad003. PMID: 36779324.

16 Okano SHP, Braga GC, Cantelli DAL, Filho LASP, Brito LGO, Lara LADS. Effect of testosterone formulations on hematocrit in transgender individuals: A systematic review. Andrology. 2025;13:422–30. doi: 10.1111/andr.13695. PMID: 39011565.

17 White Hughto JM, Reisner SL. A systematic review of the effects of hormone therapy on psychological functioning and quality of life in transgender individuals. Transgend Health. 2016;1:21–31. doi: 10.1089/trgh.2015.0008. PMID: 27595141. PMCID: PMC5010234.

18 Connolly D, Gilchrist G. Prevalence and correlates of substance use among transgender adults: A systematic review. Addict Behav. 2020;111:106544. doi: 10.1016/j.addbeh.2020.106544. PMID: 32717497.

19 Rowniak S, Bolt L, Sharifi C. Effect of cross-sex hormones on the quality of life, depression and anxiety of transgender individuals: A quantitative systematic review. JBI Database System Rev Implement Rep. 2019;17:1826–54. doi: 10.11124/JBISRIR-2017-003869. PMID: 31021971.

20 Wernick JA, Busa S, Matouk K, Nicholson J, Janssen A. A systematic review of the psychological benefits of gender-affirming surgery. Urol Clin North Am. 2019;46:475–86. doi: 10.1016/j.ucl.2019.07.002. PMID: 31582022.

21 O'Leary KB, Marcelli M. Mental health outcomes among transgender veterans and active-duty service members in the United States: A systematic review. Fed Pract. 2022;39:418–25. doi: 10.12788/fp.0321. PMID: 36744015. PMCID: PMC9896366.

22 Delgado-Ruiz R, Swanson P, Romanos G. Systematic review of the long-term effects of transgender hormone therapy on bone markers and bone mineral density and their potential effects in implant therapy. J Clin Med. 2019;8:784. doi: 10.3390/jcm8060784. PMID: 31159456. PMCID: PMC6616494.

23 Millward CP, Keshwara SM, Islim AI, Jenkinson MD, Alalade AF, Gilkes CE. Development and growth of intracranial meningiomas in transgender women taking cyproterone acetate as gender-affirming progestogen therapy: A systematic review. Transgend Health. 2022;7:473–83. doi: 10.1089/trgh.2021.0025. PMID: 36644118. PMCID: PMC9829145.

24 Spanos C, Bretherton I, Zajac JD, Cheung AS. Effects of gender-affirming hormone therapy on insulin resistance and body composition in transgender individuals: A systematic review. World J Diabetes. 2020;11:66–77. doi: 10.4239/wjd.v11.i3.66. PMID: 32180895. PMCID: PMC7061235.

25 Panday P, Ejaz S, Gurugubelli S, Prathi SK, Palou Martinez Y, Arrey Agbor DB, et al. Incidence of type 2 diabetes mellitus in transgender individuals undergoing gender affirming hormonal therapy: A systematic review. Cureus. 2024;16:e58137. doi: 10.7759/cureus.58137. PMID: 38738018. PMCID: PMC11088936.

26 Jones BA, Arcelus J, Bouman WP, Haycraft E. Sport and transgender people: A systematic review of the literature relating to sport participation and competitive sport policies. Sports Med. 2017;47:701–16. doi: 10.1007/s40279-016-0621-y. PMID: 27699698. PMCID: PMC5357259.

27 Hartley RL, Stone JP, Temple-Oberle C. Breast cancer in transgender patients: A systematic review. Part 1: Male to female. Eur J Surg Oncol. 2018;44:1455–62. doi: 10.1016/j.ejso.2018.06.035. PMID: 30087072.

28 Stone JP, Hartley RL, Temple-Oberle C. Breast cancer in transgender patients: A systematic review. Part 2: Female to male. Eur J Surg Oncol. 2018;44:1463–8. doi: 10.1016/j.ejso.2018.06.021. PMID: 30037639.

29 Joint R, Chen ZE, Cameron S. Breast and reproductive cancers in the transgender population: a systematic review. BJOG. 2018;125:1505–12. doi: 10.1111/1471-0528.15258. PMID: 29706033.

30 McFarlane T, Zajac JD, Cheung AS. Gender-affirming hormone therapy and the risk of sex hormone-dependent tumours in transgender individuals-A systematic review. Clin Endocrinol (Oxf). 2018;89:700–11. doi: 10.1111/cen.13835. PMID: 30107028.

31 Fledderus AC, Gout HA, Ogilvie AC, van Loenen DKG. Breast malignancy in female-to-male transsexuals: systematic review, case report, and recommendations for screening. Breast. 2020;53:92–100. doi: 10.1016/j.breast.2020.06.008. PMID: 32679529. PMCID: PMC7375644.

32 Harper J, O'Donnell E, Sorouri Khorashad B, McDermott H, Witcomb GL. How does hormone transition in transgender women change body composition, muscle strength and haemoglobin? Systematic review with a focus on the implications for sport participation. Br J Sports Med. 2021;55:865–72. doi: 10.1136/bjsports-2020-103106. PMID: 33648944. PMCID: PMC8311086.

33 Gurrala RR, Kumar T, Yoo A, Mundinger GS, Womac DJ, Lau FH. The impact of exogenous testosterone on breast cancer risk in transmasculine individuals. Ann Plast Surg. 2023;90:96–105. doi: 10.1097/SAP.0000000000003321. PMID: 36534108.

34 Totaro M, Palazzi S, Castellini C, Parisi A, D'Amato F, Tienforti D, et al. Risk of venous thromboembolism in transgender people undergoing hormone feminizing therapy: A prevalence meta-analysis and meta-regression study. Front Endocrinol (Lausanne). 2021;12:741866. doi: 10.3389/fendo.2021.741866. PMID: 34880832. PMCID: PMC8647165.

35 Tienforti D, Castellini C, Di Giulio F, Spagnolo L, Muselli M, Fisher AD, et al. Metabolic features of assigned female at birth transgender people on gender-affirming hormone therapy: A meta-analysis. Transgend Health. 2024;9:466–83. doi: 10.1089/trgh.2023.0040. PMID: 39735373. PMCID: PMC11669637.

36 Cotaina M, Peraire M, Boscá M, Echeverria I, Benito A, Haro G. Substance use in the transgender population: A meta-analysis. Brain Sci. 2022;12:366. doi: 10.3390/brainsci12030366. PMID: 35326322. PMCID: PMC8945921.

37 Klaver M, Dekker MJHJ, de Mutsert R, Twisk JWR, den Heijer M. Cross-sex hormone therapy in transgender persons affects total body weight, body fat and lean body mass: A meta-analysis. Andrologia. 2017;49:e12660. doi: 10.1111/and.12660. PMID: 27572683.

38 Maraka S, Singh Ospina N, Rodriguez-Gutierrez R, Davidge-Pitts CJ, Nippoldt TB, Prokop LJ, et al. Sex steroids and cardiovascular outcomes in transgender individuals: A systematic review and meta-analysis. J Clin Endocrinol Metab. 2017;102:3914–23. doi: 10.1210/jc.2017-01643. PMID: 28945852.

39 Khan J, Schmidt RL, Spittal MJ, Goldstein Z, Smock KJ, Greene DN. Venous thrombotic risk in transgender women undergoing estrogen therapy: A systematic review and metaanalysis. Clin Chem. 2019;65:57–66. doi: 10.1373/clinchem.2018.288316. PMID: 30602475.

40 van Zijverden LM, Wiepjes CM, van Diemen JJK, Thijs A, den Heijer M. Cardiovascular disease in transgender people: a systematic review and meta-analysis. Eur J Endocrinol. 2024;190:S13–S24. doi: 10.1093/ejendo/lvad170. PMID: 38302717.

41 Tienforti D, Pastori D, Barbonetti A. Effects of gender affirming hormone therapy with testosterone on coagulation and hematological parameters in transgender people assigned female at birth: A systematic review and meta-analysis. Thromb Res. 2024;236:170–8. doi: 10.1016/j.thromres.2024.02.029. PMID: 38457996.

42 Gosiker B, Moutchia J, Nguyen N, Getahun D, Goodman M. Changes in blood lipids following initiation of gender affirming hormone therapy: A systematic review and meta-analysis. J Clin Transl Endocrinol. 2024;36:100349. doi: 10.1016/j.jcte.2024.100349. PMID: 38737626. PMCID: PMC11087959.

43 Rytz CL, Miranda KT, Ronksley PE, Saad N, Raj SR, Somayaji R, et al. Association between serum estradiol and cardiovascular health among transgender adults using gender-affirming estrogen therapy. Am J Physiol Heart Circ Physiol. 2024;327:H340–H348. doi: 10.1152/ajpheart.00151.2024. PMID: 38578239.

44 Rahman SU, Manasrah N, Kumar N, Hamza M, Sharma A, Patel N, et al. Impact of gender-affirming hormonal therapy on cardiovascular risk factors in transgender health: An updated meta-analysis. JACC Adv. 2024;3:101265. doi: 10.1016/j.jacadv.2024.101265. PMID: 39309657. PMCID: PMC11414688.

45 Nobili A, Glazebrook C, Arcelus J. Quality of life of treatment-seeking transgender adults: A systematic review and meta-analysis. Rev Endocr Metab Disord. 2018;19:199–220. doi: 10.1007/s11154-018-9459-y. PMID: 30121881. PMCID: PMC6223813.

46 Singh-Ospina N, Maraka S, Rodriguez-Gutierrez R, Davidge-Pitts C, Nippoldt TB, Prokop LJ, et al. Effect of sex steroids on the bone health of transgender individuals: A systematic review and meta-analysis. J Clin Endocrinol Metab. 2017;102:3904–13. doi: 10.1210/jc.2017-01642. PMID: 28945851.

47 Fighera TM, Ziegelmann PK, Rasia da Silva T, Spritzer PM. Bone mass effects of cross-sex hormone therapy in transgender people: Updated systematic review and meta-analysis. J Endocr Soc. 2019;3:943–64. doi: 10.1210/js.2018-00413. PMID: 31020058. PMCID: PMC6469959.

48 Tienforti D, Marinelli L, Vervalcke J, Spagnolo L, Antolini F, Bichiri A, et al. Short-term changes in bone metabolism among transgender men starting gender-affirming hormone therapy: A systematic review and meta-analysis. Calcif Tissue Int. 2024;115:624–35. doi: 10.1007/s00223-024-01296-z. PMID: 39356296. PMCID: PMC11531450.

49 Ignacio KHD, Diestro JDB, Espiritu AI, Pineda-Franks MC. Stroke in male-to-female transgenders: A systematic review and meta-analysis. Can J Neurol Sci. 2022;49:76–83. doi: 10.1017/cjn.2021.54. PMID: 33766179.

50 Krupka E, Curtis S, Ferguson T, Whitlock R, Askin N, Millar AC, et al. The effect of gender-affirming hormone therapy on measures of kidney function: A systematic review and meta-analysis. Clin J Am Soc Nephrol. 2022;17:1305–15. doi: 10.2215/CJN.01890222. PMID: 35973728. PMCID: PMC9625103.

51 Corso G, Gandini S, D'Ecclesiis O, Mazza M, Magnoni F, Veronesi P, et al. Risk and incidence of breast cancer in transgender individuals: a systematic review and meta-analysis. Eur J Cancer Prev. 2023;32:207–14. doi: 10.1097/CEJ.0000000000000784. PMID: 36789830.

52 Liu C, Shahid M, Yu Q, Orra S, Ranganath B, Chao JW. Complications following breast augmentation in transfeminine individuals: A systematic review and meta-analysis. Plast Reconstr Surg. 2024;153:1240–51. doi: 10.1097/PRS.0000000000010691. PMID: 37189242.

53 Tienforti D, Savignano G, Spagnolo L, Di Giulio F, Baroni MG, Barbonetti A. Biochemical liver damage during gender affirming therapy in trans adults assigned female at birth: a meta-analysis. J Endocrinol Invest. 2025;48:161–71. doi: 10.1007/s40618-024-02418-y. PMID: 38909133. PMCID: PMC11729134.

54 Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, et al. ERS Global Lung Function Initiative. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. Eur Respir J. 2012;40:1324–43. doi: 10.1183/09031936.00080312. PMID: 22743675. PMCID: PMC3786581.

55 LoMauro A, Aliverti A. Sex and gender in respiratory physiology. Eur Respir Rev. 2021;30:210038. doi: 10.1183/16000617.0038-2021. PMID: 34750114. PMCID: PMC9488190.

56 Lippmann J, Lawrence C, Fock A. Compressed gas diving fatalities in Australian waters 2014 to 2018. Diving Hyperb Med. 2023;53:76–84. doi: 10.28920/dhm53.2.76-84. PMID: 37365124. PMCID: PMC10584389.

57 Banham N, Smart D, Wilmshurst P, Mitchell SJ, Turner MS, Bryson P. Joint position statement on immersion pulmonary oedema and diving from the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC) 2024. Diving Hyperb Med. 2024;54:344–9. doi: 10.28920/dhm54.4.344-349. PMID: 39675743. PMCID: PMC11779524.

58 Hippisley-Cox J, Coupland C, Brindle P. Development and validation of QRISK3 risk prediction algorithms to estimate future risk of cardiovascular disease: prospective cohort study. BMJ. 2017;357:j2099. doi: 10.1136/bmj.j2099. PMID: 28536104. PMCID: PMC5441081.

59 Hohman MH, Teixeira J. Transgender surgery of the head and neck. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan. PMID: 33760488.

60 Van Remoortel H, De Buck E, Compernolle V, Deldicque L, Vandekerckhove P. The effect of a standard whole blood donation on oxygen uptake and exercise capacity: a systematic review and meta-analysis. Transfusion. 2017;57:451–62. doi: 10.1111/trf.13893. PMID: 27807869.

61 Pougnet R, Loddé B, Henckes A, Dewitte JD, Pougnet L. Can a transgender person be an occupational diver? Demonstration from a case report. Int Marit Health. 2017;68:211–4. doi: 10.5603/IMH.2017.0039. PMID: 29297572.

Conflicts of interest and funding: nil

Submitted: 2 September 2024
Accepted after revision: 29 November 2025

Outcomes in the treatment of inner ear decompression sickness with hyperbaric oxygen therapy, a systematic review

Rosanna J Stokes[1,2], Jonathan Marsden[1], Doug Watts[2], Gary Smerdon[2], Stephen D Hall[1], Lisa Bunn[1]

[1] *Brain Research and Imaging Centre, University of Plymouth, Plymouth, UK*
[2] *DDRC Healthcare, Plymouth Science Park, Plymouth, UK*

Corresponding author: *Dr Rosanna J Stokes, DDRC Healthcare, Plymouth Science Park, Plymouth, UK*
ORCiD: *0009-0006-4501-0634*
rosanna.stokes@ddrc.org

Keywords
Diving; Sharpened Romberg test; Review article; Vertigo; Vestibular

Abstract
(Stokes RJ, Marsden J, Watts D, Smerdon G, Hall SD, Bunn L. Outcomes in the treatment of inner ear decompression sickness with hyperbaric oxygen therapy, a systematic review. Diving and Hyperbaric Medicine. 2026 31 March;56(1):71–82. doi: 10.28920/dhm56.1.71-82. PMID: 41875444.)
Introduction: The primary objective of this review was to evaluate the effectiveness of hyperbaric oxygen therapy (HBOT) in the treatment of inner ear decompression sickness (IEDCS). Secondary objectives were to summarise the diver characteristics, HBOT parameters and outcome measures.
Methods: All descriptive observational study designs including case series and individual case reports involving divers suffering IEDCS treated with HBOT were included. PubMed, Scopus, CINAHL and EMBASE were used to search for texts reporting the outcome for divers treated with HBOT. Eligible studies were appraised by two independent reviewers and any disagreements resolved via the third reviewer. Data were extracted using standardised tools and narrative synthesis was undertaken.
Results: 3,683 records were identified with 24 included in the final review representing 539 cases of IEDCS. Mean age was 44, average (in-water) dive depth 29 metres of seawater and dive duration 38 minutes. Mean onset of symptoms was 32 minutes and 74% had a right sided lesion. Only 37% had residual symptoms on discharge despite 68% showing dysfunction on laboratory testing. Follow-up duration and assessment methods were variable. Vestibular rehabilitation was underutilised and only 46% of divers went on to have patent foramen ovale (PFO) screening despite the well-established link to IEDCS.
Conclusions: A standardised method of examination and assessment of symptoms should be considered along with vestibular rehabilitation (or referral to this service). All divers should be counselled on PFO screening. A standard 3-month follow-up is recommended to allow for assessment of residual dysfunction / symptoms and discussion regarding returning to diving. Further research should focus on assessment of vestibular deficit / symptoms over time to assess efficacy of HBOT including the effects of delay to recompression and number of treatments. Laboratory testing should be utilised to determine the mechanism of injury and recovery.

Introduction

Inner ear decompression sickness (IEDCS) presents with acute vestibular symptoms (nausea, vertigo, nystagmus) ± cochlear symptoms (deafness, tinnitus) either following a dive or a change in the composition of inert gas in the breathing mixture. It is usually unilateral and can occur in isolation or as part as a more severe decompression sickness (such as a spinal decompression sickness). At least 70% of divers with IEDCS have an underlying right to left cardiac shunt / patent foramen ovale (PFO), allowing the venous bubbles formed during diving to cross into the arterial circulation, causing embolisation and risk of decompression sickness.[1]

IEDCS is particularly resistant to treatment with recompression, with divers often requiring several repeat treatments with hyperbaric oxygen therapy (HBOT) before recovery or a plateau of symptoms.

Choice of which HBOT tables may be used to treat IEDCS is often based on convention at the time but fundamentally all treatment tables for decompression illness must reach at least 284 kPa (2.8 atmospheres absolute [atm abs]) of pressure with 100% oxygen. The most widely used form of these tables is the USN 5 for mild decompression illness (symptoms must resolve within 10 minutes after reaching 284 kPa) and the USN 6/RN 62 with or without extensions for all other decompression illness. Tables involving compression to higher pressure e.g., the Comex 30 are sometimes used for more severe cases.[2] Approximately equivalent tables with alternative names are used in hyperbaric centres worldwide.

There is currently little guidance for dive physicians in the acute phase of treatment of IEDCS with regards to a standardised way to assess these patients, and indeed little in the way of guidance or support for general practitioners or ear nose throat (ENT) specialists who may be involved with these patients over the longer term. Often divers are left with residual symptoms and deficits in their balance.[3]

To determine how effective the current standards of care are in the acute phase of treatment for these divers a systematic review was undertaken focussing on rate of recovery following hyperbaric therapy, and how dive physicians quantify symptom burden during the hyperbaric treatment period, at discharge and at follow up. We considered factors that may affect treatment outcome such as number of HBOT sessions given and the time delay from symptom onset to the first recompression.

There are several case reports and case series documenting rate of recovery for divers with decompression sickness. Studies that involve inner ear decompression sickness treated with recompression with hyperbaric oxygen therapy according to either US Navy or UK Royal Navy standards will be included.

A preliminary search of PROSPERO, MEDLINE, the Cochrane Database of Systematic Reviews and the *JBI Evidence Synthesis* was conducted and no current or underway systematic reviews on the topic were identified.

REVIEW QUESTIONS

The review was designed to address the following questions.

- How do divers with IEDCS present and how is this assessed by physicians?
- How many hyperbaric treatments are given?
- What is the time delay from symptom onset to first recompression?
- What hyperbaric treatment tables are used and what proportion of divers are left with residual symptoms?
- What measures are being used to assess and manage residual symptoms in divers with IEDCS?

Methods

The review was conducted in accordance with the JBI methodology for systematic reviews of effectiveness evidence.[4] The review was registered with the PROSPERO registry: CRD42024521384.

INCLUSION CRITERIA

This review included descriptive observational study designs including case series and individual case reports.

All studies involving divers who had been diagnosed with a decompression sickness involving the inner ear were included. Any divers with an alternative inner ear diagnosis such as barotrauma or alternobaric vertigo were excluded. Studies that involved recompression with hyperbaric oxygen therapy were included with consideration of the number of treatments given and delay to recompression therapy.

Studies that reported the outcome for divers following recompression therapy were included with the anticipation that this was primarily reported as 'residual symptoms' or 'no residual symptoms'. We also reviewed how different centres / clinicians assess for recovery in this population and whether they are comparable methods.

SEARCH STATEGY

A three-step search strategy was applied for this review. First, an initial limited search of PubMed was undertaken to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a full search strategy for four databases: PubMed, Scopus, CINAHL and EMBASE (see *Appendix I). The search strategy, including all identified keywords and index terms, was adapted for each included database and/or information source. The reference list of all included sources of evidence was screened for additional studies involving case reports or case series of divers with inner ear decompression sickness.

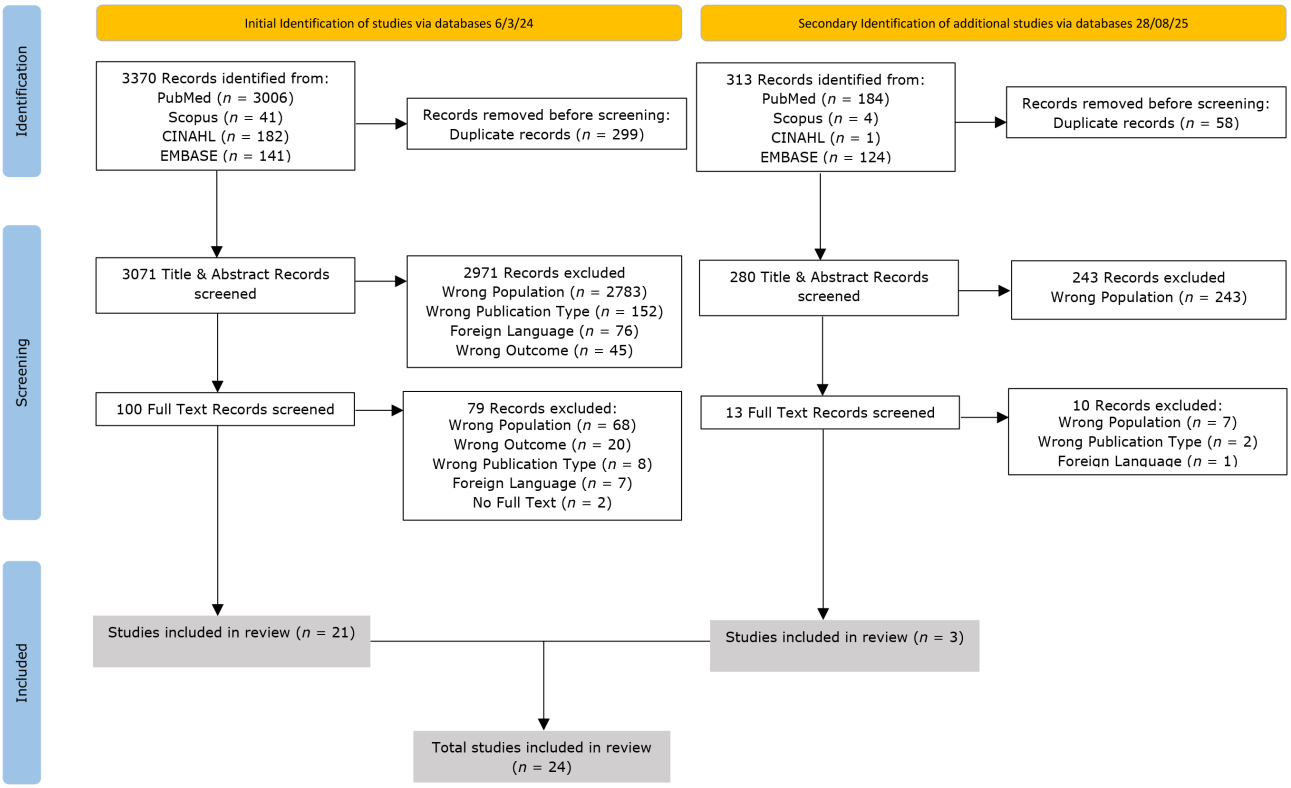
Initial search terms used included the following: ('Inner ear decompression sickness' OR 'IEDCS' OR 'Vestibular') AND ('Hyperbaric oxygen therapy' OR 'HBOT'). Only studies published in English were included.

STUDY SELECTION

Following the search, all identified citations were collated and uploaded into Rayyan[5] and duplicates removed. Following a pilot test, titles and abstracts were screened by two independent reviewers for assessment against the inclusion criteria for the review. Potentially relevant studies were retrieved in full, and their citation details imported into the JBI System for the Unified Management, Assessment and Review of Information (JBI SUMARI).[6] The full text of selected citations were assessed in detail against the inclusion criteria by two independent reviewers. Reasons for exclusion of articles at full text that did not meet the inclusion criteria were recorded. Any disagreements that arose between the reviewers at each stage of the selection process were resolved by an additional reviewer. The results of the search and the study inclusion process have been reported in full and presented in a Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram (Figure 1).[7]

*** Footnote:** Appendix I is available online on our website https://www.dhmjournal.com/index.php/journals?id=398

Figure 1
PRISMA diagram for literature search results and study selection



ASSESSMENT OF METHODOLOGICAL QUALITY

Eligible studies were critically appraised by two independent reviewers for methodological quality in the review using standardised critical appraisal instruments from JBI for case series and case reports.[8,9] Any disagreements that arose were resolved through discussion, or with a third reviewer. The results of critical appraisal were reported in narrative form and in a table. All studies, regardless of the results of their methodological quality, underwent data extraction and synthesis (where possible). GRADE evaluation was not used in this review due to the descriptive nature of the data and lack of comparative outcomes in case series / reports.

DATA EXTRACTION

Data were extracted from studies included in the review by two independent reviewers using the standardised JBI data extraction tool.

The data extracted included the study design, the demographic details of the divers, details of the provoking dive including maximum depth and breathing gas composition, the number of hyperbaric treatments, time to first recompression and the outcome; either 'residual symptoms' or 'no residual symptoms' at the end of the acute phase of treatment with hyperbaric oxygen therapy. Where this was not explicitly stated, a judgement was made based on the description of the diver post treatment.

Any disagreements that arose between the reviewers were resolved through discussion or with a third reviewer. Authors of articles were contacted to request missing or additional data, where required.

DATA SYNTHESIS

Summary data, as well as data from each individual case of IEDCS were extracted where sufficient detail was provided. This included demographic characteristics (age, gender, underlying patent foramen ovale/right to left shunt), the dive profile (depth, duration, mixed-gas use), and the treatment details (time to first recompression, number of hyperbaric treatments, method for assessing residual symptom burden, recovery outcome at time of discharge, use of vestibular rehabilitation). Results are presented for each study with the range, mean values calculated where possible. Results from all the studies were pooled to provide overall mean, range and percentage values. To evaluate whether factors such as time to recompression, age, dive depth, onset of symptoms or number of HBOT had an impact on chance of residual symptoms, all studies with sufficient details for each of these factors were pooled. Outliers were identified using box and whisker plots and removed from analysis. IMB SPSS Statistics (Version 28) was used to perform binary logistic regression with a P-value of < 0.05 used to assess significance.

Results

STUDY INCLUSION

There were 3,370 records identified in the initial search on 6/2/24. As seen in the PRISMA flow chart (Figure 1) 299 duplicates were removed. At the title and abstract screening stage 2,971 records were excluded. Some were due to the 'wrong population' (n = 2,783) with the exclusion of articles that either did not include IEDCS or were cases with concurrent disease (such as barotrauma). Some were due to the 'wrong publication' (n = 152) with exclusion of articles that were not case reports or case series. Articles with the 'wrong outcome' (n = 45) were excluded as they did not detail any treatment with recompression. Finally, articles were excluded if they were 'foreign language' (n = 76), leaving 100 articles for full text review.

After the full text review, a further 77 were excluded at this stage due to wrong population (n = 68), wrong publication type (n = 8), 'foreign language' (n = 7), 'wrong outcome' (n = 20) or no full text available (n = 2) (see *Appendix II). This process resulted in the inclusion of 21 articles.

A second search was completed on 28/08/25 with 313 new records identified, 58 duplicates were excluded. At the title and abstract screening stage 280 records were excluded due to the 'wrong population' resulting in 13 records for full text screening. Ten full text records were excluded due to 'wrong population' (n = 7), 'wrong publication type' (n = 2), or 'foreign language' (n = 1) (included in *Appendix II). This process resulted in the additional inclusion of three articles, giving a total of 24 articles.[3,10–32]

METHODOLOGICAL QUALITY

Methodological quality of the case reports (*Appendix III) was at a reasonable standard for extraction of the required information. Diver demographics and dive profiles were described. Diagnostic tests, where used, were described in varying detail. Outcome post recompression was generally reported as diver reported 'recovered' or 'not recovered'. Some articles described this in more detail with patient's residual symptoms or signs on clinical tests reported. No adverse events were reported in any of the case reports.

For the case series (*Appendix III), again methodological quality was of a reasonable quality, with clear criteria for inclusion/ exclusion. For articles including all divers with inner ear symptoms the results between divers with IEDCS and inner ear barotrauma were clearly divided. Some articles (n = 2) did not present the demographic details of the divers but did include the dive profiles, other articles with a larger number of subjects did not include details of the individual divers/dive profiles (n = 4). This missing data meant that these large cohort studies were unable to be included in the analysis of factors influencing chance of symptoms at discharge/ follow-up, therefore diminishing the reliability of the results.

CHARACTERISTICS OF INCLUDED STUDIES

The year of publication of included studies ranged from 1976 to 2024 and were from a variety of worldwide locations including USA, Central America, Europe, Australasia, Asia and South Africa (*Appendix IV). Most of the case reports and case series were from hyperbaric treatment centres (n = 20) and the rest were from ENT/ otorhinolaryngology departments (n = 4). Most articles involved recreational divers (n = 20), with others reported cases involving military divers (n = 2), commercial divers (n = 1) or hyperbaric attendants (n = 1). Some articles included all divers with inner ear symptoms however those who did not have a diagnosis of IEDCS or did not receive recompression treatment were easily identified and could be excluded from the systematic review analysis.

REVIEW FINDINGS

From the 24 articles, 539 cases of IEDCS that had been treated with recompression were included. Details of the diver demographics and initial presentation are shown in Table 1, with a summary infographic shown in Figure 2. For those articles in which demographic details were included (n = 22) mean age was 44 (range 20–77). Eighty-five percent of the divers were male and 15% female. For those articles in which the dive profiles were described (n = 20), mean dive depth was 32 metres of seawater (msw) (range 7–198) and mean dive time was 39 minutes (range 15–240). When looking at only the in-water cases of IEDCS (excluding hyperbaric chamber induced IEDCS) the mean depth and time was 29 msw (range 7–122) and 38 minutes (range 15–180) respectively.

In articles where the breathing mixture had been detailed (n = 14), 238 divers (79%) were breathing air, 38 (13%) nitrox, 16 (5%) heliox, and 10 (3%) trimix.

Mean onset of symptoms was 32 minutes after surfacing (range 0–1,140). Sixty five percent of divers had purely vestibular symptoms, 23% cochleovestibular, and 12% purely cochlear symptoms. Twelve articles included an assessment of the laterality of the lesion and of the 213 cases of IEDCS, 159 (74%) had a right sided lesion and 53 (25%) had a left sided lesion. Only one case was reported as bilateral. Sixty-two percent of divers presented with purely IEDCS symptoms whereas 38% of cases were associated with other symptoms of decompression illness.

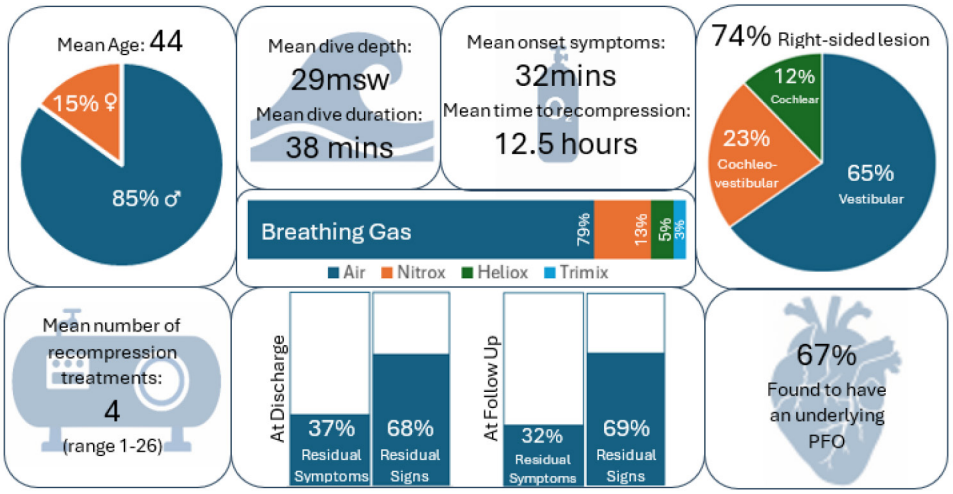
*** Footnote:** Appendix II, III and IV are available online on our website https://www.dhmjournal.com/index.php/journals?id=398

Table 1

Cases of inner ear DCS treated with hyperbaric oxygen demographics, diving, and initial presentation; means are presented with standard deviations (SD) or ranges; A – Air; C – Cochlear; CV – Cochleovestibular; F – Female; H – Heliox; I – Isolated; M – Male; N – Nitrox; N/A – not available; NI – Not isolated; Rec – Recreational diver; Tec – Technical diver; T – Trimix; V – Vestibular

Ref	*n*	Mean age	Gender	Mean depth (metres)	Mean duration (mins)	Breathing gas	Cochlear/ vestibular	Side of lesion	Isolated / non– isolated symptoms	Mean symptom latency (mins)
22	17	–	–	114 (21–198)	84 (15–240)	3 A, 14 H	5 C, 6 V, 6 CV	–	N/A	18 (0–206)
10	1	55	1M	14	90	1 A	1 CV	1 Left	1 I	5
11	115	44 (SD 11)	99 M, 16 F	41 (SD 12)	38 (SD 13)	110 A, 2 N, 3 T	7 C, 8 V, 20 CV	92 Right 23 Left	98 I, 17 NI	Median 20 (0–00)
23	1	51	1 M	50	60	1 N	1 V	1 Right	1 NI	N/A
3	99	48 (SD 11)	82 M, 17 F	37	42	–	5 C, 78 V, 16 CV	–	88 I, 11 NI	30 (8–60)
24	33	46 (31–61)	31 M, 2 F	37 (15–78)	43	22 A, 5 N, 6 T	1 C, 19 V, 13 CV	–		30 (0–120)
12	2	21 (20–21)	2 M	9	40	–	2 V	–		255 (150–360)
13	2	30	2 M	41 (32–50)	50 (35–65)	–	2 CV	2 Right	2 I	15
25	6	–	–	36 (25–55)	55 (35–65)	5 A, 1 T	1 C, 3 V, 2 CV	–	6 I	–
26	14	–	–	–	–	–	1 C, 8 V, 5 CV	–	13 I, 1 NI	–
14	2	36 (33–39)	1 M, 1 F	16 (7–24)	35 (25–45)	2 A	2 V	–	2 I	90 (0–180)
15	1	47	1 M	50	67	1 A	1 CV	1 Left	1 I	10
27	89	38 (31–44)	67 M, 22 F	Tec Median 45 (33–75) Rec Median 27 (18–34)	Tec Median 80 (56–115) Rec Median 40 (26–52)	45 A, 26 N	6 C, 72 V, 11 CV	18 Right, 4 Left 67 Unknown	16 I, 17 NI	–
28	24	45 (25–72)	22 M, 2 F	24 (10–62)	43 (15–125)	21 A, 3 N	3 C, 15 V, 6 CV	–	2 NI	89 (0–1140)
16	1	30	1 M	7	30	–	1 V	–	1 I	–
29	26	36 (22–69)	26 M	35 (15–122)	45 (22–180)	–	4 C, 8 V, 14 CV	18 Right, 8 Left	12 I, 14 NI	30 (0–120)
17	1	24	1 M	18	37	1 A	1 CV	1 Left	1 I	16
30	61	47 (24–75)	47 M, 14 F	–	–	–	28 C, 24 V, 9 CV	–	–	–
18	1	22	1 M	25	40	–	1 CV	1 Right	1 I	60
19	1	40	1 M	22	45	1 A	1 V	–	1 NI	20
31	11	40 (24–69)	11 M	32 (SD 13)	35 (SD–12)	–	3 C, 3 V, 5 CV	7 Right, 3 Left 1 Bilateral	11 Isolated	45 (5–300)
32	28	46 (20–77)	28 M	28 (15–61)	45 (25–180)	26 A, 2 H	19 V, 9 CV	16 Right, 12 Left	23 I, 5 NI	74 (10–960)
20	2	28 (25–31)	2 F	–	–	–	2 V	1 Right, 1 Unknown	1 I, 1 NI	240 (180–300)
21	1	33	1 M	27	37	1 N	1 V	–	1 NI	30

Figure 2
Infographic summarising key findings presented in Table 1



Details of the recompression treatment, assessment methods used, and outcome are shown in Table 2. Mean time from onset of symptoms to recompression treatment was 12.5 hours. Of the 451 cases in which the initial treatment table was described, 183 (41%) had a USN 6 / RN62, 166 (37%) had a USN 5, and (15%) had a Comex 30. The remaining 35 (8%) had 'other' tables. The mean number of recompression treatments was 4 (1–26).

When considering treatment outcome most articles reported whether patients had residual symptoms on discharge. Of 331 cases, 124 divers (37%) had residual symptoms, with 207 divers (63%) asymptomatic. However, few articles mentioned clinical/ laboratory examinations on discharge. Of those which did (63 cases), 43 (68%) had signs of either cochlear or vestibular dysfunction.

When considering longer-term follow-up there was little consistency in follow up periods, ranging from one week to 10 years. Of the 239 cases who had a follow-up assessment, 76 divers (32%) had residual symptoms. Of the 88 cases that had a clinical/ laboratory examination at follow-up, 61 (69%) had signs of either cochlear and/or vestibular dysfunction. Of this cohort of divers who had undergone laboratory testing with dysfunction identified, 23 cases also had the presence/ absence of symptoms described with 16 (70%) symptomatic.

The methods of assessment for IEDCS varied from simple bedside tests for nystagmus and postural stability (mentioned in 21 of the 24 articles) to full neuro-otological laboratory testing (14 of the 24 articles). Those studies based in ENT / otolaryngology departments had more comprehensive investigation when compared to hyperbaric centres, as expected due to the availability of specialist equipment and expertise. Three articles used scoring systems or questionnaires as patient outcome measures. Lindfors 2021 and Smerz 2007 used functional scoring systems whilst Gempp 2016 used the European Evaluation Vertigo Scale (EEV).[3,27,32]

Age, depth of the incident dive and time of onset of symptoms had no significant influence on the chance of symptoms at discharge or follow up. Time to recompression had no impact on the chance of symptoms at discharge but did show a relationship with chance of symptoms at follow-up ($R^2 = 0.42$, $P = 0.007$). The number of recompression treatments also showed a relationship to the chance of symptoms at discharge ($R^2 = 0.82$), $P < 0.001$), but not at follow-up ($R^2 = 0.26$, $P = 0.258$).

Of the 245 divers that had PFO testing via either transcranial doppler or bubble echocardiography, 165 (67%) had a PFO detected.

Discussion

HOW DO DIVERS WITH IEDCS PRESENT AND HOW IS THIS ASSESSED BY PHYSICIANS?

Diver demographics

Mean age (44 years old) was higher than the predominant age range for scuba divers (20–29 years old) reported by PADI Worldwide[33] however divers undertaking new certifications with PADI are a slightly different demographic to those diving as a regular sport or for occupation therefore the age disparity is not wholly unexpected. There were few cases of female divers reported, likely due to the historic male predominance in scuba diving (only nine of the 24 articles in the systematic review were within the last 10 years).

Dive details

When looking at purely in-water incidents of IEDCS with hyperbaric chamber / experimental incidents excluded, the mean dive depth and duration are within recreational limits and the gas used was mainly air or nitrox. This is as expected, as the presence of an underlying PFO represents a significant

Table 2

Recompression treatment and outcomes; BRA – brainstem response audiometry; CT – computed tomography; ENG – electronystagmography; EOG – electrooculography; HBOT – hyperbaric oxygen treatment; MRI – magnetic resonance imaging; N/A – not available; Rec – Recreational diver; SHA – sinusoidal harmonic acceleration; Tec – Technical diver; USN – United States Navy; Vest rehab – vestibular rehabilitation; VNG – videonystagmography

Ref	Mean time to HBOT (hours)	Treatment table	Mean No. HBOT	Symptoms at discharge	Symptoms at follow up	Methods of assessment	Vest. rehab	PFO testing
22	1 (0–6)	17 Other	1	6 of 17 symptomatic	N/A	Nystagmus, Audiogram	No	N/A
10	5	1 USN6	7	1 of 1 symptomatic 1 of 1 signs	1 of 1 symptomatic (3 months)	Nystagmus, Rinne/Weber, Postural instability (Gait, Romberg's), MRI scan	Yes	0/1 +ve
11	4 (0.5–35)	76 USN5 13 USN6 26 Comex30	Median 5 (2–11)	12 of 58 symptomatic 34 of 50 signs	N/A	Nystagmus (Frenzel's), Postural stability (Romberg, Fukuda, Tandem Walk), Lab tests (Audiometry, ENG, calorics, posturography)	No	95/115 +ve 20/115 -ve
23	2	1 USN5	1	1 of 1 symptomatic 1 of 1 signs	1 of 1 symptomatic 1 of 1 signs (6 weeks)	Nystagmus (Frenzels), Postural stability (Romberg's), Lab tests (ENG, caloric, tympanometry, audiometry)	Yes	0/1 +ve
3	Median 3	77 USN5 12 USN6 10 Other	N/A	N/A	25 of 99 symptomatic 39 of 58 signs (3 months)	Laboratory tests (audiometry, posturography, VNG, caloric), Postural stability (Gait)	Yes	N/A
24	6 (1–36)	1 USN5 21 USN6 11 Comex30	9 (1–20)	26 of 33 symptomatic	10 of 33 symptomatic (3 months)	Postural stability (Romberg, Unterberger)	No	3/33 Not tested 24/30 +ve 6/30 -ve
12	NA	2 USN6	2 (1–2)	0 of 2 symptomatic	0 of 2 symptomatic (6 weeks)	'Physical examination', 'Laboratory studies', CT Head	No	0/2 +ve
13	1.5	N/A	1.5 (1–10)	0 of 2 symptomatic	0 symptomatic 0 signs (2 months)	Postural stability (Romberg), Lab tests (Audiometry, Tympanometry, Caloric, Auditory brainstem responses, MRI)	No	1/1 +ve
25	10 (1.5–24)	N/A	N/A	2 of 6 symptomatic 5 of 6 signs	N/A	Lab. tests (tympanometry, audiometry, BRA, caloric), MRI scans	Yes	8/9 +ve 1/9 -ve
26	41 (1.5–240)	N/A	N/A	N/A	10 of 14 symptomatic 11 of 14 signs (1 week – 36 months)	Laboratory tests (audiometry, energy video-oculography)	No	11/14 +ve 3/14 -ve
14	N/A	2 Other	1	0 of 2 symptomatic	N/A	N/A	No	N/A
15	4.5	1 RN62	7	0 of 1 symptomatic	0 of 1 symptomatic 0 of 1 signs (4 weeks)	Nystagmus, Fistula test, Rinne/Weber Postural stability (Romberg)	No	1/1 Not tested

Table 2 continued.

27	Tec. Median 17 (6–24) Rec. Median 24 (7–60)	15 USN5 71 USN6 3 Other	Median 2 (1–5)	29 of 89 symptomatic	4 of 49 symptomatic (N/A)	Postural stability	No	N/A
28	49 (4–216)	23 USN6 1 Other	6 (1–15)	10 of 24 symptomatic	N/A	Nystagmus, Audiometry (46%)	No	13/23 Not tested 6/10 +ve 4/10 -ve
16	12	1 RN62	2	0 of 1 symptomatic	N/A	Postural stability (Gait, Romberg, Unterberger), Rinne/Weber, Fistula test, Lab tests (Audiometry)	No	N/A
29	24 (1–336)	22 USN6 2 Comex30 2 Other	5 (1–12)	NA	21 of 26 symptomatic (1 week – 4.5 years)	Tuning fork, Nystagmus (Frenzel's), Head thrust, Lab tests (Audiometry, EOG, calorics, SHA, ABR), CT/MRI head	No	N/A
17	22	1 USN6	2	1 of 1 symptomatic 1 of 1 signs	NA	Nystagmus, Postural stability (Gait), MRI scans, Laboratory tests (caloric)	Yes	1/1 +ve
30	N/A	N/A	N/A	27 of 61 symptomatic	N/A	Nystagmus, Lab tests (VNG, audiometry)	No	19/61 +ve 42/61 -ve
18	1.5	1 USN6	1	0 of 1 symptomatic 1 of 1 signs	0 of 1 symptomatic 0 of 1 signs (1 week)	Nystagmus, Postural stability (Romberg, gait), Rinne/Weber, Fistula test, Lab tests (audiometry, tympanometry)	No	N/A
19	10	1 USN6	4	0 of 1 symptomatic	N/A	CT scanning, Laboratory tests (audiometry, tympanometry), Postural stability (Romberg's, gait)	No	1/1 +ve
31	12.9 (3–48)	11 USN6	N/A	N/A	4 of 11 symptomatic 10 of 11 signs (22–119 months)	Tuning fork, nystagmus (Frenzel's), head thrust, Postural stability (Romberg's, tandem walk, stepping), Laboratory tests (Audiometry, ENG, caloric, SHA, posturography)	No	N/A
32	9 (2–35)	28 Other	6 (1–26)	9 of 28 symptomatic	N/A	Postural stability (Rombergs, Fujuda, Unterberger, heel-toe), Nystagmus (Frenzels), Rinne/Weber, Lab tests (ENG, audiogram, tympanography)	No	25 not tested 1/1 +ve
20	60 (26–96)	1 USN 5 1 USN 6	1	0 of 2 symptomatic 0 of 2 signs	N/A	Postural stability (Fukuda, tandem walk), Lab tests (audiometry, tympanometry, ENG, SHA)	No	N/A
21	4	1 RN62	6	0 of 1 symptomatic 0 of 1 signs	N/A	Nystagmus, Postural stability (Romberg's, gait)	No	1/1 +ve

risk factor in the majority of IEDCS cases,[1] allowing bubble shunting to occur within table limits. The 1976 Farmer paper included US Navy experimental dives with much deeper profiles (majority were 100–170 msw) and results should be interpreted with caution, however it is valuable in demonstrating the danger of such provocative profiles.[22]

Symptom presentation

Time from the end of the dive to the onset of symptoms had a large range, as often seen in clinical practice. The mean onset of symptoms of 32 minutes post dive correlates with other studies that include a broader range of decompression sickness cases. A large series in China of 5,278 cases had 2,548 divers (48%) with symptom onset within the first 30 minutes post-dive, and 1,648 (31%) within 30 minutes to one hour post-dive.[34]

Laterality of the lesion to the right in IEDCS supports prior findings in the wider literature and is thought to be due to the anatomical asymmetry in the diameter of the vertebral arteries, with the right often narrower than the left and therefore more prone to embolisation.[35,36] However, the focus of pathology in IEDCS, whether it affects the end organ and / or nerve and whether there is a predilection for certain structures (e.g., semicircular canals / otoliths) is unclear.

Clinical assessment

There was little detail in how divers were assessed at the hyperbaric centres but a basic bedside assessment of eye movements for nystagmus and assessment of gait / Romberg's for postural stability did seem to be routinely used. The lack of detailed vestibular assessment is due to the lack of specialist vestibular equipment and expertise at these sites. The clinical head impulse test, which is a simple bedside test used to detect the presence and laterality of a peripheral vestibular lesion first described in 1988[37] was not mentioned by any of the articles.

HOW MANY HYPERBARIC TREATMENTS ARE GIVEN?

The mean number of recompression treatments was 4 (range 1–26). In the large series in China including all cases of decompression illness 97% of the patients had only one recompression treatment but there was a large range of additional sessions (1–100+) for those who had incomplete/no recovery after the first recompression.[34] A Geneva based case series reported a median of five sessions (range 1–55) for their severe cases, significantly higher than their mild cases (median 2, range 1–4).[38] It can be inferred that IEDCS symptoms are more likely to persist after the first recompression therapy when compared to all decompression cases and that a similar number of repeated sessions are required to those with severe decompression sickness (e.g., spinal).

WHAT IS THE TIME DELAY FROM SYMPTOM ONSET TO FIRST RECOMPRESSION?

Time from onset of symptoms to recompression therapy had a wide range from 0 to 336 hours likely representing the variances in geographical location as well as access to recompression services and diver awareness of symptoms of decompression sickness. In the large case series in China, they had a median time delay of nine hours (1–204 hours) reporting that many divers failed to recognise that their symptoms were decompression sickness or were reluctant to seek treatment.[34]

WHAT HYPERBARIC TREATMENT TABLES ARE USED AND WHAT PROPORTION OF DIVERS ARE LEFT WITH RESIDUAL SYMPTOMS?

Choice of dive tables are often institution / region specific. The Diving Medical Advisory Committee (DMAC) advises that following air or nitrox dives to 50 msw almost all cases of decompression illness can be treated with a 284 kPa (18 msw) table, i.e., a USN 6 or RN 62. However, IEDCS with only partial improvement during initial compression may benefit from a Comex 30 table.[39]

The USN 5 table is a short 284 kPa (18 msw) table recommended for pain-only decompression sickness therefore deeming it an inadequate treatment for IEDCS.[40] It is unclear why it was used in such a high proportion in these studies (37%); however, it may have been due to mild symptoms, or resolution of symptoms at treatment pressure.

When considering residual symptoms, IEDCS appears to be quite resistant to hyperbaric therapy. Studies including other types of decompression illness show varying resolution rates with severity of decompression illness correlating with outcome.[34,38] As there is no consistent way of assessing or grading the severity of symptoms in IEDCS the studies lack sufficient detail to understand if this is also the case in IEDCS. Review of patient reported outcomes vs vestibular laboratory testing outcomes showed that although around two thirds of patients have signs of vestibular dysfunction only one third report residual symptoms. This mismatch is felt to reflect central compensation which is a known phenomenon that occurs in peripheral vestibular disorders and involves processes including adaptation, sensory substitution and habituation to allow the brain to adjust to the abnormal and asymmetric vestibular function.[41]

Increasing age has been identified as a risk factor for decompression illness and risk of incomplete recovery[42] however no correlation was seen in this review. There was also no statistically significant correlation between depth of the incident dive or time of onset of symptoms and the chance of symptoms at discharge / follow-up.

Some relationship was seen between time to recompression and the chance of symptoms at follow-up ($R^2 = 0.42$,

$P = 0.007$). There is little consistency of published data on the effect of delay to recompression and long-term outcomes. Studies have shown that delayed recompression remains effective[43] however, it is widely accepted that immediate recompression results in better outcomes (as suggested by the 1976 Farmer paper).[22] There are likely several confounding variables affecting outcome for example use of first aid normobaric oxygen which was not detailed by any of the papers.

The number of recompression treatments had a significant relationship with the chance of symptoms at discharge ($R^2 = 0.82$, $P < 0.001$). As the standard practise is to repeat HBOT until symptoms resolve or plateau it correlates that those with residual symptoms were given more HBOT sessions and may have still been symptomatic at discharge (i.e., at plateau). There was no relationship to chance of symptoms at follow up ($R^2 = 0.26$, $P = 0.258$) which may be due to the smaller population size, or improvement of symptoms post-hyperbaric therapy (between discharge and follow-up).

WHAT MEASURES ARE BEING USED TO ASSESS AND MANAGE RESIDUAL SYMPTOMS IN DIVERS WITH IEDCS?

Only three sites used functional scoring systems / patient outcome measures as an objective measure of residual symptoms. The large range in follow up period makes it difficult to compare outcomes from recompression therapy.

Five of the articles mentioned use of vestibular rehabilitation but none detailed the specifics of the exercises used, duration, or compared used vs. not used. Meta-analysis has shown that vestibular rehabilitation is effective for unilateral peripheral vestibular dysfunction (moderate to strong evidence)[44] and literature reviews have detailed the exercises that can be used in these cases.[45]

The strong correlation between PFO and IEDCS has long been established[46,47] however, only 245/529 (46%) of divers underwent PFO screening. Some of this may be due to the diver not returning to diving or it was the diver's preference not to have the test, but it is important that PFO screening is explained to divers if they present with IEDCS as it will impact on their safety if considering returning to diving.

LIMITATIONS

There are several limitations in this systematic review. Firstly, only English-language studies were included, and grey literature was not utilised. Of the studies that were included there is likely to be a high risk of publication bias due to the nature of case reports / case series.

The absence of individual diver data in several of the large case series meant that they were unable to be included in analysis of factors influencing change of symptoms at discharge / follow-up. There was also often insufficient detail in how the divers were considered recovered / not recovered which resulted in incomplete or inconsistent reporting of outcomes across the included studies.

Conclusions

Overall, there was clear description of diver demographics, dive profiles, initial presenting symptoms and treatment given. However, there was scant detail regarding the assessment of severity of symptoms and how this changed following treatments. Very few centres used objective scoring systems or questionnaires to measure symptom burden. There appeared to be a divide between articles by ENT / neuro-otologists with detailed vestibular assessment and articles by hyperbaric / dive physicians with very basic clinical review of eye movement and gait. There was little mention of vestibular rehabilitation or discussion on how residual damage may impact returning to diving. Follow-up assessments revealed that whilst only 32% of divers reported residual symptoms, 69% had signs of either cochlear and / or vestibular dysfunction. A surprisingly low number of divers had PFO investigation despite the well documented link to IEDCS, it is unknown what proportion of these divers returned to diving.

RECOMMENDATIONS FOR PRACTICE OR POLICY

A standardised method of clinical assessment by hyperbaric physicians should be considered for divers with IEDCS. Although this needs further development and research, one suggested initial approach would be: the head impulse test and assessment of nystagmus with / without Frenzel's glasses, a stopwatch timed Sharpened Romberg's test (best of three with consistency of preferred leading leg), and the dynamic gait index.[48] There is currently no appropriate validated questionnaire to provide an objective measure of symptom burden in both the acute and chronic stages of IEDCS and this should be an area of focus for future research.

Alongside this, a standardised follow-up period should be considered to allow for assessment of residual vestibular dysfunction/symptoms and discussion regarding risks involved in returning to diving. Current DMAC guidance advises a three month period without diving following IEDCS and this would be an optimum time point for this assessment.[49]

Vestibular rehabilitation (or referral to this service) should be considered at first presentation to optimise symptom recovery. All presenting divers should be counselled on the link between IEDCS and PFO and should be advised to have screening if they intend to return to diving.

RECOMMENDATIONS FOR RESEARCH

Further research to establish a standardised method of assessment of residual vestibular deficit / symptom burden pre-treatment, post-treatment and at a set follow up periods would allow for a better understanding of the time course of recovery, efficacy of hyperbaric treatment and the effects of delay to recompression and number of hyperbaric treatments. Despite detailed vestibular laboratory assessments have been undertaken in some of the IEDCS cohort, results have not provided an understanding of the mechanism of injury i.e., which parts of the vestibular system are affected and how functionality changes over time. Lastly, vestibular rehabilitation is underutilised and there is little understanding on its efficacy in divers with IEDCS; it could theoretically provide adjunctive therapy to promote recovery of vestibular impairment or adaptation to a persistent ipsilateral lesion.

References

1 Cantais E, Louge P, Suppini A, Foster PP, Palmier B. Right-to-left shunt and risk of decompression illness with cochleovestibular and cerebral symptoms in divers: case control study in 101 consecutive dive accidents. Crit Care Med. 2003;31:84–8. doi: 10.1097/00003246-200301000-00013. PMID: 12544998.

2 Antonelli C, Franchi F, Della Marta ME, Carinci A, Sbrana G, Tanasi P, et al. Guiding principles in choosing a therapeutic table for DCI hyperbaric therapy. Minerva Anestesiol. 2009;75:151–61. PMID: 19221544.

3 Gempp E, Louge P, de Maistre S, Morvan JB, Vallée N, Blatteau JE. Initial severity scoring and residual deficit in scuba divers with inner ear decompression sickness. Aerosp Med Hum Perform. 2016;87:735–9. doi: 10.3357/AMHP.4535.2016. PMID: 27634609.

4 Tufanaru C, Munn Z, Aromataris E, Campbell J, Hopp L. Chapter 3: Systematic reviews of effectiveness. In: Aromataris E, Munn Z, editors. JBI Manual for Evidence Synthesis. JBI; 2020.

5 Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210. doi: 10.1186/s13643-016-0384-4. PMID: 27919275. PMCID: PMC5139140.

6 Munn Z, Aromataris E, Tufanaru C, Stern C, Porritt K, Farrow J, et al. The development of software to support multiple systematic review types: the Joanna Briggs Institute System for the Unified Management, Assessment and Review of Information (JBI SUMARI). Int J Evid Based Healthc. 2019;17:36–43. doi: 10.1097/XEB.0000000000000152. PMID: 30239357.

7 Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. PLoS Med. 2021;18(3):e1003583. doi: 10.1371/journal.pmed.1003583. PMID: 33780438. PMCID: PMC8007028.

8 Munn Z, Barker TH, Moola S, Tufanaru C, Stern C, McArthur A, et al. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. JBI Evid Synth. 2020;18:2127–33. doi: 10.11124/JBISRIR-D-19-00099. PMID: 33038125.

9 Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetcu R, et al. Chapter 7: Systematic reviews of etiology and risk. In: Aromataris E, Munn Z, editors. JBI Manual for Evidence Synthesis. JBI; 2020.

10 Gelmann D, Jasani G, Moayedi S, Sward D. Inner ear decompression sickness in a hyperbaric chamber inside tender: a case report. Undersea Hyperb Med. 2021;48:443–8. PMID: 34847308.

11 Gempp E, Louge P. Inner ear decompression sickness in scuba divers: a review of 115 cases. Eur Arch Otorhinolaryngol. 2013;270:1831–7. doi: 10.1007/s00405-012-2233-y. PMID: 23100085.

12 Inman AL, Sorrell LP, Lagina AT. Decompression sickness responsive to delayed treatment with hyperbaric oxygen: a case report of two divers. Undersea Hyperb Med. 2020;47:551–4. doi: 10.22462/10.12.2020.3. PMID: 33227830.

13 Klingmann C, Knauth M, Ries S, Kern R, Tasman AJ. Recurrent inner ear decompression sickness associated with a patent foramen ovale. Arch Otolaryngol Head Neck Surg. 2002;128:586–8. doi: 10.1001/archotol.128.5.586. PMID: 12003593.

14 Landsberg PG. Decompression sickness in South African sport divers. S Afr Med J. 1979;55:213–7. PMID: 441853.

15 Leverment, J, Wolfers D, Kertesz T. Isolated inner ear decompression illness following a nitrogen/oxygen dive: The difficulty in differentiating inner ear decompression illness and inner ear barotrauma. SPUMS Journal. 2003;33:2–5. [cited 2025 Sep 1]. Available from: https://dhmjournal.com/images/IndividArticles/33March/Leverment_dhm.33.1.2-5.pdf.

16 McGeoch, G. Two divers with acute vertigo and loss of balance. Diving Hyperb Med. 2007;37:40–1. [cited 2025 Sep 1]. Available from: https://dhmjournal.com/images/IndividArticles/37March/McGeoch_dhm.37.1.40-41.pdf.

17 Parsons D, Utz E, Kidd G, Virgilio G. Inner ear decompression sickness after a routine dive and recompression chamber drill. Undersea Hyperb Med. 2024;51:129–35. PMID: 38985149.

18 Reissman P, Shupak A, Nachum Z, Melamed Y. Inner ear decompression sickness following a shallow scuba dive. Aviat Space Environ Med. 1990;61:563–6. PMID: 2369397.

19 Schmitz G, Aguero S. Bispectral index with density spectral array (BIS-DSA) monitoring in a patient with inner ear and cerebral decompression sickness. Diving Hyperb Med. 2024;54:237–41. doi: 10.28920/dhm54.3.237-241. PMID: 39288931. PMCID: PMC11659078.

20 Tal D, Domachevsky L, Bar R, Adir Y, Shupak A. Inner ear decompression sickness and mal de debarquement. Otol Neurotol. 2005;26:1204–7. doi: 10.1097/01.mao.0000181180.39872.80. PMID: 16272943.

21 Wilson CM, Sayer MD. Cerebral arterial gas embolism in a professional diver with a persistent foramen ovale. Diving Hyperb Med. 2015;45:124–6. PMID: 26165536. [cited 2025 Sep 1]. Available from: https://dhmjournal.com/images/IndividArticles/45June/Wilson_dhm.45.2.124-126.pdf.

22 Farmer JC, Thomas WG, Youngblood DG, Bennett PB. Inner ear decompression sickness. Laryngoscope. 1976;86:1315–27. doi: 10.1288/00005537-197609000-00003. PMID: 957843.

23 Gempp E, Lacroix G, Cournac JM, Louge P. Severe capillary leak syndrome after inner ear decompression sickness in a recreational scuba diver. J Emerg Med. 2013;45:70–3. doi: 10.1016/j.jemermed.2012.11.101. PMID: 23602149.

24 Ignatescu M, Bryson P, Klingmann C. Susceptibility of the inner ear structure to shunt-related decompression sickness. Aviat Space Environ Med. 2012;83:1145–51. doi: 10.3357/asem.3326.2012. PMID: 23316542.

25 Klingmann C, Benton PJ, Ringleb PA, Knauth M. Embolic inner ear decompression illness: correlation with a right-to-left shunt. Laryngoscope. 2003;113:1356–61. doi: 10.1097/00005537-200308000-00017. PMID: 12897559.

26 Klingmann C, Praetorius M, Baumann I, Plinkert PK. Barotrauma and decompression illness of the inner ear: 46 cases during treatment and follow-up. Otol Neurotol. 2007;28:447–54. doi: 10.1097/MAO.0b013e318030d356. PMID: 17417111.

27 Lindfors OH, Lundell RV, Arola OJ, Hirvonen TP, Sinkkonen ST, Räisänen-Sokolowski AK. Inner ear decompression sickness in Finland: a retrospective 20-year multicenter study. Undersea Hyperb Med. 2021;48(4):399–408. PMID: 34847303.

28 Mason JS, Buzzacott P, Gawthrope IC, Banham ND. A retrospective review of divers treated for inner ear decompression sickness at Fiona Stanley Hospital hyperbaric medicine unit 2014–2020. Diving Hyperb Med. 2023;53:243–50. doi: 10.28920/dhm53.3.243-250. PMID: 37718299. PMCID: PMC10735645.

29 Nachum Z, Shupak A, Spitzer O, Sharoni Z, Doweck I, Gordon CR. Inner ear decompression sickness in sport compressed-air diving. Laryngoscope. 2001;111:851–6. doi: 10.1097/00005537-200105000-00018. PMID: 11359165.

30 Quatre R, Delafosse B, Schmerber S, Soriano E. Decompression sickness of the inner ear and relationship with a patent oval foramen: a study of 61 cases. Eur Arch Otorhinolaryngol. 2024;281:4057–61. doi: 10.1007/s00405-024-08544-w. PMID: 38470517.

31 Shupak A, Gil A, Nachum Z, Miller S, Gordon CR, Tal D. Inner ear decompression sickness and inner ear barotrauma in recreational divers: a long-term follow-up. Laryngoscope. 2003;113:2141–7. doi: 10.1097/00005537-200312000-00017. PMID: 14660917.

32 Smerz R. A descriptive epidemiological analysis of isolated inner ear decompression illness in recreational divers in Hawaii. SPUMS Journal. 2007;37:2–9. [cited 2025 Sep 1]. Available from: https://dhmjournal.com/images/IndividArticles/37March/Smerz_dhm.37.1.2-9.pdf.

33 PADI. (December 2024). '2024 Worldwide Corporate Statistics'. [cited 2025 Sep 1]. Available from: https://www.padi.com/sites/default/files/documents/2025-02/PADI%20Worldwide%20Corporate%20Statistics%20%281%29.pdf.

34 Xu W, Liu W, Huang G, Zou Z, Cai Z, Xu W. Decompression illness: clinical aspects of 5278 consecutive cases treated in a single hyperbaric unit. PLoS One. 2012;7(11):e50079. doi: 10.1371/journal.pone.0050079. PMID: 23185538. PMCID: PMC3503765.

35 Seidel E, Eicke BM, Tettenborn B, Krummenauer F. Reference values for vertebral artery flow volume by duplex sonography in young and elderly adults. Stroke. 1999;30:2692–6. doi: 10.1161/01.str.30.12.2692. PMID: 10582999.

36 Yuan RY, Yip PK, Liu HM, Hwang BS, Chen RC. The value of duplex and continuous wave Doppler sonography for evaluation of the extracranial vertebral arteries: a prospective comparison with angiography. Zhonghua Yi Xue Za Zhi (Taipei). 1994;53:42–8. PMID: 8173999.

37 Halmagyi GM, Curthoys IS. A clinical sign of canal paresis. Arch Neurol. 1988;45:737–9. doi: 10.1001/archneur.1988.00520310043015. PMID: 3390028.

38 Thaler J, Pignel R, Magnan MA, Pellegrini M, Louge P. Decompression illness treated at the Geneva hyperbaric facility 2010–2016: A retrospective analysis of local cases. Diving Hyperb Med. 2020;50:370–6. doi: 10.28920/dhm50.4.370-376. PMID: 33325018. PMCID: PMC8038901.

39 The Diving Medical Advisory Committee. (June 2014). 'The use of heliox in treating decompression illness'. [cited 2025 Dec 3]. Available from: https://www.dmac-diving.org/guidance/DMAC23.pdf

40 United States Navy. 'U.S. Navy Diving Manual'. [cited 2025 Dec 3]. Available from: https://dykketabeller.no/Referanser/USN Diving Manual Rev 5.pdf

41 Deveze A, Bernard-Demanze L, Xavier F, Lavieille JP, Elziere M. Vestibular compensation and vestibular rehabilitation. Current concepts and new trends. Neurophysiol Clin. 2014;44:49–57. doi: 10.1016/j.neucli.2013.10.138. PMID: 24502905.

42 Smerz RW. Age associated risks of recreational scuba diving. Hawaii Med J. 2006;65:140–1, 153. PMID: 16774142.

43 Sokolowski SA, Räisänen-Sokolowski AK, Tuominen LJ, Lundell RV. Delayed treatment for decompression illness: factors associated with long treatment delays and treatment outcome. Diving Hyperb Med. 2022;52:271–6. doi: 10.28920/dhm52.4.271-276. PMID: 36525684. PMCID: PMC10026386.

44 McDonnell MN, Hillier SL. Vestibular rehabilitation for unilateral peripheral vestibular dysfunction. Cochrane Database Syst Rev. 2015;1(1):CD005397. doi: 10.1002/14651858.CD005397.pub4. PMID: 25581507. PMCID: PMC11259236.

45 Cabrera Kang CM, Tusa RJ. Vestibular rehabilitation: rationale and indications. Semin Neurol. 2013;33:276–85. doi: 10.1055/s-0033-1354593. PMID: 24057831.

46 Wilmshurst PT. The role of persistent foramen ovale and other shunts in decompression illness. Diving Hyperb Med. 2015;45:98–104. PMID: 26165532. [cited 2025 Sep 1]. Available from: https://dhmjournal.com/images/IndividArticles/45June/Wilmshurst_dhm.45.2.98-104.pdf.

47 Smart D, Wilmshurst P, Banham N, Turner M, Mitchell SJ. Joint position statement on atrial shunts (persistent [patent] foramen ovale and atrial septal defects) and diving: 2025 update. South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC). Diving Hyperb Med. 2025;55:51–5. doi: 10.28920/dhm55.1.51-55. PMID: 40090026. PMCID: PMC12043516.

48 Stokes RJ, Watts D, Smerdon G, Hall SD, Bunn L, Marsden J. Vestibular rehabilitation and recovery in divers with inner ear decompression sickness: a case series. Diving Hyperb Med. 2025;55:236–45. doi: 10.28920/dhm55.3.236-245. PMID: 40986919.

49 The Diving Medical Advisory Committee. (December 2022). 'Fitness to return to diving after decompression illness'. [cited 2025 May 1]. Available from: https://www.dmac-diving.org/guidance/DMAC13.pdf.

Conflicts of interest and funding

This systematic review was undertaken as part of a funded PhD studentship with joint funding by the University of Plymouth, Plymouth, UK and the DDRC Healthcare, Plymouth, UK. No conflicts of interest were declared.

Submitted: 4 September 2025
Accepted after revision: 31 January 2026

Short communication

Efficacy and safety of potential irrigation diluents following 'caustic cocktail' ingestion

Adam Lee[1,*], Catherine Moore[1,*], Adam Griffiths[1]

[1] *Underwater Medicine Department, Institute of Naval Medicine, Portsmouth, UK*
** Drs Lee and Moore contributed equally to this paper*

Corresponding author: *Adam Lee, Surgeon Lieutenant Commander Royal Navy, Institute of Naval Medicine, Gosport, Portsmouth, UK*
adam.lee416@mod.gov.uk

Keywords
Diving medicine; First aid; Injuries; Military diving; Rebreathers - closed circuit; Treatment

Abstract

(Lee A, Moore C, Griffiths A. Efficacy and safety of potential irrigation diluents following 'caustic cocktail' ingestion. Diving and Hyperbaric Medicine. 2026 31 March;56(1):83–87. doi: 10.28920/dhm56.1.83-87. PMID: 41875445.) Closed circuit rebreather (CCR) diving sets use soda lime, a sodium hydroxide-based 'scrubber' substance to remove CO_2 from exhaled breathing gas thus prolonging dive time and efficiency. Inadvertent water ingress into the set may result in reaction with the scrubber and a highly alkaline solution known as a 'caustic cocktail' may be formed. Ingestion or aspiration of this solution can cause severe chemical burns. Irrigation with freshwater is the mainstay of initial treatment of 'caustic cocktail' injuries in CCR divers. Published advice advises divers never to use acidic diluents to irrigate and neutralise a caustic cocktail solution due to concerns over the potentially exothermic nature of the neutralisation reaction. However, there is limited available evidence to support this advice, and it was felt that further research into the best treatment options available for caustic cocktails is required. This study used an *in vitro* model of an ingested caustic cocktail to investigate pH and temperature changes after adding different diluents (including acidic diluents orange juice or coca cola) to a solution of sodium hydroxide. Acidic diluents reduce pH significantly more than neutral diluents with a respective mean drop in pH of 5.99 compared to 0.78 ($P = 0.015$). There is no statistically significant difference in temperature change noted between the two types of diluent ($P = 0.32$) with no exothermia generated. We propose that orange juice or coca cola are more effective irrigation solutions than fresh or seawater, and that advice to divers who use CCRs could change.

Introduction

Closed circuit rebreather (CCR) systems are popular amongst commercial, military and recreational divers, offering extended dive times, more efficient and quieter dives with an absence of bubbles. They remove CO_2 from exhaled gases via a soda lime scrubber. Scrubbers can contain a range of substances, but most feature a significant quantity of sodium hydroxide. Any water that ingresses into the scrubber may react with the soda lime, forming a highly alkaline liquid 'cocktail' comprised primarily of sodium hydroxide solution (Figure 1), within the breathing loop of the CCR. The diver breathing from this system may then aspirate or ingest this caustic cocktail. This can cause acute, necrotic caustic burns of the airway and oesophagus[1] with the mechanism of this injury due to saponification of fats.[2]

The current Diver's Alert Network (DAN) recommendation for immediate first aid[3] is to repeatedly flush the diver's oesophagus with freshwater, to reduce the contact time between caustic cocktail and oesophageal tissues, and to dilute the caustic liquid. UK military divers are similarly instructed as per defence doctrine to use freshwater as the preferred diluent. There is widespread informal resistance to the use of acidic diluents in the diving medicine community based on fears of generating an exothermic reaction during neutralisation and there is specific published advice available stating that affected divers should never use acidic diluents as part of the treatment process.[4] Dilution of the caustic liquid by any less alkaline diluent (such as freshwater) is known to reduce the pH of the ingested mixture, but it was predicted that a mildly acidic diluent (rather than approximately neutral) would do so more rapidly thus minimising 'burn time'. It was unknown if using a mildly acidic diluent to help neutralise an alkaline caustic solution generated a clinically significant exothermic reaction, which could in turn cause further tissue damage. An effective diluent would be one that reduces the pH of the caustic cocktail without making it overly acidic, whilst not generating any significant level of exothermia. We identified a need to investigate pH reduction, over the dilutional effect alone, and the associated potentially exothermic nature of this reaction.

Figure 1
A caustic cocktail solution drained from a CCR set following a UK military diving exercise

Various diluents have been suggested but there is a limited evidence base regarding their ability to alter the pH of the caustic liquid or whether this neutralisation itself may cause exothermic damage to tissues.[5] Diluents such as cola drinks and fruit juice have been proposed given their acidity and potential to more effectively neutralise the caustic solution. There is evidence suggesting that acidic neutralisers prolong a potential exothermic reaction compared to diluents such as water or milk.[6] Alternative evidence suggests that orange juice reduces pH without increasing temperature and that thermal generation is dependent on volume of fluid but independent of type of fluid, whilst pH is independent of volume but dependent on type of fluid.[7] A 1997 canine study found that the addition of 75 ml orange juice to a 50% sodium hydroxide solution within the gastric lumen of 18 subjects caused a temperature reduction in both the lumen and mucosa of 2.1°C and 1.1°C respectively. Where freshwater was used as a diluent, temperature reductions of 2.4°C and 2.1°C were observed.[8] This supports the suggestion that using a mildly acidic diluent does not increase the risk of exothermic injury.

Our study aimed to investigate whether diluents other than freshwater have the potential to reduce pH more quickly and to document the extent, if any, of the exothermic nature of this neutralisation.

Methods

This was a single centre, demonstration-of-concept, observational study.

Diluents tested were freshwater, seawater, cola soft drink (Coca-Cola brand) and orange juice. These diluents were selected as they are the standard suggestions for first aid and are portable for remote dive teams. Milk was excluded as this is not practical for dive teams to carry.

All investigations took place in a temperature and humidity-controlled chamber, with parameters set to 35.0–37.0°C and 60–70% humidity. This temperature allows for a measurement of the neutralisation and exothermic reactions in the context of the temperature of the normothermic human body. The controlled humidity prevented variation in evaporation of solutions and is approximate to the humidity range used in diving equipment to maintain comfortable breathing and prevent dehydration.[9]

The pH of the sodium hydroxide solution and the diluents was tested and recorded prior to use.

The samples were not randomised as an observer would be able to distinguish diluents by their appearance and smell.

A single trial was conducted for each diluent. We combined the datasets for the orange and coca cola trials and for the salt water and freshwater trials to assess for a difference between acidic and neutral diluents.

pH and temperature measurements were carried out in 1 L conical flasks. The conical flask is a model for the contained environment of the oesophagus *in vivo*. Five test sets were assembled:
a. 50 ml sodium hydroxide
b. 50 ml sodium hydroxide + 300 ml freshwater added at 60 seconds
c. 50 ml sodium hydroxide + 300 ml cola drink added at 60 seconds
d. 50 ml sodium hydroxide + 300 ml orange juice added at 60 seconds
e. 50 ml sodium hydroxide + 300 ml salt water added at 60 seconds

Baseline pH and temperature were measured at commencement using digital thermometers and pH meters. The pH meters were calibrated with known pH solutions prior to the experiment beginning. Thermometers were similarly calibrated. The pH and temperature probes were immersed in the solution being tested. Diluents were added at 60 seconds. Thereafter pH and temperature were measured every 10 seconds for first two minutes, every 30 seconds from two minutes to four and a half minutes with final observations at 30 minutes and 60 minutes.

Results

No clinically significant exothermia was detected in any of the tests carried out. The mean change in temperature of the acidic diluents was -5.85°C (standard deviation [SD] 0.05) and the mean change in temperature of the neutral diluents

Table 1
pH and temperature changes throughout duration of testing

Time (s)	Control		Fresh water		Salt water		Cola drink		Orange juice	
	Temp °C	pH	Temp °C	pH	Temp °C	pH	Temp °C	pH	Temp °C	pH
0	33.5	11.93	31.8	11.89	32.4	11.92	34.1	11.89	34.1	11.77
10	35.9	12.04	26.3	11.76	25.8	10.49	28.3	7.03	28.2	4.66
20	35.9	12.02	26.5	11.68	25.8	10.32	28.5	6.29	28.2	4.54
30	36.0	11.98	26.6	11.65	25.8	10.18	28.5	6.2	28.5	4.47
40	36.1	11.97	26.8	11.62	25.1	10.09	28.5	6.16	28.6	4.44
50	36.1	11.92	27.0	11.60	26.0	10.01	28.5	6.14	28.9	4.41
60	36.1	11.95	26.4	11.58	26.1	9.97	28.8	6.14	29.0	4.4
70	36.1	11.95	26.8	11.58	26.1	9.9	28.8	6.14	29.1	4.39
80	36.3	11.94	27.0	11.58	26.2	9.87	28.8	6.13	29.2	4.39
90	36.5	11.94	27.1	11.58	26.4	9.86	28.9	6.12	28.7	4.37
100	36.6	11.94	27.3	11.57	26.3	9.85	28.9	6.12	28.8	4.37
110	36.5	11.94	27.5	11.57	26.4	9.83	28.9	6.12	28.9	4.36
120	36.4	11.94	27.5	11.57	26.4	9.82	29	6.13	29.0	4.36
150	36.5	11.94	27.7	11.57	26.4	9.81	29.1	6.12	28.9	4.34
180	36.4	11.94	27.9	11.56	26.4	9.79	29.5	6.12	29.1	4.35
210	36.5	11.94	28.0	11.56	27.1	9.76	29.5	6.12	29.4	4.35
240	37.1	11.94	28.2	11.56	27.1	9.75	29.4	6.12	29.6	4.34
270	37.5	11.94	28.5	11.56	27.5	9.74	29.4	6.12	29.3	4.34
300			28.5	11.56	27.7	9.73	29.4	6.12	29.6	4.34
1800			31.2	11.48	31.1	9.52	32.1	6.20	32.9	4.29
3600			33.2	11.41	33.1	9.42	33.8	6.24	34.8	4.27

was -6.05°C (SD 0.55). The pH was reduced substantially more by addition of acidic diluents than neutral diluents; the mean change in pH of the acidic diluents was -5.99 (SD 1.125) and for the neutral diluents was -0.78 (SD 0.65). Changes in temperature and pH over time are shown for the various combinations of caustic solution and diluents in Table 1 and Figures 2 and 3.

Discussion

These results may provide an initial evidence-base to guide recommendations for first aid actions to be taken in caustic cocktail incidents.

We demonstrated that there is no exothermia generated by any of the diluents used, and hence mildly acidic diluents should not be discounted based on concerns over further injury being caused by heat generation. Instead, we observed that all diluents reduced the overall temperature of the mixture as they were held at normal room temperature outside the controlled chamber. Furthermore, the acidic diluents used reduced pH of the cocktail solution significantly more than pH neutral diluents. This supports our suggestion that neutralisation of the alkaline solution may be better achieved with household acidic drinks than with neutral diluents. As the acidic diluents used are both approved for and regularly consumed by humans, we know that there is no risk of their inherent acidity resulting in tissue damage. The lowest pH mixture we measured was 4.27, although Coca Cola alone was measured to have a pH of 2.74. Further study would be required to better understand if subjecting injured tissue to a greater pH absolute change is more harmful than reducing it to a neutral pH.

Only a single trial was conducted for each diluent as a demonstration of concept. However, we did observe a substantial difference between the acidic and neutral diluents.

There are limitations to extrapolating this work to the *in-vivo* setting. The *in-vitro* model of this work allowed us to control for endogenous temperature and pH fluctuations. The absolute nature of the temperature and pH changes in an *in-vivo* setting will depend on many factors including body temperature, diluent temperature, gastric pH, and oesophageal pH. It does not take into account the human body's own physiological buffering systems, although these are likely to have limited effect given the very high pH of a typical caustic cocktail solution.

Further testing would be required on living tissue to assess for any specific gross damage caused by a particular combination of diluent and caustic solution. However, in this study nothing has been identified that would rule out any of the diluents being used as a potential first aid measure.

We acknowledge that the ability of the diluent to wash away the caustic cocktail from the affected tissue is not measured. However, this is likely to be a constant for all diluents tested and has no bearing on pH reduction or exothermia.

Figure 2

Figure illustrating absence of clinically significant exothermia generated during testing; gradual warming of all solutions reflects background temperature of the heat chamber (~37°C)

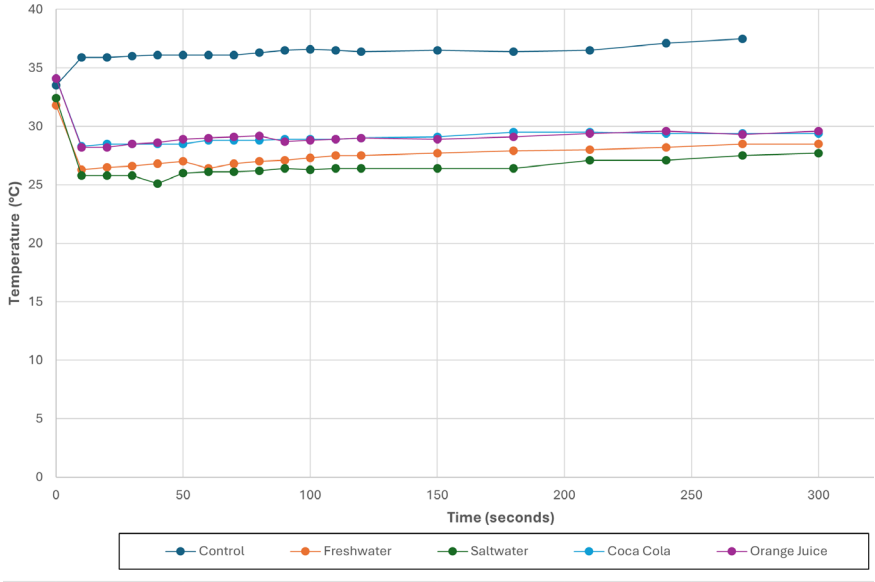
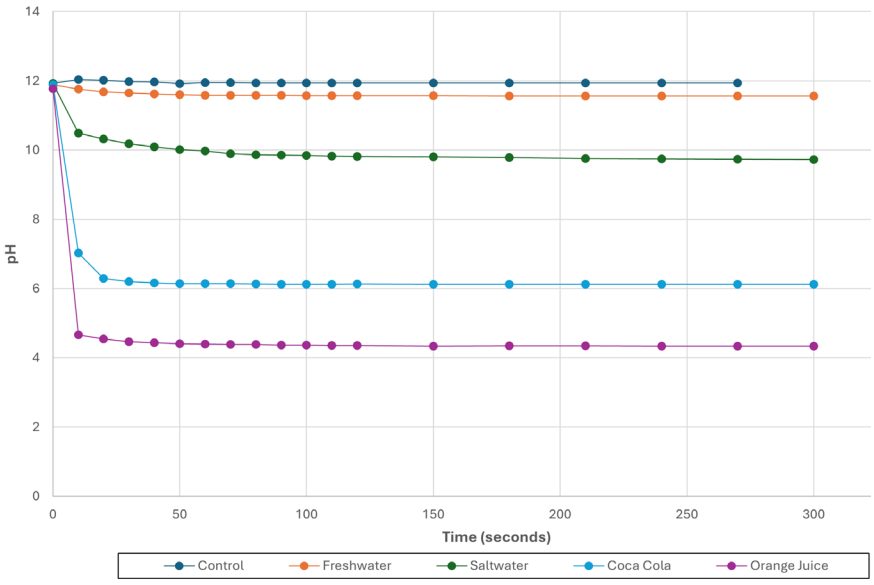


Figure 3

Figure demonstrating improved pH reduction using mildly acidic diluents in comparison to neutral diluents



Conclusions

This observational study indicated that mildly acidic diluents are more effective neutralising agents than their more alkaline counterparts. They reduce pH more quickly and do not generate exothermia to any significant extent. Where freshwater was used there was almost no reduction in pH. This study highlights that traditional guidance for the first aid management of caustic cocktails should be reviewed. We suggest that mildly acidic diluents should be considered as an alternative to water for flushing of the oral cavity, and ingestion for oesophageal flushing, as part of the first aid management of caustic cocktail injury patients. Guidance for CCR divers, supervisors and those at risk of caustic cocktail ingestion may be changed to reflect this. This area would benefit from further study using a wider range of diluents and using live tissue models.

References

1 Hendrickx L, Hubens A, van Hee W. Emergency oesophageal stripping, an aggressive approach to acute, necrotic caustic burns of the oesophagus and stomach. Acta Chir Belg. 1990;90:46–9. PMID: 2356676.

2 Hoffman R, Burns M, Gosselin S. Ingestion of caustic

substances. N Engl J Med. 2020;381:1739–48. doi: 10.1056/NEJMra1810769. PMID: 32348645.
3 Divers' Alert Network [Internet]. A case of caustic cocktail. [cited 2025 Jan 18]. Available from: https://dan.org/safety-prevention/diver-safety/case-summaries/a-case-of-caustic-cocktail/#:~:text=The%E2%80%AFfirst%20aid%20treatment%E2%80%AFfor%20ingestion%20of%20caustic%20soda%20is.
4 Walker III JR, Murphy-Lavoie HM. Diving rebreathers [Internet]. Treasure Island: StatPearls Publishing; 2025. [cited 2025 Jan 25]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK482469/.
5 Buzzacott P, Dong G, Brenner R,Tillmans F. A survey of caustic cocktail events in rebreather divers. Diving and Hyperb Med. 2022;52:92–6. doi: 10.28920/dhm52.2.92-96. PMID: 35732280. PMCID: PMC9522607.
6 Rumack B, Burrington J. Caustic ingestions: a rational look at diluents. Clin Toxicol. 1977;11:27–34. doi: 10.3109/15563657708989816. PMID: 577479.
7 Lacouture P, Gaudreault P, Lovejoy F Jr. Clinitest® tablet ingestion: an in vitro investigation concerned with initial emergency management. Ann Emerg Med. 1986;15:143–6. doi: 10.1016/s0196-0644(86)80008-7. PMID: 3753830.
8 Homan C, Singer A, Henry M, Thode Jr H. Thermal effects of neutralization therapy and water dilution for acute alkali exposure in canines. Acad Emerg Med. 1997;4:27–32. doi: 10.1111/j.1553-2712.1997.tb03639.x. PMID: 9110008.
9 Burman F. Scuba air quality Part 1: What do the limits really mean? [Internet]. [cited 2024 Jul 8]. Available from: https://dan.org/wp-content/uploads/2020/07/air-quality-article-i.pdf.

Acknowledgements

The authors would like to thank the Royal Navy's Institute of Naval Medicine for kind provision of its thermal chamber and funding for this experiment.

Conflicts of interest and funding

The temperature and humidity controlled clinical space was kindly provided by the Institute of Naval Medicine, Environmental Medicine. Funding for the equipment and materials was obtained from the Institute of Naval Medicine, Underwater Medicine Division and Royal Navy Diving. No conflicts of interest were declared.

Submitted: 17 January 2025
Accepted after revision: 5 January 2026

World as it is

Dual rebreathers in practice: example experiences from the Wetmules and COBRA Divers

Daniel Lee[1], Craig Challen[2], Gareth Lock[3]

[1] *COBRA Dive Team, Darmstadt, Germany*
[2] *Wetmules Dive Team, Perth, Australia*
[3] *The Human Diver, Wilts, UK*

Corresponding author: *Daniel Lee, COBRA Dive Team, Mathildenstrasse 43, 64285 Darmstadt, Germany*
erget2005@gmail.com

Keywords
Cave diving; Deep diving; Equipment; Rebreathers - closed circuit; Remote locations; Safety; Technical diving

Abstract

(Lee D, Challen C, Lock G. Dual rebreathers in practice: example experiences from the Wetmules and COBRA Divers. Diving and Hyperbaric Medicine. 2026 31 March;56(1):88–94. doi: 10.28920/dhm56.1.88-94. PMID: 41875446.)
Closed-circuit rebreathers have opened new frontiers in technical diving, but rebreathers are not invulnerable and therefore a 'bailout' gas supply is required. For extreme dives, open-circuit bailout is logistically impossible. This has led teams to adopt dual rebreather configurations, where a second rebreather serves as bailout. This article presents operational experiences from the Wetmules and COBRA Divers, who independently developed dual rebreather practices for extended range diving. The teams evolved contrasting approaches through extensive field testing. The Wetmules initially adopted partially integrated configurations, sharing components between rebreathers to reduce complexity for deep dives with straightforward access to dive sites. COBRA Divers used fully independent dual rebreathers, prioritising complete redundancy for remote locations with challenging logistics. Both developed techniques to ensure the operational status of the inactive rebreather including gas content variability, buoyancy control, and fault detection. Real-world experience validated theoretical benefits while revealing additional considerations. Both teams significantly reduced open-circuit bailout requirements, enabling extended penetrations and depths that were previously extremely difficult. Key operational insights included maintaining breathable gas mixtures in inactive loops, regular integrity checks, and managing variable buoyancy. The approach introduced new challenges: increased task loading, maintenance requirements, and novel failure modes specific to inactive rebreathers, showing that equipment redundancy does not automatically enhance safety. Dual rebreathers extend operational envelopes but introduce significant complexity. Benefits include eliminating gas switches during emergencies and maintaining optimal decompression profiles. However, inactive rebreathers remain vulnerable to undetected failures and demand higher operator proficiency. The contrasting approaches - integration versus full independence - reflect different operational priorities and mission parameters. This article contributes operational experience to support informed decision-making within the technical diving community.

Introduction

Closed-circuit rebreather (CCR) diving has opened new frontiers in technical diving in terms of depth and penetration range. Alongside these CCRs, open-circuit bailout serves as a gas supply backup to a failed CCR. However, for the most challenging dives, open-circuit bailout is not an option. For example, logistic difficulties may be encountered both underwater and topside. These challenges include issues with failing cylinders or regulators in addition to the sheer number of cylinders that need to be obtained, filled, and transported to the dive site before they are even carried or staged underwater. Staging cylinders for the duration of a project risks cylinder failure that may only be detected when bailout is needed.[1] Even if it is possible to carry all the open-circuit bailout required, it may be very cumbersome on the dive. Planning for open-circuit bailout often does not account for breathing cold, dry gas; multiple gas changes during decompression; and difficulties locating and mounting staged cylinders. Divers who wish to complete major dives without relying on their CCR as a single point of failure are obliged to dive with multiple CCRs so that they can bail out to another CCR, should their primary unit fail.

The feasibility of this approach is driven by the increased availability of CCRs. The community's experience and trust in CCRs has grown, and their advantages for gas needs, decompression comfort, and efficiency are well known. Additionally, CCRs offer degraded operation modes (such as allowing the use of additional gas sources should the

Table 1
Glossary of technical diving and CCR terminology used in this article

Term	Definition
Closed-circuit rebreather (CCR)	Underwater breathing apparatus that recycles exhaled gas by removing carbon dioxide and adding oxygen, as opposed to open-circuit systems that exhaust all exhaled gas
Open-circuit bailout	Emergency breathing gas carried in conventional scuba cylinders as backup to a rebreather
Diluent	A gas mixture added to the breathing loop to maintain volume and reduce oxygen partial pressure by diluting the oxygen, typically by using helium or another inert gas
Breathing loop	The closed circuit through which gas circulates in a rebreather, consisting of the mouthpiece, hoses, counterlung, and scrubber
PPO_2	Partial pressure of oxygen
Scrubber	The carbon dioxide absorbent material in a rebreather
Staging (cylinders)	Placing gas cylinders along the planned dive route for use as backup gas that the diver does not carry at all times
Setpoint	The target PPO_2 that the rebreather attempts to maintain in the breathing loop
Automatic diluent valve (ADV)	Device that automatically adds diluent to the loop when ambient pressure increases, thus decreasing the volume of the breathing loop, during descent
Constant mass flow valve	Device that continuously adds oxygen at a fixed rate
Dive-surface valve (DSV)	Mouthpiece valve that can be sealed, isolating the breathing loop when removed from the diver's mouth
Bailout valve (BOV)	Integrated mouthpiece that allows switching between rebreather and open-circuit bailout with a single action
eCCR (electronically controlled CCR)	Rebreather that uses oxygen sensors and electronically controlled solenoid valves to automatically maintain setpoint
Penetration range	The horizontal distance a diver travels from their entry point (particularly relevant in overhead environments)
Work of breathing	The respiratory effort required to breathe from a breathing apparatus
Gas density	A measure of the density the breathing gas attains at pressure, which increases respiratory effort and CO_2 retention risk
Back-mount	Rebreather configuration worn on the diver's back, similar to traditional scuba tanks
Side-mount	Rebreather configuration worn at the diver's sides rather than on the back

onboard cylinders fail, or the operation of the CCR in semi-closed mode) allowing underwater problem correction, and issues can be resolved with less haste than with open-circuit diving, reducing time pressures.

This article presents the operational experiences of two teams who dive with dual CCRs: the Wetmules and COBRA Divers. It describes the mission parameters that have driven the design decisions that each team has made, the trade-offs involved, and the insights gained. Dual CCRs offer extended range and reduced reliance on open-circuit bailout. However, they introduce additional complexity and do not necessarily improve safety. This article examines both the advantages and the challenges that dual configurations create.

The equipment setups and procedures described reflect team circumstances – diving locations, teamwork approach, and available support. Other teams using dual CCRs will likely reach different conclusions for valid reasons. This article serves as a starting point for discussions around dual CCR use in order to increase the level of safety in the community.

Key technical terms used throughout this article are defined in Table 1.

Two paths to redundancy

Bailout CCRs significantly extend operational range and improve safety margins – but these benefits come at a cost.[1] These costs include increased maintenance demands, procedural complexity, heightened task loading, and the cognitive effort involved in switching between systems during both normal and contingent operations.

A well-maintained, actively monitored single CCR in the hands of a competent diver is highly reliable. Minor problems on a CCR in active use may be detected and resolved in a timely manner. Introducing a second CCR brings new fault pathways that are harder to detect and resolve, including:

» Variability in gas content across CCRs e.g., through the addition of diluent, oxygen, or the use of a constant mass flow valve.
» Changes to the ambient pressure and thus the partial pressures of gases in the breathing loop.
» Buoyancy variability caused by gas additions or venting of inactive loops.
» Subtle faults that may go undetected if the unit is not actively breathed - e.g. a non-functioning automatic diluent valve (ADV) on descent, slow water ingress, or a situation where an electronic CCR attempts to raise PPO_2 on ascent by injecting oxygen into a loop where gas isn't circulating, so that the sensor's oxygen reading is inaccurate.
» Additional maintenance and preparation requirements, including duplicate scrubber management, gas logistics, and functional checks.
» Inconsistency between primary and redundant units, potentially causing challenges when diagnosing issues or executing emergency procedures because each unit behaves differently.

These considerations drove different design priorities. The Wetmules prioritised operational efficiency through integration and simplification, accepting certain single points of failure in exchange for reduced complexity and improved usability on deep dives with straightforward access from the surface. COBRA divers have complete redundancy, accepting increased complexity to eliminate shared failure points while maintaining flexibility for autonomous diving in environments with more challenging logistics. These contrasting requirements create different mission parameters and operational constraints that have shaped each team's equipment configuration. The following sections will describe each team's setup and how it was developed in greater detail.

WETMULES – INTEGRATED BAILOUT

The Wetmules use a mix of different configurations. Multiple twin Megalodon™ (InnerSpace Systems Corp., Centralia, Washington, USA) back-mounts and a twin JJ-CCR (JJ-CCR ApS, Praestø, Denmark) are in use. These are not fully independent, as the CCRs share some single failure points – the mouthpiece, and in some cases oxygen and diluent are shared across both CCRs. Precise configuration varies among team members. Some team members use back-mount/side-mount combinations, utilising a KISS Sidekick rebreather (KISS CCRs LLC, Fort Smith, Arkansas, USA), and twin side-mount Liberty rebreathers (Divesoft s.r.o., Roudnice nad Labem, Czech Republic).

Use of twin CCRs in the Wetmules started in 2006 when a dual back-mount CCR was constructed for experimental purposes. The setup was initially composed of two fully redundant CCRs but there followed a process of simplification over several years to make the apparatus lighter and more user-friendly. This was achieved at the cost of introducing single points of failure. These changes are considered acceptable due to the low probability of these failure points actually causing a catastrophic failure.

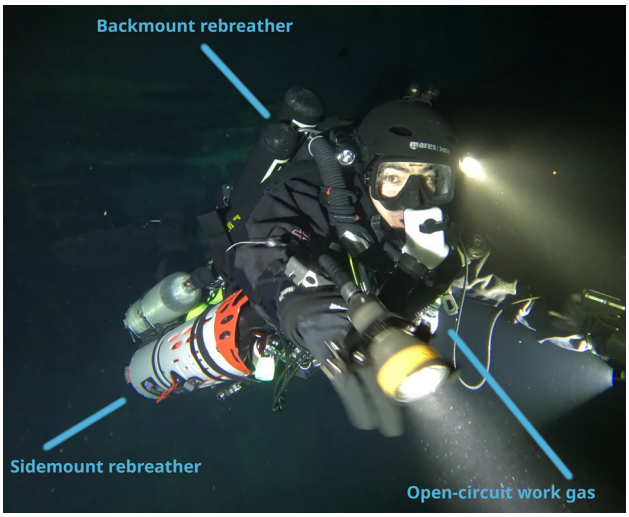
These changes are:
1. The use of a combination twin dive-surface valve (DSV) and open-circuit bailout valve (BOV). This integrates both breathing loops and open-circuit bailout into a single switchable valve that allows switching between breathing loops and open-circuit with a single one-handed operation. It is therefore quick and easy to test the integrity of both CCRs during the dive with minimal interruption to other tasks. It is recognised however, that failure of the mouthpiece or structural failure of the combined valve would present a very serious problem as this would compromise both units simultaneously.
2. Simplification of oxygen supply: use of one oxygen cylinder for both CCRs, with a Y- or H valve and two first stage regulators, to reduce weight and bulk.
3. Simplification of diluent supply: use of one diluent cylinder for both CCRs. This is only suitable where there is a continuous ascent to the surface - if multiple ascents in a 'saw-tooth' profile are required there should be redundancy in the diluent supply.
4. Reducing the number of displays (handsets and head-up displays). These may be reduced as far as one handset and head-up display for the primary loop and one handset for the secondary loop, to reduce clutter and confusion and simplify equipment donning.

The twin back-mount configuration is optimised for deep dives with easy access to the water (i.e., the equipment does not have to be carried far or over difficult terrain). This configuration does not have the capacity to divide the two CCRs into individual units that can be transported or dived separately. When these features are required (e.g., a long-range multi-sump cave dive), alternative configurations are used: either back-mount/side-mount or twin side-mount combinations. Figures 1 and 2 show the dual-back-mount setup from the front and back, respectively.

Figure 1
View of the front of a Wetmules setup showing the integrated BOV

Figure 2
Rear view of the Wetmules setup showing the scrubbers and gas supply

Figure 3
Example of a COBRA setup; on this dive the side-mount CCR, mounted on the diver's right, is being used as the primary, with the breathing loop of the back-mount CCR stowed under the diver's chin. Open-circuit gas used for work purposes and as an emergency gas to transition between CCR loops is mounted on the diver's left



The Wetmules have a less integrated approach than COBRA, it being left to individual divers to determine the configuration that fits their individual requirements and those of the mission at hand, although with plentiful discussion and mutual review. However, in many cases an innovation made by one team member has been adopted generally by others.

COBRA DIVERS – FULL INDEPENDENCE

The COBRA divers use a mixture of platforms, including SF2 (ScubaForce, Mönchengladbach, Germany), JJ, rEvo® (rEvo BVBA, Brugge, Belgium), and side-mounted Liberty, T-Reb® (Other Gravity, Piaseczno, Poland), KISS Sidekick, and a custom build. An example of a typical setup is shown in Figure 3.

COBRA divers began using dual CCRs when it became clear that open-circuit bailout was becoming logistically impossible for their diving objectives. This was driven by the remoteness of many dive locations where sufficient gases for open-circuit bailout are unavailable, and the impracticality of carrying sufficient bailout to complete decompression obligations on extended range dives. Unlike some teams with dedicated support, COBRA divers operate autonomously - carrying, staging, and donning all equipment themselves, often setting up from vehicles or improvised staging areas near dive sites. This setup allows staging CCRs individually and donning the side-mount CCR in water unassisted.

The team prioritises complete independence between CCRs. Each unit maintains fully separate gas supplies, loops, and electronics, with no shared components that could introduce single points of failure.

The evolution of COBRA's dual CCR practices occurred through systematic experimentation. Initially, the team explored side-mount CCRs as bailout units, some of which lacked onboard diluent supplies and required gas from bailout cylinders. Operational experience showed this to be impractical because it required time-consuming steps between entering the water and descent. Consequently, the team transitioned to fully independent CCRs, each with integrated diluent and oxygen supplies.

When diving with dual CCRs, the team uses a combination of back-mount and side-mount. With few exceptions, both units are eCCRs. During a typical dive, the same diluent gas mixture is used in both CCRs, and decompression is tracked via an independent computer rather than relying on the decompression calculated by one of the CCR controllers.

Equipment selection has been optimised for work of breathing and operational requirements. Where necessary, CCRs needed modification. Constant mass flow valves were removed from some units to prevent oxygen accumulation in inactive loops. The team standardised offboard gas connectors across all platforms to ensure compatibility. This makes it possible to connect any cylinder used on the dive with any of the CCRs used. On a given dive, one of the CCRs will be primary, but the primary varies between dives as the team maintains equal proficiency with both units. Each CCR has its own handset and heads-up display, ensuring independent monitoring and control of both systems. For COBRA divers, dual CCRs have become standard practice for dives requiring more than one bailout cylinder, as a second CCR provides comparable mounting complexity to a stage cylinder but superior performance underwater.

Design decisions undergo team review and testing. Often members adopt improvements that have proven effective through in-water evaluation, creating a process of convergence without an explicit desire for standardisation. Pre-dive briefings review equipment configurations when changes have been made, ensuring the team is familiar with each other's setups.

Pre-dive procedures require additional steps compared to integrated systems. Following community guidance,[2] COBRA divers employ challenge-and-response checklists to verify readiness of both units before entering the water. Final gear configuration is typically completed in water. This costs time and procedures must be adapted to the environment, for example to tight cave or mine entrances. The full independence of the units adds steps to in-water procedures; for example, switching loops requires closing the active mouthpiece, switching to the backup loop, and purging and opening its mouthpiece – a sequence requiring multiple seconds and careful execution. It is essential that this can be performed with high workloads, such as when managing other equipment such as diver propulsion vehicles.

Unlike stage tanks with fixed gas mixture and buoyancy, CCRs have variable gas content and volume that shift throughout the dive. While functionally advantageous, this variability is procedurally hazardous as the system could add gas unsupervised or contain unbreathable mixtures. COBRA divers designed procedures to maintain bailout CCRs in a known, safe state throughout the dive. The objective is maintaining the setpoint in a breathable range (0.5–1.3 bar) by flushing the loop with diluent during descent once the diluent's PPO_2 exceeds the low setpoint. This prevents electronic oxygen injection, avoids buoyancy fluctuations and maintains stable loop composition. Only diluent addition is needed to maintain loop volume. During ascent, the team switches to the bailout CCR when its PPO_2 approaches the low setpoint and manually raises the PPO_2 to the high setpoint, preventing the addition of oxygen while gas isn't circulating. These practices restore the predictability of open-circuit systems without sacrificing the CCR's performance advantages.

The secondary CCR can become unusable without detection. The COBRAs mitigate this risk by maintaining a breathable gas mixture by regularly monitoring the PPO_2 of both CCRs with equal vigilance and verifying loop integrity at critical points during the dive. These integrity checks are performed by briefly switching onto the secondary unit and breathing it to circulate the gas. This is done when the PPO_2 approaches the edge of the acceptable range, and prior to work to ensure periodic validation at a static depth. This leads to a minimum of the interaction points shown in the example in Figure 4, which is a controller output from a shallow cave dive.

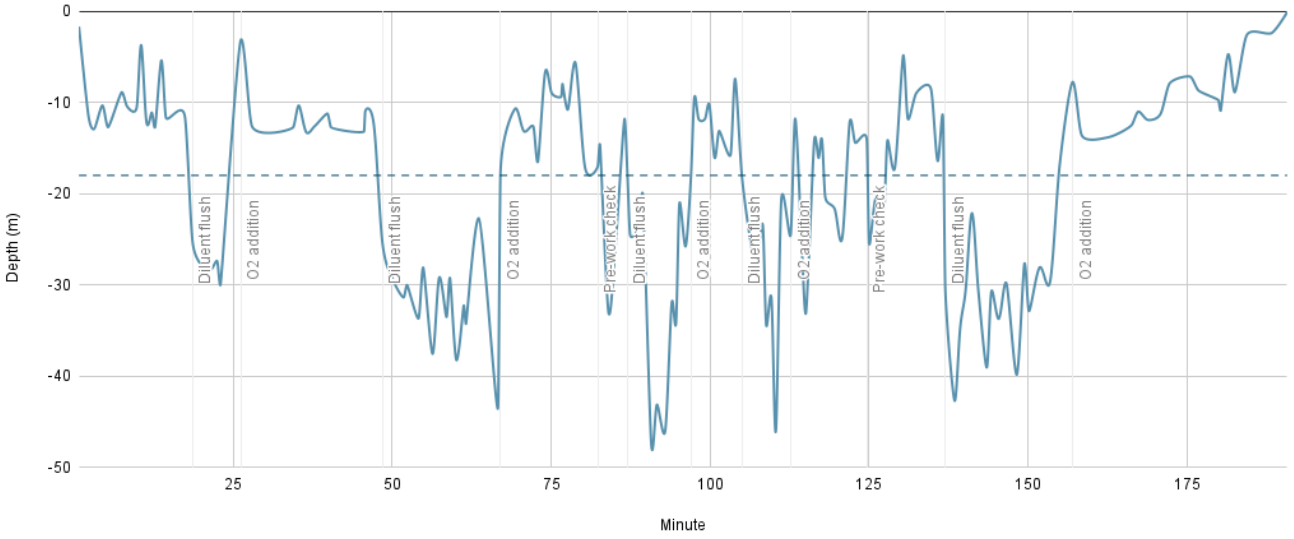
Operational experience

Both teams have developed sufficient confidence in their dual CCR systems to significantly reduce open-circuit bailout requirements. Where previously four or more bailout cylinders were carried – which may still be insufficient for complete decompression – current practice involves carrying only one or two open-circuit bailout cylinders.

The approach has proven effective in actual contingency conditions. During one incident on a dive several kilometres into a cave, it was necessary to bailout from the primary CCR at a depth of 60 m. The procedures had maintained a breathable gas mixture in the secondary unit, and the switching procedure functioned correctly despite the stress of an unplanned problem. This real-world test confirmed that the procedures function effectively under actual emergency conditions.

Figure 4

Example log showing minimal interaction points with secondary CCR; these occur on descents and ascents, and before critical points, e.g., before working or traversing restrictions. Dashed line depicts depth where PPO_2 of diluent gas exceeds low setpoint. The primary CCR is using its high setpoint except for the descents and the last decompression stops, where the PPO_2 is controlled manually



Lessons learned

This article describes techniques adopted by two teams using dual CCRs for challenging dives. While both teams solved similar problems, their solutions reflect different operational priorities - the Wetmules optimised for deep diving efficiency through integration, while COBRA prioritised redundancy and portability. There are advantages and disadvantages to each setup. These experiences are shared to make it easier for other teams to decide if and how they should adopt the use of multiple CCRs in their dives. To that end, this section examines what makes the use of multiple CCRs unattractive – what problems multiple CCRs do not solve, and what problems they create.

The practices described in this article represent highly specialised techniques developed by experienced teams and should not be interpreted as instructional material. Dual CCR diving demands the highest level of CCR competency. Divers must demonstrate absolute mastery of each individual CCR unit before attempting dual configurations, all foreseeable failures should be manageable in-water under high task load, without requiring extensive conscious thought. This capability must be second nature. Environmental challenges such as cave or wreck penetration add substantial task loading and should be mastered separately before being combined with dual CCR complexity. The absence of formal training pathways or mentorship for these techniques reflects their pioneering nature; divers considering dual CCR configurations must recognise they are developing expertise in an area where established standards do not yet exist.

The Wetmules and COBRAs dive with multiple CCRs while acknowledging that a second CCR itself brings its own risks. These include:

- Variability of the state of the CCR and breathing loop, producing additional workload and possibly breathing inappropriate gas mixtures.
- Rendering the CCR inoperable due to user error.
- The CCR failing in an undetected and unrecoverable manner.

In addition to the task loading demands that bailout CCRs place on their users, bailout CCRs are often used in contexts with a high workload. This means that high proficiency is needed for all tasks necessary for both safe and successful completion of the mission. Certain practices that have proven useful in addressing these aspects of dual CCR use are set forth in Table 2.

With the use of bailout CCRs, other challenges have a higher impact due to the greater depth and range achieved by the dive team, such as navigation, temperature, and oxygen toxicity. Also, a second CCR does not mitigate hypercapnia due to respiratory insufficiency endogenous to the diver.[3] This risk of respiratory insufficiency must be mitigated by lowering gas density. In this area, the limitations of helium have led to experiments of using hydrogen in diluent.[4] In short, pushing the boundaries using a second CCR quickly reveals new boundaries that must be overcome in different ways if divers wish to continue diving deeper or farther.

In the cases of the Wetmules and COBRA divers, the use of dual CCRs has provided vast benefits without causing adverse outcomes. However, it must be acknowledged that the absence of adverse events does not mean that these practices are ‘safe’. Nevertheless, it is the hope of the authors that sharing these experiences will help divers

Table 2
Risks that arise when using multiple CCRs above and beyond the risks associated with deep and extended range diving, and practices that have proven useful for both teams to mitigate these risks

Status	Risk	Mitigation
Mitigation in place	Non-active rebreather condition deteriorates unnoticed	Check rebreather frequently during logical activity points. Event- rather than time-based triggers are more preferred.
	Unbreathable gas mix in non-active unit	Use procedures to keep the mix in the second unit breathable, checking regularly, at a minimum at critical points in the dive.
	Decompression calculation errors due to different setpoints in each rebreather	Use an independent computer for decompression with a fixed setpoint matching what is breathed.
	User error renders non-active rebreather inoperable	Practice and drill with critical feedback to reduce operator error in nominal and contingency operations.
Risk tolerated	Failure of both rebreathers	As in open-circuit bailout, failure of both the primary and secondary rebreather is catastrophic. The likelihood of this risk materialising is considered sufficiently low that the risk is tolerated.
	High procedural complexity in bailout scenarios	A second rebreather does not help - bailing out is a complex activity, independent of what type of bailout system is used
	Issues arising from gas density and work of breathing	A second rebreather does not help and may be inferior to open-circuit due to the additional work of breathing imposed by the closed-circuit breathing system.

who are considering closed-circuit bailout to make more informed decisions.

Conclusions

The use of dual CCRs in technical diving is becoming increasingly common as the community pushes operational boundaries beyond what would be possible with open-circuit bailout. This evolution opens new frontiers in underwater exploration but simultaneously introduces new challenges.

It is valuable to anticipate problems arising from introducing significant changes to the dive system, and test these systems under low-risk conditions. This methodology surfaces issues emerging from the integration of equipment, team, and the real environment, allowing for adaptation before use in exploration. An iterative approach, combined with extensive practice, has proven effective. The cycle of diving, learning, adapting, and repeating should be constant - perfection is neither expected nor achievable.

Looking forward, CCRs will likely become increasingly accessible, providing scope for these techniques to become more widespread. As dual CCR use increases within the technical diving community, the development of training frameworks and standardised procedures remains an unfilled gap for the broader CCR training ecosystem. Dual CCR adoption should proceed thoughtfully and cautiously, with appropriate recognition of the additional complexity and risk factors involved.

References

1 Covington DB, Sadler C, Bielawski A, Lock G, Pitkin A. Is more complex safer in the case of bail-out CCRs for extended range cave diving? Diving Hyperb Med. 2022;52:49–53. doi: 10.28920/dhm52.1.49-53. PMID: 35313373. PMCID: PMC9177436.

2 Mitchell SJ, Pollock NW. Rebreather Forum Four consensus statements. Diving Hyperb Med. 2023;53:142–6. doi: 10.28920/dhm53.2.142-146. PMID: 37365132. PMCID: PMC10584388.

3 Anthony TG, Mitchell SJ. Respiratory physiology of CCR diving. In: Pollock NW, Sellers SH, Godfrey JM, editors. Rebreathers and scientific diving: Proceedings of the NPS/NOAA/DAN/AAUS June 16–19, 2015 Workshop, Wrigley Marine Science Center, Catalina Island, CA. Durham (NC): American Academy of Underwater Sciences; 2016. p. 66–79. [cited 2025 Jul 17]. Available from: https://www.omao.noaa.gov/sites/default/files/documents/CCRs%20and%20Scientific%20Diving%20Proceedings%202016.pdf.

4 Harris RJ, Challen CJ, Mitchell SJ. The first deep rebreather dive using hydrogen; case report. Diving Hyperb Med. 2024;54:69–72. doi: 10.28920/dhm54.1.65-68. PMID: 38507913. PMCID: PMC11065502.

Conflicts of interest and funding: nil

Submitted: 30 July 2025
Accepted after revision: 18 January 2026

Letters to the Editor

Liver disease and the Diver Medical Participant Questionnaire

The diver medical participant questionnaire created by the Diver Medical Screening Committee (DMSC) provides an established minimum health standard for recreational diving. As keen divers with a background in Hepatology, it seems clear that liver disease is overlooked by this safety standard.

The prevalence of chronic liver disease (CLD) is rising globally - largely driven by an increase in obesity and alcohol consumption. Over one third of the global population (37.5%) are estimated to have steatotic liver disease (SLD), an umbrella term including both alcohol-related liver disease (ALD) and metabolic dysfunction-associated steatotic liver disease (MASLD).[1] Liver disease is typically occult until the later stages but the development of non-invasive diagnostics including transient elastography has changed the landscape with increased focus on early detection and prevention.

The consequences of diving with liver disease can be significant.

It is estimated that 1.3% global population have liver cirrhosis and around one third will have oesophageal varices at diagnosis.[2] Diving may precipitate variceal rupture by inducing a transient increase in portal pressure. The literature reports a case of massive variceal bleeding in a 29-year-old with cryptogenic liver cirrhosis after two dives to 16 metres of sea water. Treatment entailed a somatostatin analogue and band ligation.[3] In our practice, we have identified patients with a known history of portal hypertension and oesophageal varices who had continued to engage in recreational diving due to the lack of sensitivity of the Diver Medical Participant Questionnaire.

Nitrogen and other inert gases are highly soluble in adipose tissue and obesity is a known risk factor for decompression injury (DCI). Divers with SLD are at increased risk of localised inert gas excess. The risk of DCI in this cohort has not been studied but steatotic liver disease is a known non-traumatic risk factor for fat embolism. Local bubble formation may induce rupture of fat cells and potentiate risk of fat embolism in those with SLD.

Diving fatalities are rare but frequently attributed to cardiovascular events. We know that people living with CLD have a twofold greater incidence of cardiovascular disease. In conditions such as lean MASLD (hepatic steatosis with a normal BMI), the background of liver disease may be the only clue to underlying cardiovascular risk and this is currently missed on the Diver Medical Participant Questionnaire.

Portal venous gas (PVG) accumulation is a common finding amongst recreational divers and has been linked to the formation of portal vein thrombosis.[4,5] Portal vein thrombosis is a known complication of CLD and its prevalence rises with disease severity. The combination of CLD and portal venous gas accumulation secondary to recreational diving may heighten risk of portal vein thrombosis.

In addition to the above, we anticipate significant risk of diving with the complications of CLD including hepatic encephalopathy (HE) and ascites. Both can be subtle to detect but in the hyperbaric environment may contribute to mental obtundation and fluid shifts respectively.

Unlike many chronic illnesses, patients with compensated CLD are frequently managed without specific medications and may not be highlighted by the 'prescription medication' section of the questionnaire.

It is clear from a brief review of recreational diving forums that the combination of liver disease and diving is a consistent query. Given the rising prevalence and inherent risks of diving with chronic liver disease, we advocate for the inclusion of the word 'liver' to question nine of the Diver Medical Participant Questionnaire. It would read "*I have had stomach, liver or intestine problems, including recent diarrhea*". This could be clarified with an additional point in Box G "*I have had chronic liver disease or portal hypertension*".

References

1 Ho GJK, Tan FXN, Sasikumar NA, Tham EKJ, Ko D, Kim DH, et al. High global prevalence of steatotic liver disease and associated subtypes: A meta-analysis. Clin Gastroenterol Hepatol. 2025;23:2423–2432.e1. doi: 10.1016/j.cgh.2025.02.006. PMID: 40204206.

2 Zamani M, Alizadeh-Tabari S, Ajmera V, Singh S, Murad MH, Loomba R. Global prevalence of advanced liver fibrosis and cirrhosis in the general population: A systematic review and meta-analysis. Clin Gastroenterol Hepatol. 2025;23:1123–34. doi: 10.1016/j.cgh.2024.08.020. PMID: 39209202.

3 Nguyen MH, Ernsting KS, Proctor DD. Massive variceal bleeding caused by scuba diving. Am J Gastroenterol. 2000;95:3677–8. doi: 10.1111/j.1572-0241.2000.03417.x. PMID: 11151937.

4 L'abbate A, Marabotti C, Kusmic C, Pagliazzo A, Navari A, Positano V, et al. Post-dive ultrasound detection of gas in the liver of rats and scuba divers. Eur J Appl Physiol. 2011;111:2213–9. doi: 10.1007/s00421-011-1857-8. PMID: 21318312.

5 Righini M, Gueddi S, Maurel B, Coulange M. Scuba diving and portal vein thrombosis: A case report. Clin J Sport Med. 2010;20:497–9. doi: 10.1097/JSM.0b013e3181fab19d. PMID: 21079451.

Andrew George Watson[1], Tiong Yeng Lim[1]

[1] Department of Hepatology, Royal London Hospital, Barts Health NHS Trust, London, UK

Corresponding author: *Dr Andrew George Watson, Department of Hepatology, Royal London Hospital, Barts Health NHS Trust, London, UK*
ORCiD: *0009-0007-0517-7197*
andrewgeorge.watson@nhs.net

doi: 10.28920/dhm56.1.95-96. PMID: 41875447.

Submitted: 29 October 2025
Accepted: 5 January 2026

Keywords
Fitness to dive; Liver, Medical-diving; Questionnaire; Recreational divers; Risk assessment

Comment on 'Effects of fluid loss on the physiology of closed-circuit rebreather divers after 100- and 45-metre dives by Tuominen, et al.'

We have some difficulty in understanding the publication by Tuominen and colleagues because the description of methods and the presentation of results are less detailed than is required.[1] Those details could be provided in an on-line supplement.

Dehydration is when there is so much net loss of body fluid that it impairs normal bodily functions. There is no doubt that immersion promotes natriuresis and diuresis, but during most dives net fluid loss is not enough to impair normal bodily function: so there is not dehydration. We do not know of any convincing evidence that the amount of diuresis experienced by divers increases the risk of decompression sickness. There is more convincing evidence that high oral fluid intake before diving can increase the risk of immersion pulmonary oedema, which can prove fatal.

If one wishes to study the effect of diuresis when diving on any aspect of physiology the research should be conducted with adherence to strict scientific methods and protocols. For example it might involve a group of subjects having repeat interventions with every aspect held constant as far as that is possible other than the intervention that one is studying.

In the study by Tuominen and colleagues, a group of divers performed two dives (to 45 and 100 mfw) on separate occasions, but there was no consistency of dive durations between subjects. We are not told the range of durations for each depth, but the interquartile durations of the 45 mfw dives were 63–71 mins and of the 100 mfw dives were 155–178 mins, which represent greater than 10% variation for each depth. Partial pressures of gases breathed and uptake and elimination of inert gases during the dives were obviously very different between the two depths of dives and also between the different subjects doing the dives to the same depths because their dive durations were not identical.

It does not seem that there was a consistent interval between divers being weighed pre-dive and entering the water, during which interval the divers were putting on their diving suit and equipment, and we are not told how long this interval was for each diver. Neither was there a consistent interval between surfacing, de-kitting and getting weighed and we are not told what those intervals were. During the pre-dive and post-dive intervals there would have been urine production which will add to the weight change during the times the divers were underwater.

The weights of divers were measured using an InBody 720 composition analyser. It is used for measuring body composition using bioelectrical impedance rather than specifically designed for accurate total body weight. We cannot find reports on reproducibility of the equipment for weight measurement. It only measures to the nearest 0.1 kg which does not have enough precision for the small changes in weight reported.

Weights of individual divers or mean / median weights of the groups before and after each dive are not stated. We are told only the median weight loss and IQR for each dive.

There is a major concern that pre-dive hydration was different between the two dive depths and between divers doing the same dive. The divers had restriction of fluid intake for two hours before the 45mfw dives. For the 100 mfw dive "*the divers were allowed to hydrate as they normally do*" but we are not told how much water or other fluid each diver drank. Furthermore, during the dive the divers were allowed to urinate freely but the urine was not collected and the quantity produced by each diver was not measured.

If a diver consumed a large amount of fluid before the 100 mfw dives, his (or her) pre-dive weight would include the

weight of fluid in his gastrointestinal tract which is strictly extracorporeal. It is possible that absorption of water from the gastrointestinal tract during the dive would exceed the urine loss, so that weight would decrease but so would haematocrit as a result of haemodilution. This possibility is supported by the finding that after the 100mfw dive haematocrit decreased by 0.8%.

The authors of the study have assumed that the change in weight of a diver at the surface who is fully kitted up but did not perform the dives would be zero, i.e., there would be no insensible losses or production of urine over these periods of respectively more than 68 min for the 45 mfw dive and more than 170 min for the 100 mfw dive. (We say 'more than' because we do not know the amount of time out of the water before and after the dives between the two measurements of weight.) Not only is this assumption unrealistic but it skews the reported statistics in favour of a very small *P*-value. Furthermore, we have repeated the calculation of the regression coefficient for VGE grade versus weight change (Figure 2 in the paper) for the 45 mfw dive and we find that, in contradiction to the authors, the regression coefficient is *not* significantly different from zero, implying that there is *no* correlation between weight loss and VGE score.

We ask that the authors address these issues.

Reference

1 Tuominen L, Lundell R, Balestra C, Wuorimaa T, Koponen L, Sokolowski S, et al. Effects of fluid loss on the physiology of closed-circuit rebreather divers after 100- and 45-metre dives. Diving Hyperb Med 2025;55:391–7. doi: 10.28920/dhm55.4.391-397. PMID: 41364863.

Peter T Wilmshurst[1], Christopher Edge[2]

[1] United Kingdom Diving Medical Committee, UK
[2] Imperial College, Department of Life Sciences, London, United Kingdom

Corresponding author: *Dr Peter T Wilmshurst, United Kingdom Diving Medical Committee, Atcham, SY5 6QE, UK*
peter.wilmshurst@doctors.org.uk

doi: 10.28920/dhm56.1.96-97. PMID: 41875448.

Submitted: 21 January 2026
Accepted: 25 January 2026

Keywords
Bubbles; Deep diving; Diuresis; Immersion; Weight change

Reply to comment by Peter T Wilmhurst and Christopher Edge

We would like to express our appreciation to Dr Wilmshurst and Dr Edge for their interest in our article[1] and raising conversation about divers' fluid balance.

We agree that there is no convincing evidence that the amount of diuresis experienced by divers increases the risk of DCS. Also, there is no convincing evidence that dehydration is a risk factor for DCS. Yet, there are a lot of anecdotal reports of divers suffering from dehydration. It is quite common that divers experience severe thirst after longer dives. After one liter of fluid intake after longer dives, divers still report being thirsty, but are not at that point 'gasping' for fluids anymore. It might still take hours until these divers feel the need to urinate despite the large amount of fluid intake.

Outside of extremes, clinical signs and symptoms of dehydration in adults are subtle and assessment is difficult. No single diagnostic test exists to accurately determine volume status.[2,3] Early symptoms (mild dehydration, 1–3% loss of body weight) may include increased thirst, dry mouth, weakness, and decreased urine output,[3] symptoms divers tend to have after longer dives.

To address the criticism of "*there was no consistency of dive durations between subjects*" we would like to address that the dive protocols were designed to be as identical as possible: the instruction was to use the same depth, the same route, the same diluent gases, the same pO_2 setpoints and the same ascent algorithm. However, in real life circumstances it is impossible to achieve a precisely identical dive profile for all dives. A strict scientific approach from laboratory-like environments as in the Navy Experimental Diving Unit (NEDU), or in the deep pools in Belgium or Italy provide a superior setting for addressing specific scientific questions, whereas our research group had the goal to study divers in a 'real-life' situation, although it creates challenges to control confounding factors.

We were careful to protect the divers' privacy as the number of divers performing at this level in Finland is very limited. Therefore, we decided to present the results as shown in the article. After careful consideration and assurance that this goal would not be jeopardised, we decided to now add more detailed data, which is now shown in Table 1. Here we demonstrate each diver's dive (depth and time) and weight loss. The weight is shown as a pre and post dive difference rather than absolute values, again to protect diver anonymity. This also addresses the criticism raised to use InBody 720 composition analyser, as both measurements are done with the same equipment and therefore even if there were inaccuracies in absolute values, it would not skew the values that show the change in weight. The InBody 720 composition

Table 1
The individual divers' maximum diving depth and time, and difference in weight before and after dive measured after voiding bladder and in underwear only

Diver #	Depth (mfw)	Dive time (min)	Δ weight (kg)	Depth (mfw)	Dive time (min)	Δ weight (kg)
1	47	70	-2.0	102	180	-1.8
2	46	59	-1.1	103	180	-2.1
3	45	63	-1.9	102	176	-1.7
4	46	70	-1.0	103	171	-1.2
5	45	68	-1.2	102	170	-0.8
6	45	62	-0.6	100	170	-1.1
7	45	74	-1.0	104	155	-2.2
8	44	72	-1.0	103	155	-1.1
9	46	64	-1.1	105	148	-1.5

analyser was used in our study as we were also interested in divers' body composition, like fat-%, although these data were not reported in this study.

Although we are not able to determine the exact minute schedule of measuring weight before and after dives, the process was as following: The diver voided the bladder, he / she was weighed in underwear, he / she went to don the undergarment, drysuit, and mounted the preset CCR unit, did the safety checks and prebreathing, and started to dive. During the dive the divers were able to use a *P*-valve allowing them to urinate. Immediately after undonning their equipment, they voided the bladder, and were weighed wearing the same underwear before the first VGE measurement.

One of the limitations in our study was that we did not ask the divers to have a food and drink diary before the test dives. For safety reasons, we did not want to restrict or guide their eating or drinking before a challenging dive to 100 mfw. All divers were very skilled and experienced and had developed their own habits on how to prepare for the dives as challenging as this. The researchers chose not to interfere with their protocol.

Dr Wilmshurst and Dr Edge state they have repeated the calculation of the regression coefficient for VGE grade versus weight change. We were actually calculating correlation coefficient, not regression coefficient. According to our professional statistician, also involved in this study, Spearman's method looks for a monotonic correlation, whereas the linear regression specifically looks for a linear effect. Our dataset most likely is simply too small for linear regression analyses, as the recommended minimum is around 25. Our professional statistician chose the best option to present the data.[4]

From the confidence interval, it can be seen that although there was correlation in our data, it is practically negligible, in other words, the result is very weak. Considering that the number of participants was small, we stated in the article that caution is needed when interpreting causal relationships and our study did not offer new evidence supporting the notion that dehydration simply measured by weight loss, increases decompression stress in divers. Our study produced a null result, which is rarely reported in diving medicine research.

The authors thank for this opportunity to clarify these issues and share some additional data with the *Diving and Hyperbaric Medicine* journal readers.

References

1 Tuominen L, Lundell R, Balestra C, Wuorimaa T, Koponen L, Sokolowski S,et al. Effects of fluid loss on the physiology of closed-circuit rebreather divers after 100- and 45-metre dives. Diving Hyperb Med. 2025;55:391–7. doi: 10.28920/dhm55.4.391-397. PMID: 41364863.

2 Lacey J, Corbett J, Forni L, Hooper L, Hughes F, Minto G, et al. A multidisciplinary consensus on dehydration: definitions, diagnostic methods and clinical implications. Ann Med. 2019;51:232–51. doi: 10.1080/07853890.2019.1628352. PMID: 31204514. PMCID: PMC7877883.

3 Taylor K, Tripathi AK. Adult Dehydration. Treasure Island (FL): StatPearls Publishing; 2025. [cited 2026 Feb 14]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK555956/.

4 Jenkins DG, Quintana-Ascencio PF. A solution to minimum sample size for regressions. PLoS One. 2020;15(2):e0229345. doi: 10.1371/journal.pone.0229345. PMID: 32084211. PMCID: PMC7034864.

Laura J Tuominen[1], Anne K Räisänen-Sokolowski[2], Richard V Lundell[3]

[1] Tampere University Hospital, Centre for Prehospital Emergency Care, Finland
[2] Helsinki University Hospital and Helsinki University, Pathology, Finland
[3] Centre for Military Medicine, Finnish Defense Forces, Diving Medical Centre, Finland

Corresponding author: *Dr Laura J Tuominen, Tampere University Hospital, Centre for Prehospital Emergency Care, Annalankatu 17 D 15, Tampere, Finland*
ORCID: *0000-0003-0826-4679*
tuominenl@gmail.com

doi: 10.28920/dhm56.1.97-98. PMID: 41875449.

Submitted: 14 February 2026
Accepted: 22 February 2026

Keywords
Diving medicine; Letters (to the Editor); Physiology; Safety; Technical diving

Obituary

Daniel Mathieu, MD, PhD

Professor in Respiratory Medicine and Intensive Care and Professor in Hyperbaric Medicine
12 June 1953 – 15 January 2026

We are saddened to report that Professor Daniel Mathieu has passed away after a short course of illness. His contributions to the scientific development and the recognition of hyperbaric medicine in Europe cannot be underestimated, and the team of Lille, which he led for many years, has been at the forefront of the practice of HBO on the academic level.

Mr. Mathieu was an exceptional clinician, possessing an encyclopaedic and broad knowledge base, which he used to analyse and synthesise even the most complex situations. He was able to transmit his skills with both rigor and kindness, thanks to his pedagogical abilities and exemplary conduct. His knowledge extended far beyond medicine, allowing for lively discussions on politics, literature, philosophy, or simply the art of living. He was a true embodiment of humanism and humanity, both with his patients and colleagues, and possessed a dry, sometimes disarming sense of humour that gave rise to a few playful remarks. He was also a charismatic leader, capable of exercising authority yet always kind in his demands, able to bring out the best in everyone and to nurture his students, because, as he said, "*being a leader means knowing when to step aside for the benefit of others*", with his characteristic humility and modesty.

Deeply involved in the life of his hospital, he successively held, in line with his broad range of skills, the positions of head of an intensive care unit and the regional hyperbaric oxygen therapy centre, then head of the Intensive Care Department, as well as head of several committees at the Lille University Hospital. He was involved in developing the hospital's master plan and the institution's sustainable development strategy and was also a member of the board of directors. He played a significant but always discrete role in managing numerous health crises.

On the academic front, his notable contributions include the creation of the national inter-university diploma (DIU) in underwater and hyperbaric medicine, which he coordinated for 20 years; his presidency of the French scientific society MedSubHyp, and his co-founding of the European Society for Hyperbaric Medicine (ECHM). He was internationally recognised in the field of underwater and hyperbaric medicine and brought renown to Lille by organising the two 'global' ECHM Consensus Conferences on the Accepted Indications for Hyperbaric Oxygen Therapy there, in 1994 and 2004. He initiated the code of good practice at the French Ministry of Labor and subsequently initiated and supervised the development of the European Code of Good Practice in Hyperbaric Medicine (ECGP) by the COST B14 Action of the European Commission.

He was also an accomplished researcher, a true scientific mentor in the laboratory and in applied cross-disciplinary research, in fields as varied as the breadth of his knowledge: sepsis, microcirculation, ARDS, severe soft tissue infections, and hyperbaric oxygen therapy, combining pathophysiological approaches and biomarker evaluation, in the early stages of personalised medicine.

A passionate and energetic worker, he continued to serve the public hospital to which he was so devoted after his retirement, even providing consulting and expert services to the institution just days before his death. All those who had the privilege of working alongside him will cherish the memory of a rigorous, demanding, yet caring leader, attentive to the entire healthcare team and the doctors he trained.

For those of us who have been practicing hyperbaric medicine elsewhere in Europe and the world, he will be remembered as the diplomatic, yet firm, president of the European Committee for Hyperbaric Medicine (ECHM). Never placing his own persona centre stage, he discreetly steered the Committee into developing rigorously scientific guidelines and recommendations, that now serve as the basis for social security coverage in many European countries. In an era where 'evidence-based medicine' is, on one hand, considered most important and, on the other hand, often disregarded in favour of 'experience-based medicine', adherence to strict scientific principles while keeping a realistic view of the 'real' world, is a quality few others possessed in a similar way. Daniel Mathieu was proud of the accomplishments of the ECHM and the collaboration of ECHM as a new committee of EUBS, to be finalised next September, was somewhat cautiously accepted as he valued the independency of ECHM above all. We trust that this independency will be maintained with the acceptance of the new Bylaws of both Societies, and will strive to do so, in his honour.

Erika Parmentier[1], Peter Germonpré[2], Jacek Kot[3], Alessandro Marroni[4]

[1] Medical Director of the Centre for Hyperbaric Medicine, Intensive Care and Reanimation Department, University Hospital Lille, France
[2] Medical Director, Centre for Hyperbaric Oxygen Therapy, Military Hospital Brussels, Belgium
[3] Head of National Centre for Hyperbaric Medicine, Gdynia, Poland, Chairman of ECHM
[4] President, DAN Europe Foundation, Roseto, Italy, Vice-Chairman of ECHM

SPUMS
South Pacific Underwater Medicine Society

Notices and news

SPUMS notices and news and all other society information can be found on:
https://spums.org.au/

President's report

Neil Banham

This report is the last of my 6-year tenure as SPUMS President. At our 54th Annual Scientific Meeting (ASM) in 2026 in Palau, our President-elect Stephan Roehr will take over as President, and I will replace David Smart as Immediate Past President. Thank you David for all your work for SPUMS over many years.

Six years have gone by very fast! My early Presidency was drastically affected by the COVID-19 emergency, which required changes to the way we worked, played and held our ASMs. It also thwarted my planned travel to the UHMS and EUBS conferences to represent our Society.

Despite the trials and tribulations of COVID, our Society continues to thrive, with increasing membership, notable ASMs and a great journal which continues to be the leader in its field.

Some of the achievements of SPUMS during my Presidency:

- Access to all back issues (from the first *SPUMS Newsletter* in 1971!) of *Diving and Hyperbaric Medicine* (DHM) on the SPUMS (and DHM) website-funded by the Australasian Diving Safety Foundation (ADSF).
- A new and updated SPUMS website – which also allows ASM payments and registrations, hence avoiding the need for a third-party provider.
- New SPUMS logo.
- Successful ASMs both during and post COVID.
- Update of the SPUMS Medical (September 2025).
- SPUMS ASM Convenor Manual update.
- Update of SPUMS Purposes and Rules (now gender neutral).
- SPUMS Position Statement regarding paediatric and adolescent diving.
- Educational video regarding paediatric and adolescent diving.
- Joint Position Statement on immersion pulmonary oedema and diving from the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC) 2024.
- Joint Position Statement on atrial shunts (persistent [patent] foramen ovale and atrial septal defects) and diving: 2025 update. South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC).
- The creation of the Mike Bennett Scholarship.
- Updated list of Australasian Hyperbaric Units.
- Update of the Diving Doctor list on the SPUMS website.
- Listing of SPUMS Life Members on the SPUMS website.
- Continued success of the ANZHMG Introductory Course in Diving and Hyperbaric Medicine (which is always fully subscribed).
- Migration of HBO Evidence to the SPUMS website.
- Establishment of the Australasian Decompression Illness (DCI) Registry.
- Development of a short course in diving medicine/fitness to dive to educate medical practitioners and enable them to safely perform recreational dive medicals. This initiative has been funded by ADSF, with the first pre-course videos recently produced by Richard Harris and Simon Mitchell.
- Development of DHM policy regarding the use of Generative Artificial Intelligence.
- Update (2025) of the SPUMS Diploma requirements.

These achievements were as part of a fantastic team, your ExCom.

I also had the opportunity to represent SPUMS at the 3rd International Conference on Diving and Hyperbaric Medicine in Oman in February 2025 and at the 18th Annual Scientific Meeting of the Asian Hyperbaric and Diving Medicine Association (AHDMA) in July which was held in Da Nang, Vietnam.

Preparations for the SPUMS 54th ASM in 2026 to be held at the Palasia Hotel in Palau in May are well under way, with about 150 registrants so far. It promises to be a great meeting, with a diverse programme and fabulous diving.

2026 SPUMS ASM
Palasia Hotel, Palau
10–15 May 2026
Theme: *Free diving*
Keynote speakers: Professor Peter Lindholm and Professor Erika Schagatay

Qantas fly to Koror, Palau, departing Brisbane on Saturday mornings and returning Sunday morning. Flights to Koror

may also be via Taipei or Tokyo (Narita). Please contact spumstravel@diveplanit.com if you would like assistance with flights.

Registration, then booking of accommodation, diving and a pre- or post-conference liveaboard diving trip (via Diveplanit) are now available via the SPUMS website. South Pacific Underwater Medicine Society - SPUMS-ASM

The **2027 SPUMS 55th ASM** has been confirmed as follows:

Dates: 16–22 May 2027
Venue: Atmosphere Resort, Dumaguete, Philippines
Theme: *Innovation in Diving and Hyperbaric Medicine*
Cathy Meehan is the Convenor and Lizzie Elliott the Scientific Convenor.

Register your interest now for a pre-ASM liveaboard trip to Tubbataha. Diveplanit has optioned a full charter on the Philippines Aggressor II for the 8–15 May trip which fits well with the conference dates. https://diveplanit.wetravel.com/trips/spums-2027-philippines-tubbataha-liveaboard-add-on-diveplanit-travel-pty-ltd-99120653.

More information will be available soon, save the date!

Options for our 2028 ASM are being considered- further ideas are welcome.

The SPUMS Position Statement regarding paediatric and adolescent diving, published in the December 2024 issue of DHM, has just been made into an educational video by Richard 'Harry' Harris, co-hosted with Lizzie Elliott and dive instructor Charlotte Barbosa. Thank you to John Lippmann and the ADSF for funding this and making it happen. The video aims to educate parents, dive instructors, medical professionals and the prospective divers. It is now available via the SPUMS website: South Pacific Underwater Medicine Society - SPUMS - Health aspects of children diving.

SPUMS, with the assistance of ADSF, has commenced development of a Short Course in Diving Medicine to educate medical practitioners to enable them to safely assess fitness to dive and perform recreational dive medicals. The plan is to have a one- or two-day face to face course (possibly rotated between Australasian cities) with pre-course videos for prior learning. The first pre-course videos (Physics/physiology and Decompression Illness) were recently produced by Richard Harris and Simon Mitchell. Details of the course will be posted on the SPUMS website when confirmed.

The updated SPUMS Medical (6th edition 2025) is now available on the SPUMS website: South Pacific Underwater Medicine Society - SPUMS-Full Medical.

The ANZHMG Introductory Course in Diving and Hyperbaric Medicine was held in mid-February 2026, again in Fremantle. The 2026 course was full with a waitlist, so I strongly suggest that you register your interest early for 2027 if you are considering attending. https://spums.au/index.php/education/spums-approved-courses-for-doctors.

The Unsworth-Bennett Prize for the best candidate was awarded to Tony Yan.

Scholarships for trainees to attend this course are available thanks to the generosity of the ADSF. Please contact John Lippmann at johnl@adsf.org.au for more information. ADSF has also generously sponsored SPUMS membership for a year for Course participants.

Data entry into the Australasian Decompression Illness (DCI) Registry has now been active for more than a year (from 1st July 2024). Almost all Australasian hyperbaric facilities are currently participating, with the remainder hopefully completing the bureaucracy to participate soon. The Registry is hosted by Monash University and generously funded by ADSF and collects data on all divers treated for DCI. In the near future, this data will be available for research purposes and will be a potential resource for those seeking to complete their SPUMS Diploma thesis.

The Mike Bennett Scholarship for 2026 has been awarded to Xavier Vrijdag, who will present his work on the recent advances in measuring nitrogen narcosis at our Palau ASM. Congratulations Xavier.

There were four applications, showing that Mike's legacy continues to thrive.

The Mike Bennett Scholarship applications for 2027 are open and will close on the 31st of December 2026. The successful applicant will be funded to attend a scientific meeting of relevance to diving and hyperbaric medicine. Full updated details can be found here: South Pacific Underwater Medicine Society - SPUMS - Mike Bennett Scholarship.

In closing, I would like to again thank ExCom for their work over the term of my Presidency.

I would also like to express my sincere appreciation to Nicky Telles who continues to do a fantastic job managing our website and our journal.

Dr Neil Banham
SPUMS President

SPUMS Facebook page
Find us at:
SPUMS on Facebook

Mike Bennett Scholarship

Dr Sue Pugh, the wife of the late Professor Mike Bennett AM (a past SPUMS President and mentor to many), has bequeathed funds to create a Scholarship ('The Mike Bennett Scholarship') to fund the successful applicant to attend a Scientific Meeting of relevance to diving and hyperbaric medicine.

Suitable meetings may include (but are not limited to) the Annual Scientific Meeting (ASM) of South Pacific Underwater Medicine Society (SPUMS), Undersea and Hyperbaric Medical Society (UHMS), European Underwater and Baromedical Society (EUBS), Hyperbaric Technicians and Nurses Association (HTNA), British Hyperbaric Association (BHA).

The Mike Bennett Scholarship will be offered annually with one successful applicant chosen if they are considered to meet the selection criteria. The Scholarship may not be awarded in any given year if the applications received are not deemed suitable by the Selection Panel.

The Mike Bennett Scholarship is open to anyone working in the field of diving and hyperbaric medicine, including doctors, technical staff, nurses and those performing research in the field. Applications from those from Pacific nations who might not otherwise have the opportunity to attend an international scientific meeting are also encouraged.

Selection of the successful applicant will be overseen by a SPUMS Selection Panel comprising:

» Dr Sue Pugh
» SPUMS President (currently Dr Neil Banham)
» SPUMS Immediate Past President (currently Professor David Smart)
» SPUMS Education Officer (currently Dr David Cooper)
» *Diving and Hyperbaric Medicine* Journal Editor (currently Professor Simon Mitchell)

The successful applicant for The Mike Bennett Scholarship will have the actual costs of ASM Registration, travel and accommodation funded to a maximum of AUD $10,000. However, the applicant will be responsible for all other expenses incurred.

There are no rigidly defined selection criteria, however, preference will be given to the following:

- SPUMS members
- Presenting at the ASM:
  (1) A diving or hyperbaric medicine presentation
  (2) An evidence-based medicine presentation
- Those who have previously made a significant contribution to SPUMS.

Applications should include a structured abstract of their planned presentation and be submitted to president@spums.org.au.

Closing date: 31 December 2026

Dr Neil Banham MBBS, FACEM, DipDHM, ANZCA DipAdvDHM
SPUMS President

The Australian and New Zealand Hyperbaric Medicine Group

Introductory Course in Diving and Hyperbaric Medicine

Please note: This course is fully subscribed with a waiting list. If you are considering attending the course in 2027, dates are as below.

Dates: 15–26 February 2027
Venue: Hougoumont Hotel, Fremantle, Western Australia
Cost: AUD $3,500.00 (inclusive of GST) for two weeks

Successful completion of this course will allow the doctor to perform Recreational and Occupational (as per AS / NZS 2299.1) fitness for diving medicals and be listed for such on the SPUMS Diving Doctors List (provided that they continue to be a financial SPUMS member).

The course content includes:

- History of diving medicine and hyperbaric oxygen treatment
- Physics and physiology of diving and compressed gases
- Presentation, diagnosis and management of diving injuries
- Assessment of fitness to dive
- Visit to RFDS base for flying and diving workshop
- Accepted indications for hyperbaric oxygen treatment
- Hyperbaric oxygen evidence based medicine
- Wound management and transcutaneous oximetry
- In water rescue and management of a seriously ill diver
- Visit to HMAS Stirling
- Practical workshops
- Marine Envenomation

Contact for information:
Sam Swale, Course Administrator
Phone:*+61-(0)8-6152-5222*
Fax:*+61-(0)8-6152-4943*
Email: *fsh.hyperbaric@health.wa.gov.au*
Accommodation information can be provided on request.

Royal Australian Navy Medical Officers' Underwater Medicine Course

Dates: 19–30 October 2026
8–19 March 2027, 11–22 October 2027

Venue: HMAS Penguin, Sydney

The MOUM course seeks to provide the medical practitioner with an understanding of the range of potential medical problems faced by divers. Emphasis is placed on the contraindications to diving and the diving medical assessment, together with the pathophysiology, diagnosis and management of common diving-related illnesses. The course includes scenario-based simulation focusing on the management of diving emergencies and workshops covering the key components of the diving medical.

Cost: The course cost is AUD $2,332.00 (excl GST) but is subject to change.

Successful completion of this course will allow the doctor to perform Recreational and Occupational (as per AS/ NZS 2299.1) fitness for diving medicals and be listed for such on the SPUMS Diving Doctors List (provided that they continue to be a financial SPUMS member).

For information and application forms contact:
Rajeev Karekar, for Officer in Charge
Submarine and Underwater Medicine Unit
HMAS Penguin
Middle Head Rd, Mosman
NSW 2088, Australia
Phone: *+61 (0)2-9494-7292*
Email: *rajeev.karekar@defence.gov.au*

SPUMS Diploma in Diving and Hyperbaric Medicine

(Updated June 2025)

Requirements for candidates

For the Diploma of Diving and Hyperbaric Medicine (Dip DHM) to be awarded by the Society, the candidate must:

- be medically qualified;
- remain a current financial member of the Society for the duration of their candidacy for the Diploma;
- pay such administrative fees and charges (e.g., candidate registration fee) as may, from time-to-time, be approved by the Society's Executive;
- supply evidence of satisfactory completion of an examined two-week fulltime course in Diving and Hyperbaric Medicine at an approved facility. The list of such facilities may be found on the SPUMS website;
- have completed the equivalent (as determined by the Education Officer) of at least six months' fulltime clinical training in an approved Hyperbaric Medicine Unit;
- submit a written proposal for research in an area of relevance to underwater or hyperbaric medicine, in a standard format, for approval *before* commencing their research project;
- produce, to the satisfaction of the Academic Board, a written report on the approved research project, in the form of a scientific paper suitable for publication. Accompanying this written report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–5 above.

In the absence of documentation otherwise, it will be assumed that the paper is to be submitted for publication in *Diving and Hyperbaric Medicine*. As such, the structure of the paper should broadly comply with the 'Instructions for authors' available on the SPUMS website www.spums.org.au or at South Pacific Underwater Medicine Society - Submitting to DHM.

The paper may be submitted to journals other than *Diving and Hyperbaric Medicine*; however, even if published in another journal, the completed paper must be submitted to the Education Officer for assessment as a diploma paper. If the paper has been accepted for publication or published in another journal, then evidence of this should be provided.

The diploma paper will be assessed, and changes may be requested, before it is regarded to be of the standard required for award of the Diploma. Once completed to the reviewers' satisfaction, papers not already submitted to, or accepted by, other journals should be forwarded to the Editor of *Diving and Hyperbaric Medicine* for consideration. At this point the Diploma will be awarded, provided all other requirements are satisfied. Diploma projects submitted to *Diving and Hyperbaric Medicine* for consideration of publication will be subject to the Journal's own, independent peer review process.

Additional information – prospective approval of projects is required

The candidate must contact the Education Officer in writing (email is acceptable) to advise of their intended candidacy, and to discuss the proposed topic of their research. A written research proposal must be submitted before commencing the research project.

All research reports must clearly test a hypothesis. Original basic or clinical research is acceptable. Case series reports may be acceptable if thoroughly documented, subject to quantitative analysis, and the subject is extensively researched and discussed in detail. Reports of a single case are insufficient. Review articles may be acceptable if the international literature is thoroughly analysed and discussed, and the subject has not recently been similarly reviewed. Previously published material will not be considered. It is expected that the research project and the written report will be primarily the work of the candidate, and that the candidate is the first author where there are more than one. Evidence of each author's specific contributions should be provided in the case of multi-author papers.

The preferred format for submission of the final project is as a single file (Word or unlocked pdf), 1.5-line spaced, Times New Roman 12-point font, unformatted, with all figures and tables embedded in the document at an appropriate location.

It is expected that all research will be conducted in accordance with the joint NHMRC/AVCC statement and guidelines on research practice, available at: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/r39.pdf. or the equivalent requirement of the country in which the research is conducted. All research involving humans or animals must be accompanied by documentary evidence of approval by an appropriate research Ethics Committee. Human studies must comply with the Declaration of Helsinki (1975, revised 2013). Clinical trials commenced after 2011 must have been registered at a recognised trial registry site such as the Australia and New Zealand Clinical Trials Registry http://www.anzctr.org.au/ and details of the registration provided in the accompanying letter. Studies using animals must comply with National Health and Medical Research Council Guidelines or their equivalent in the country in which the work was conducted.

The SPUMS Diploma will not be awarded until all requirements are completed. The individual components do not necessarily need to be completed in the order outlined

above. However, it is mandatory that the research project is approved prior to commencing research.

As of 01 July 2025, projects will be deemed to have lapsed if:
(1) The project is inactive for a period of three years, or
(2) The candidate fails to renew SPUMS Membership in any year after their Diploma project is registered (but not completed).

For unforeseen delays where the project will exceed three years, candidates must advise the Education Officer in writing if they wish their Diploma project to remain active, and a three-year extension may be approved. If there are extenuating circumstances why a candidate is unable to maintain financial membership, then these must be advised in writing to the Education Officer for consideration by the SPUMS Executive. If a project has lapsed, then the candidate must submit a new application as per these guidelines.

Fees and charges: From 01 January 2026 a one-off Registration Fee of AUD $250.00 will be payable at the time of enrolment for the Diploma. This is in addition to the annual Society Membership Fee.

The Academic Board reserves the right to modify any of these requirements from time to time.

As of June 2025, the SPUMS Academic Board consists of:
Dr David Cooper, Education Officer
Associate Professor Simon Mitchell.

All enquiries and applications should be sent to:
Dr David Cooper
Email: *education@spums.org.au*

Keywords
Qualifications; Underwater medicine; Hyperbaric oxygen; Research; Medical society

---

Notices and news

EUBS notices and news and all other society information can be found on:
http://www.eubs.org/

President's report

Bengüsu Mirasoğlu

Artificial intelligence in academic research: Friend or foe?

Artificial intelligence has rapidly become part of our everyday lives. From digital assistants and translation tools to recommendation systems and automated data analysis, AI technologies are increasingly integrated into the way we work, communicate, and access information. It is therefore neither surprising nor avoidable that these tools are also beginning to influence academic life and scientific research. Medicine and biomedical research have always evolved alongside technological innovation. From typewriters to word processors, and from printed indexes to digital literature databases, each step has made research dissemination faster and more accessible. AI tools represent the next stage of this progression. Large language models and AI-assisted platforms can help researchers navigate vast amounts of scientific literature, support data analysis, assist with statistical interpretation, and even help prepare or refine scientific manuscripts.

In many ways, these capabilities offer clear advantages. AI tools may help synthesize information, identify patterns within large datasets, and improve efficiency, enabling investigators to focus more on scientific interpretation and innovation. Similarly, AI-assisted language tools may help researchers present their findings more clearly, improve clarity in writing, and reduce language barriers that often disadvantage non-native English speakers. This may contribute to more equitable participation in the global research dialogue.

However, it is important to recognise the limitations of these technologies. Artificial intelligence systems do not possess scientific reasoning or critical judgment. Their outputs are generated from patterns in existing data rather than true scientific understanding. As a result, they may produce inaccuracies, incomplete interpretations, statements expressed with unwarranted confidence, or occasionally even fabricated references.

The responsibility for the accuracy, originality, and integrity of scientific work, including the design, conduct, interpretation, and reporting of research, must therefore remain entirely with the human authors. For this reason, AI tools should be viewed as supportive instruments rather than substitutes for scientific expertise. In this context, transparency in the use of AI tools, careful verification of generated content and adherence to established principles of research integrity are essential for maintaining trust in the scientific record.

For the research community, the key question is not whether AI will influence scientific writing and research, it already has, but rather how these tools can be integrated responsibly. AI should be regarded as an assistive technology rather than a replacement for scholarly expertise. Critical thinking, methodological rigor, and intellectual ownership remain the defining features of high-quality research.

Professional scientific societies also have an important role in guiding the thoughtful adoption of emerging technologies. Beyond establishing ethical standards, supporting education on the responsible use of AI in research practice, and encouraging open discussion about its benefits and limitations, scientific communities can help ensure that technological progress strengthens rather than undermines scientific integrity.

As researchers and clinicians, we have always adapted to new tools that enhance our ability to generate and communicate knowledge. Artificial intelligence will almost certainly become an increasingly common presence in research and academic writing in the coming years. Our goal should not be to resist technological change, but to engage with it thoughtfully. When used responsibly, AI has the potential to become a valuable tool in supporting rigorous research, fostering collaboration, and ultimately improving the knowledge that benefits our patients and society.

Bengüsu Mirasoğlu
President EUBS

EUBS Facebook page

Find us at:
https://www.facebook.com/p/European-Underwater-and-Baromedical-Society-100057593314089/

EUBS Notices and news

Annual Scientific Meeting 2026

EUBS is happy to invite you to our 50th Scientific Meeting which will take place from 14–18 September 2026 in Geneva. It will be the second time our Annual Meeting is organised in Switzerland (the first time was exactly 10 years ago) and it will take place again at the Geneva International Conference Centre (CICG). The Geneva University Hospitals (HUG) and the Swiss Society of Underwater and Hyperbaric Medicine (SUHMS) are joint organisers. The Swiss Confederation has an international reputation in the world of diving thanks to the work of Professor A Bühlmann in Zürich. Geneva makes the perfect choice because of the presence of the only hyperbaric hospital facility in Switzerland at the University Hospital of Geneva.

This 50th congress will be a perfect blend of scientific exchanges and unforgettable activities to celebrate this jubilee edition of EUBS.

During the Congress week, we will also host the ECHM Consensus Conference on Indications of Hyperbaric Oxygen Therapy. Organised every 10 years, this will be the fourth edition and will update the Indications List established in 2017 (see *Mathieu D, Marroni A, Kot J. Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. Diving Hyperb Med. 2017 Mar;47(1):24–32. doi: 10.28920/dhm47.1.24-32. PMID: 28357821. PMCID: PMC6147240*). From then on, ECHM will be closely integrated with EUBS as an independent scientific committee.

It is expected that close to 400 colleagues in the field of diving and hyperbaric medicine from the five continents will attend this important scientific meeting.

EUBS are delighted to welcome you to participate in this meeting and contribute to its success. If you have been monitoring the conference website http://www.eubs2026.com you will have noticed that the registration and abstract submission are now open.

Important deadlines are:
30 March 2026 – end of early bird registration period.
27 April 2026 abstract submission deadline.

So gear up, write your abstract, register, remember to bring your partner and kids along – and we'll meet again sooner than you think.

If you would like to apply for a student travel grant for this meeting, please read the rules and procedure here: https://www.eubs.org/?page_id=914

EUBS Executive Committee

This year, we must elect a new Member-at-Large for ExCom, to replace Anne Räisänen-Sokolowski; our 2022 Member-at-Large, after a tenure of four years. Nominations for this position can be sent by email to secretary@eubs.org; you can nominate yourself or someone else, stating briefly why you think he/she/you are suited for the position. ExCom will contact the persons nominated and discuss with them further; then, in early June, a shortlist of candidates will made available for voting, in the usual manner.

If you want to contribute and help our Society, please come forward and send your short CV to our secretary (secretary@eubs.org) before 1 June 2026.

If you do not feel up to presenting yourself, why not nominate someone else? Suggestions are welcome at the same email address.

EUBS Affiliate Society agreements

For 2026, the agreement has been renewed with the following scientific societies in order to promote membership and contact among the hyperbaric and diving scientists and practitioners in Europe and (why not) worldwide. Members of these societies benefit from a 10% reduction on the EUBS membership fees, when providing proof of their membership of the 'other' society. Simply indicate the Affiliate Society from the drop-down list on the EUBS Membership Application or Renewal Form.
Belgian Society for Diving and Hyperbaric Medicine (http://www.sbmhs-bvoog.be)
Scott Haldane Foundation, The Netherlands (http://www.scotthaldane.org)
Italian Society for Diving and Hyperbaric Medicine (http://www.simsi.it/)
German Society for Diving and Underwater Medicine (http://www.gtuem.org)

French Society for Diving and Hyperbaric Medicine (http://www.medsubhyp.com)
Swiss Society for Underwater and Hyperbaric Medicine (http://www.suhms.org)
Undersea and Hyperbaric Medical Society (http://www.uhms.org)
Spanish Society for Diving and Hyperbaric Medicine (www.asemhs.org)
Austrian Society for Underwater and Hyperbaric Medicine (www.asuhm.at)
Dutch Society for Diving Medicine (www.duikgeneeskunde.nl)
Finnish Society for Diving and Hyperbaric Medicine (www.sukelluslaakarit.fi)

We are pleased to announce that in exchange, EUBS members benefit from a substantial reduction to their UHMS membership, simply mention your EUBS membership when enrolling/renewing your UHMS membership.

EUBS Website

Please visit the EUBS Website for the latest news and updates. The 'EUBS History' section (under the Menu item 'The Society') is still missing some information missing in the list of EUBS Meetings, Presidents and Members-at-Large – please dig into your memories and help us complete this list!

By popular demand, EUBS Members can also download the complete Abstract Book of previous EUBS Meetings from the Member Area.

While on the EUBS website, make sure you look at our Corporate Members' webpage (http://www.eubs.org/?page_id=91). On this page, logos and links are placed of those organizations, societies and companies that support EUBS financially. EUBS is grateful for their continuing support and would suggest that if you contact any of them, please do so by clicking on the link at that page, so they'll know that you did so through the EUBS website.

OXYNET Database

Since 2004, a public online database of European Hyperbaric Chambers and Centers has been available, started and initially maintained by the OXYNET Working Group of the COST B14 project of the European Commission, later by the European Committee for Hyperbaric Medicine (ECHM). The original website www.oxynet.org is no longer accessible, and the full OXYNET database of hyperbaric centers has been placed on the EUBS website (http://www.eubs.org/?page_id=1366).

If you have updated information or any other request or remark, please send an e-mail to oxynet@eubs.org. If you can collect information for more than one center in your area or country, please do.

The EUBS website is at
http://www.eubs.org/
Members are encouraged to log in and keep their personal details up to date.

The latest issues of *Diving and Hyperbaric Medicine* are via your society website login.

Events, courses & news

The Science of Diving

Support EUBS by buying the PHYPODE book '*The science of diving*'. Written for anyone with an interest in the latest research in diving physiology and pathology. The royalties from this book are being donated to the EUBS.

Available from:
Morebooks
https://www.morebooks.de/store/gb/book/the-science-of-diving/isbn/978-3-659-66233-1

Historical Diving Society Australia - Pacific

P O Box 347, Dingley Village Victoria, 3172, Australia
Email: info@historicaldivingsociety.com.au
Website: https://www.historicaldivingsociety.com.au/

Publications database of the German Diving and Hyperbaric Medical Society (GTÜM)

EUBS and SPUMS members are able to access the German Society's large database of publications in diving and hyperbaric medicine. EUBS members have had this access for many years. For SPUMS members access will be available soon for you, GTÜM has a new website and access is being created specifically for you. There will be a link in the 'members only' area of the SPUMS website. We are working to get this link updated, so keep an eye out.

Diving and Hyperbaric Medicine Journal copyright statement 2026

DHM Journal Facebook

Find us at:
https://www.facebook.com/divingandhyperbaricmedicine

Scott Haldane Foundation

An institute dedicated to education in diving medicine for 50 years, the Scott Haldane Foundation (SHF) has organised more than 320 courses all over the world and has educated over 2000 physicians in diving medicine. SHF is targeting an international audience with courses worldwide, conducted in English.

As of 1 January 2026, the Director of SHF, Drs Jan-Jaap Brandt Corstius, has taken his retirement – after a career of over 50 years in diving medicine education. He has made the Scott Haldane Foundation to the success it is now, and even though his organisational talents and personality will be sorely missed, we are confident that the quality of the courses and the 'spirit' of SHF will continue in the future – rising to even higher levels. The SHF Managing Team now consists of Mr Guy Thomas (Director/CEO) and Mrs Jean Spits (Course/Office Manager). Contact information remains the same: info@scotthaldane.nl.

Below is the schedule of upcoming SHF-courses in 2026. The courses Medical Examiner of Divers (part 1 and 2) and SHF In-depth courses, as modules of the Level 2d Diving Medicine Physician course, fully comply with the ECHM/EDTC curriculum for Level 1 and 2d respectively and are accredited by the European College of Baromedicine (ECB).

25–29 May 2026: 32nd In-depth course 'What a Diving Doctor MUST know' – Utrecht, The Netherlands
29 August – 6 September 2026: Level I course Medical Examiner of Divers – Hurghada, Egypt (full)
7–14 November 2026: 33rd In-depth course 'Breathe in, Breathe out, Repeat" (level 2d) – Dauin, Philippines
14–21 November 2026: 33rd In-depth course 'Breathe in, Breathe out, Repeat" (level 2d) – Dauin, Philippines

On request: Internship HBOT (level 2d) NL/Belgium

The course calendar will be updated regularly. For the latest information see: www.scotthaldane.org.

Diving and Hyperbaric Medicine: Instructions for authors

(Full version – updated January 2026)

Diving and Hyperbaric Medicine (DHM) is the joint journal of the South Pacific Underwater Medicine Society (SPUMS) and the European Underwater and Baromedical Society (EUBS). The journal publishes high-quality papers on all aspects of diving and hyperbaric medicine that are of interest to diving medical professionals, physicians of all specialties, scientists, members of the diving and hyperbaric industries, and divers themselves.

Manuscripts must be submitted exclusively to DHM, unless an authenticated copyright exemption accompanies the work. After editorial pre-screening all submissions chosen to progress are subject to peer review. Occasional exceptions to this are societal policy documents or the products of consensus or committee processes. Accepted manuscripts will be edited for clarity, style, and journal format.

Correspondence may be directed to:
Editor, Diving and Hyperbaric Medicine
Department of Anaesthesiology, University of Auckland
Private Bag 92019, Auckland 1142, New Zealand
Email: editor@dhmjournal.com
Phone: +64 (0)27 4141 212
Editorial Manager: editorialassist@dhmjournal.com
European Editor: euroeditor@dhmjournal.com
General Journal enquiries: info@dhmjournal.com
All submissions must be made through Manuscript Manager: http://www.manuscriptmanager.net/dhm.

Authors must create a user account with a personal username and password, which should be kept for future submissions. Only the submitting author can correspond during the peer review process, and this role must remain unchanged throughout. The platform provides on-screen help to guide authors through each stage of submission.

Article types

DHM publishes several categories of articles, each with specific length and formatting requirements.

Original articles, technical reports, consensus reports and large case series should generally not exceed 3,000 words, with a maximum of 30 references. Longer submissions may be considered at the discretion of the Editor. These articles must include a structured abstract of up to 250 words (divided into *Introduction, Methods, Results, and Conclusions*), followed by the main text organised as *Introduction, Methods, Results, Discussion, Conclusions, References, Acknowledgements, Conflicts of Interest and funding.* Captions for tables and figures should be placed at the end of the manuscript.

Review articles should normally not exceed 5,000 words, with a maximum of 50 references. Abstracts must not exceed 300 words. The structure of both the article and the abstract is at the discretion of the author. DHM rarely accepts purely narrative reviews that do not describe a systematic search and filtering strategy with article selection summarised in a PRISMA diagram.

Short communications, small case series, and case reports are limited to 1,500 words and 20 references. Abstracts are usually unstructured, and contain no more than 200 words. There are no rigid criteria defining subject matter for case reports, but manuscripts describing unique, rare or highly interesting observations or cases are most likely to be accepted. Reports describing common clinical scenarios (such as the treatment of an established indication with hyperbaric oxygen) or cases with features that have often been reported previously are very unlikely to be progressed.

Letters to the Editor must not exceed 600 words and may contain a single table or figure, with up to five references.

The journal occasionally publishes "**World as it is**" articles, which report on matters of general interest to divers, especially where methodology is of insufficient rigour for an original study. These follow the length and reference limits of an original article but may be more flexible in structure. Abstracts are encouraged but not mandatory.

Supplements may be published occasionally for longer works or thematic collections. Proposals for supplements should be discussed with the Editor in advance.

Manuscript preparation

All manuscripts must be submitted in Microsoft Word (.doc or .docx) or Rich Text Format (.rtf). Text must be formatted in Times New Roman, size 11 or 12, with 1.5 line spacing. Pages should be numbered consecutively, and line numbering must be continuous throughout. Do not use headers or footers.

Title page

The title page must include the full article title, full names of all authors with their institutional affiliations, and complete contact details for the first and corresponding authors. The corresponding author must supply an ORCiD ID, which should also be entered into Manuscript Manager.

Keywords

A maximum of seven keywords must be listed, chosen from the DHM keyword list (available on the journal website

or Manuscript Manager). Terms already in the article title should not be repeated as keywords. Authors may propose new keywords consistent with MeSH terminology, https://www.nlm.nih.gov/mesh/meshhome.html/, subject to editorial approval.

Text structure

Original research articles should follow the structure outlined under "**Article types**." Review articles and other formats may adopt flexible structures but must remain clear and coherent.
Section headings must conform to DHM style:
Main section heading in bold and sentence case (e.g., **Introduction**)
SUBSECTION HEADING 1 IN UPPER CASE
Subsection heading 2 in italic sentence case

English spelling must follow the *Concise Oxford Dictionary* (11th edition or later).

Measurements

Measurements will normally be in SI units (mmHg are acceptable for blood pressure measurements) and normal ranges should be included where appropriate. Authors are referred to the online BIPM brochure, International Bureau of Weights and Measures (2006), The International System of Units (SI), 8th ed, available as a pdf at https://www.bipm.org/en/publications/si-brochure/. Atmospheric and gas partial pressures and blood gas values should be presented in kPa (atmospheres absolute [abbreviated as atm abs]/bar/mmHg may be provided in parenthesis). The ambient pressure should always be given in absolute not gauge values unless there is a particular reason to use gauge pressure and the distinction is made clear. Water depths should be presented in metres of sea (or fresh) water (msw or mfw). Cylinder pressures may be presented as 'bar' or megapascals.

Abbreviations and equations

Abbreviations should be introduced in parentheses after the full term on first use, and separately in both the abstract and the main text. Only standard abbreviations should be used. Overuse of abbreviations is strongly discouraged.

Equations must be camera-ready, prepared in Times New Roman font, and submitted as TIFF files.

References

References must be numbered consecutively in the order they appear in the text, tables, or figures, and cited using **superscript numbers**[2], please do not use [2] or (2). They should not appear in the abstract. References cited in tables or figures should continue the sequence from the main text.

The reference style of DHM follows the recommendations of the International Committee of Medical Journal Editors (ICMJE). *Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals: Sample References* (updated June 2024). Journal names must be abbreviated according to PubMed. If a journal is not listed on PubMed write its name in full. Where available, all of doi, PMID, and PMCID identifiers (in that order) must be included for all journal articles. Do not include epub dates.

Examples:
Journal article:
Wilson CM, Sayer MDJ. Transportation of divers with decompression illness on the west coast of Scotland. Diving Hyperb Med. 2011;41:64–9.
Journal article with identifiers:
Doolette DJ, Mitchell SJ. In-water recompression. Diving Hyperb Med. 2018;48:84–95. doi: 10.28920/dhm48.2.84-95. PMID: 29888380. PMCID: PMC6156824.
Book:
Kindwall EP, Whelan HT, editors. *Hyperbaric medicine practice.* 3rd ed. Flagstaff (AZ): Best Publishing Company; 2008.
Chapter in a book:
Moon RE, Gorman DF. Treatment of decompression disorders. In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving.* Edinburgh: Saunders; 2003. p. 600–50.
Workshop or conference proceedings:
Vann RD, Mitchell SJ, Denoble PJ, Anthony TG, editors. *Technical diving conference proceedings*. Durham (NC): Divers Alert Network; 2009.
NEDU technical reports:
Goodman MW, Workman RD. *Minimal-recompression, oxygen-breathing approach to treatment of decompression sickness in divers and aviators*. Research Report NEDU TR 5-65. Washington DC: Navy Experimental Diving Unit; 1965.

For all material / reports / publications that are not books or journal articles and that are available online please provide a cited date and web address in the format:
[cited Year Mo Day]. Available from: http://www.xxxxxxxxxxxxxxxxxxxxxxxxxx. e.g., [cited 2018 January 02]. Available from: http://www.dtic.mil/get-tr-doc/pdf?AD=ADA452905.

Further examples are available on the ICMJE website and National Library of Medicine: https://www.nlm.nih.gov/bsd/uniform_requirements.html. Authors are responsible for checking all references against the original sources.

Abstracts from meeting proceedings should be avoided unless essential. Personal communications should be cited only in the text. EndNote and other reference managers may be used, but all field codes must be removed before submission.

Tables and figures

Tables must be submitted as separate Word documents, one file per table, and uploaded through Manuscript Manager under the "*Table*" category. Each file should be labelled with the first author's name and table number. Tables must be prepared using Word's table function, with framed cells (all borders showing), and without bold lines or shading. Please avoid using autoformatting functions in tables. Very large tables may be published online as supplementary material at the Editor's discretion.

Figures must be submitted separately as high-resolution TIFF or JPEG files, uploaded in numerical order. Each file should be named with the first author's name and figure number. Captions and legends must be provided at the end of the manuscript, not within the figure itself. Captions should normally contain fewer than 40 words and define all abbreviations used in the figure.

Graphs should use simple, clear formatting without 3D effects. Axis labels must use sentence case (not all capitalised words), and font sizes should remain legible when reduced for single-column presentation unless the graph obviously requires full page width. Graphs prepared in Excel should be submitted with their original data tables, uploaded as a separate Excel file. Please see data formatting guidelines below when preparing graphs because (for example) axes labels should also conform with these formatting guidelines.

All patient images must be anonymised.

The approximate positions of tables and figures should also be identified in the manuscript text e.g., "*Differences in rates of decompression illness were not significant (Table 1)*", etc.

Authors are responsible for obtaining permission to reproduce any figures, images, or tables from previous publications. This permission must be acknowledged in the figure caption using the format "*Reproduced with permission of …*" or as specified by the copyright holder.

Data formatting guidelines

Express variability as mean (SD), not mean ± SD.
Use composite units like $g{\cdot}L^{-1}$ or $mL{\cdot}kg^{-1}{\cdot}min^{-1}$, not g/L or mL/kg/min.
Add a space after symbols like <, >, ≤, ≥ (e.g., > 25, not >25).
Use decimal points, not commas (e.g., 2.5, not 2,5).
Use commas in numbers > 1000 (e.g., 1,000 or 25,300,000).
Include a space between a number and its unit (e.g., 25 msw).
Italicise n (sample size) and P (P-values).
Use spaces in expressions like n = 25 and P < 0.05, not n=25 or P<0.05.
Use an en-dash (–) with no spaces for number or page ranges (e.g., 17–420).
Place the percent sign directly after the number (e.g., 51%, not 51 %).
For numbers ≥ 10 use numerals. For numbers < 10 use words, unless the number appears before an abbreviated unit of measurement, e.g., 6 m, 6 h,

Appendices and supplementary material

(Appended on the DHM website and linked in the text)
Submit appendices and supplementary material using the same formatting guidelines as tables or figures:
Figures: Submit as TIFF or JPG files.
Tables: Submit in Word format.
Other documents: PDFs are also accepted.
Clearly label each file (e.g., *Appendix 1*, *Supplement 2*) and include a caption at the top. Be sure to indicate in the manuscript text where each appendix or supplement is referenced.

Other manuscript requirements and guidelines

General Standards:
DHM adheres closely to the *Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals* (ICMJE, Dec 2015). Authors are encouraged to read these recommendations and other resources on the ICMJE website: www.icmje.org/recommendations.

Study-Specific Guidelines:
Authors should follow appropriate guidelines for their study type (e.g., CONSORT for randomised trials, PRISMA for reviews, STROBE for observational studies). See: www.equator-network.org.

Trial design and reporting:
Before writing their manuscript, authors should review DHM's guidance on trial design, sample size, statistical methods, and results presentation: Trial Design and Analysis PDF

Ethics and consent:
Human studies must comply with the 1975 Helsinki Declaration (rev. 2013).
Interventional human studies: Include a statement of Ethics Committee/IRB approval (with approval number) at the beginning of the Methods section. A copy of the approval must be uploaded. Also, include a statement confirming written informed consent where applicable.
Observational human studies: Almost always require Ethics Committee/IRB approval, documented as above.
Retrospective human studies such as database mining: Typically require Ethics Committee/IRB approval but DHM recognises that some studies in some jurisdictions may be exempt. However, author attestation to that effect must be confirmed by a suitable authority such as an ethics committee chair.
Animal Studies: Must follow NHMRC guidelines or equivalent in the country of research. Include a statement of Ethics Committee/IRB approval (with approval number)

at the beginning of the Methods section. Details on animal welfare must not rely on past publications. For guidance, see: The Physiological Society's advice
Clinical trials: All trials started after 2011 must be registered with a recognized registry (e.g., ANZCTR, EudraCT). Registration details must appear in both the manuscript and the Mandatory Submission Form (MSF).
Case reports and series: For individual case reports, written patient consent for anonymous publication (clinical details/images) must be provided. A statement that the patient provided such consent must appear at the start of the case report section of the manuscript. For case series with only anonymous summary data, ethics committee review is likely required. Check with your local ethics committee if unsure.

Authorship:
Only those who made significant contributions should be listed as authors. See DHM's Authorship Guidelines. More than six authors must be justified. Additional contributors may be mentioned in Acknowledgements.

Mandatory Submission Form (MSF):
All submissions must include a fully completed MSF, signed by the first author and corresponding author (if different). Authors must be listed in publication order. The MSF requires full contact details for the first and corresponding authors. Download the MSF from: Author Instructions

Conflict of interest:
Conflicts must be summarised in the MSF. If the paper is accepted, detailed disclosures must be submitted using the ICMJE form: ICMJE Disclosure, one per author with a conflict. All financial or other conflicts (e.g., consulting, patents, data access limitations, or publication control) must be declared. DHM may request clarification. Conflicts, or a declaration of none, will be published with the article.
Omitting conflicts before peer review may delay or prevent publication.

Peer review and publication process

All submissions chosen by the editorial office for progression are subject to open peer review, generally involving Editorial Board members and external reviewers. In most cases, reviewers' names are disclosed to authors in the interests of transparency. Reviews are normally completed within four weeks, though this may vary depending on availability.

Most manuscripts require revision before acceptance. Revised manuscripts must be uploaded to Manuscript Manager using the "**resubmit**" function, not as a new submission.
Proofs of accepted articles are sent as PDF files to the corresponding author. Authors must check proofs carefully and return corrections within the specified time.

Language and editing support

All manuscripts must be written in clear English. The editorial team may provide limited assistance for authors whose first language is not English, but responsibility for language clarity rests with the author. Independent editing services are available through the European Association of Science Editors (EASE).

Copyright and access

By submitting to DHM, authors agree to grant the journal a non-exclusive licence to publish their article in digital form, while retaining copyright. Articles remain under a one-year embargo, after which they are freely available on the DHM website and PubMed Central. Authors may deposit the restricted PDF version in institutional repositories during the embargo period. Immediate open access is available upon payment of a release fee set by the publishers.

No publication fees are charged for standard submissions. After publication, two PDF versions will be provided to the corresponding author: one restricted for institutional use and one unrestricted for later use.

Use of artificial intelligence

AI-generated content, including text or images produced by tools such as ChatGPT, may not be included in submissions without explicit approval from the Editor. If approved, such use must be fully documented in the Methods or Acknowledgements sections. DHM follows the COPE position statement on AI-generated content.

Submission checklist

At submission, the following files must be uploaded: the completed Mandatory Submission Form; ethics approval and patient consent documents, where relevant; the main manuscript; tables (one per file); figures (one per file); any supplementary material or appendices; Excel data files if graphs were generated in Excel; and a submission letter confirming that the article is offered exclusively to DHM.

Supporting documents, including keyword lists, authorship guidelines, reference samples, trial design advice, and ethics resources, are available on the DHM website.

For your convenience, we have provided a downloadable checklist to guide you through the submission process. Please ensure that all necessary steps are completed and that all required documents are included before submitting your manuscript to DHM. This checklist will help you verify that you have adhered to all guidelines and ensure a smooth submission process.

IN THE EVENT OF A LIFE THREATENING EMERGENCY PLEASE CALL YOUR LOCAL EMERGENCY SERVICES FIRST

For an accident in Australia, call the nearest public hospital with a Hyperbaric Unit and ask for the Duty Hyperbaric Doctor – see list below:

New South Wales/ACT **(02) 9382 2222** (Prince of Wales Hospital)
Northern Territory **(08) 8922 8888** (Royal Darwin Hospital)
Queensland **(07) 3646 8111** (Royal Brisbane Hospital) **(07) 4433 1111** (Townsville Hospital)
South Australia **(08) 7074 0000** (Royal Adelaide Hospital)
Tasmania **(03) 6166 8308** (Royal Hobart Hospital)
Victoria **(03) 9076 2000** (The Alfred)
Western Australia **(08) 6152 2222** (Fiona Stanley Hospital)

If you have a diver emergency **OUTSIDE AUSTRALIA**, please use one of the contact numbers below:

New Zealand from within New Zealand:
0800-4DES 111
(Diving Emergency Service)
New Zealand from overseas:
+64 9 445 8454
Asia, Pacific Islands **+618-8212 9242** (DAN World)
Americas **+1-919-684 9111** (DAN)
Europe **+39-06-4211 8685** (DAN EUROPE)
Southern Africa **+27-10-209 8112** (DAN SOUTHERN AFRICA)

Scholarships for Diving Medical Training for Doctors

The Australasian Diving Safety Foundation is proud to offer a series of annual Diving Medical Training scholarships. We are offering these scholarships to qualified medical doctors to increase their knowledge of diving medicine by participating in an approved diving medicine training programme. These scholarships are mainly available to doctors who reside in Australia. However, exceptions may be considered for regional overseas residents, especially in places frequented by Australian divers. The awarding of such a scholarship will be at the sole discretion of the ADSF. It will be based on a variety of criteria such as the location of the applicant, their working environment, financial need and the perception of where and how the training would likely be utilised to reduce diving morbidity and mortality. Each scholarship is to the value of AUD $5,000.00.

ADSF
AUSTRALASIAN DIVING SAFETY FOUNDATION

There are two categories of scholarships:

1. ADSF scholarships for any approved diving medical training program such as the annual ANZHMG course at Fiona Stanley Hospital in Perth, Western Australia.
2. The Carl Edmonds Memorial Diving Medicine Scholarship specifically for training at the Royal Australian Navy Medical Officers' Underwater Medicine Course, HMAS Penguin, Sydney, Australia.

Interested persons should first enrol in the chosen course, then complete the relevant ADSF Scholarship application form available at: https://www.adsf.org.au/r/diving-medical-training-scholarships and send it by email to John Lippmann at johnl@adsf.org.au.
