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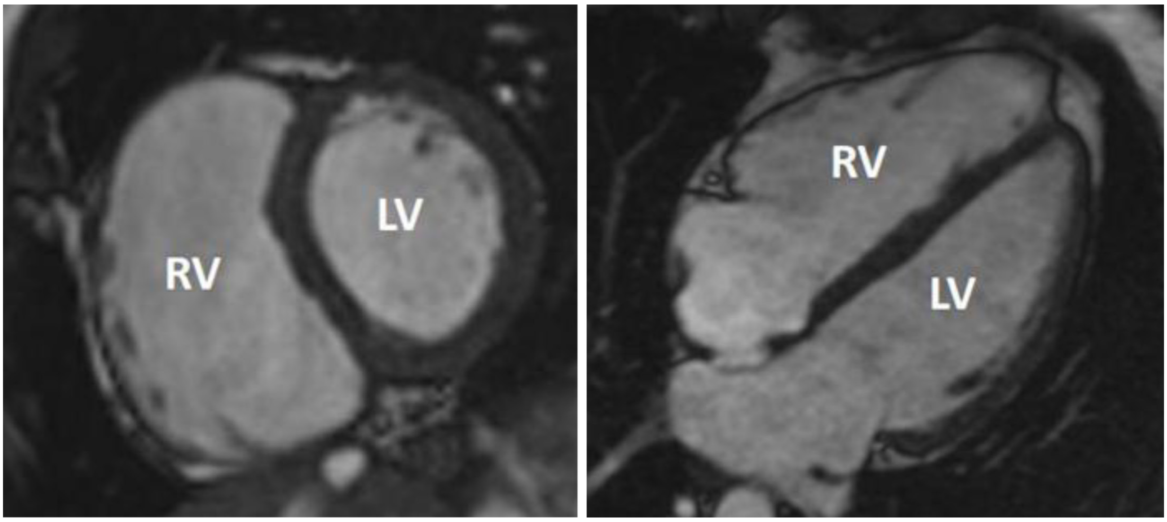

Decompression sickness with right heart dilation

Precordial vs subclavian Doppler for bubble detection

Spirometry changes in hyperbaric chamber attendants

Are large lungs a risk in diving?

Influence of thick wetsuits on spirometry

Diving fatalities in Victoria, Australia

Relationship of venous bubbles to decompression sickness

Guideline on patent foramen ovale and diving

Hyperbaric oxygen for complications of facial filler

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To publish a journal and to convene members of each Society annually at a scientific conference

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CONTENTS

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The Editor's offering

Welcome to the first issue of Diving and Hyperbaric Medicine Journal for 2025. We go to press with high anticipation of a fabulous SPUMS ASM in Bali, 18–23 May (see notice page 69). We also advocate forward planning for the EUBS ASM in Helsinki 2–6 September. Both meetings are in terrific locations and promise to be extremely high quality.

This issue leads off with an evaluation by Lesley Blogg and colleagues of concordance between post-dive Doppler bubble grades obtained at the precordial and subclavian sites. Concordance was relatively poor, especially in respect of movement grades, and the authors conclude that observations from both positions will give the most comprehensive appraisal of bubble load.

Kübra Canarslan Demir and colleagues present a longitudinal study of spirometry in hyperbaric chamber attendants after an average exposure to 141 hyperbaric sessions. They found no significant changes in any spirometric measure with the exception of the $FEF_{25\text{-}75}$ which declined by 16% but only in attendants who had participated in more than 150 session. This was a fragile result based on small numbers. The authors concluded that within the range of experience they studied, there are no clinically significant changes in the lung function of hyperbaric attendants.

Pieter-Jan van Ooij and Rob van Hulst present a fascinating appraisal of the significance of larger lungs in relation to the risk of lung lesions like bullae being present, and the risk of decompression illness (including pulmonary barotrauma). Despite subjects with large lungs exhibiting a lower FEV_1/FVC ratio, they found no relationship between large lungs, bullae and decompression illness.

Graham Stevens and David Smart present an evaluation the effect of thick wetsuits on spirometry performance in divers. Although the changes were relatively small, reductions in FVC and FEV_1 were seen when wetsuits ≥ 7 mm were worn. The clinical significance of these findings is uncertain.

John Lippmann presents an evaluation of both scuba and snorkelling diving fatalities from the Australian state of Victoria over a 22-year period. As in his previous publications, this includes a chain-of-events analysis to identify predisposing factors, triggers, disabling agents and disabling conditions. As in other studies, pre-existing medical conditions were associated with many fatalities.

Joshua Currens and colleagues present a large dataset of 1,196 experimental dives that included post-dive echocardiography with bubble detection and grading using a Navy Experimental Diving Unit grading system. There were 41 cases of decompression sickness (DCS). As in previous studies, there was a clear increase in the incidence of DCS as bubble grade increased, but also as previous, the positive predictive value of venous bubble grade for DCS symptoms is poor. An editorial discussing this often misinterpreted finding (among other related things) is planned for the June issue of DHM.

At the previous SPUMS meeting David Smart led a workshop to review and revise the 2015 SPUMS / UK Diving Medical Committee guidelines on atrial shunts (primarily persistent [patent] foramen ovale [PFO]). These guidelines address who should be tested for PFO, how to test, and options for the diver in the event of a positive test. Importantly, they also contain a comprehensive guide to performing bubble contrast transthoracic echocardiography as an online appendix.

There are two case reports. In the first, Graham Stevens and Iestyn Lewis describe a case of facial vascular occlusion arising after hyaluronic acid filler was injected to the upper lip area. After an initially poor response to hyaluronidase injection, the persistent signs of occlusion improved after treatment with hyperbaric oxygen. Since this paper was accepted a similar case has appeared in Undersea and Hyperbaric Medicine Journal. The option of hyperbaric oxygen for this condition makes biological sense and although it is not technically an established indication, it could probably be seen as a compromised acute wound. In the second, Jeremy Mason and colleagues describe a case of severe neurological DCS in a patient who also exhibited right ventricular dilation. The authors make a credible argument that the latter was not a pre-existing problem and if so, this would be a relatively unique finding. They postulate that a high venous bubble load impacting the pulmonary circulation may have caused in acute increase in pulmonary artery pressure with consequent right heart dilation, and that increased pressures in the right heart promoted right to left shunting of bubbles (the patient also had a PFO) leading to neurological DCS.

The journal team wish all society members a great start to the year.

Professor Simon J Mitchell
Editor, Diving and Hyperbaric Medicine

Cover photo: Cardiac magnetic resonance imaging showing right ventricular dilation in a diver who suffered severe decompression sickness, see Mason et al. in this issue.

Original articles

Agreement of precordial and subclavian Doppler ultrasound venous gas emboli grades in a large diving data set

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Keywords
Bubbles; Decompression; Decompression sickness; Diving research

Abstract
(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 and Hyperbaric Medicine. 2025 31 March;55(1):2–10. doi: 10.28920/dhm55.1.2-10. PMID: 40090020.)

Introduction: Doppler ultrasound is used to detect inert gas bubbles in the body following decompression from dives. Two sites may be monitored, the precordial (PC) and subclavian (SC) positions. PC is the predominant site, allowing observation of bubbles returning from the entire body. However, the SC site provides unambiguous signals, whereas the PC site is noisy and difficult to grade. This retrospective study compared agreement of PC and SC Doppler data.

Methods: Datasets from the large University of California at San Diego Doppler database were graded on the Kisman Masurel (KM) scale and included: one PC measurement at rest followed by three during movement ($n = 4$ measurements); this was repeated for the left ($n = 4$ measurements) and right ($n = 4$ measurements) SC veins, producing a set of 12 grades. Primary analysis included: agreement between resting PC and SC grades, between movement PC and SC grades, and for unmatched grades, whether the SC grade was higher or lower than PC.

Results: Four-hundred and fifty-three datasets were available (5,436 individual recordings). At rest, 281 (62.0%) PC and SC grades matched (weighted kappa agreement 0.33, 95% CI ± 0.04), while only 176 (38.9%) movement grades matched (0.29, ± 0.02). Of the unmatched data, resting SC grades were higher than PC in 70.3% and lower in 29.6%; after movement, SC grades were higher in 45.8% and lower in 54.2%.

Conclusions: These data revealed a large discrepancy between PC and SC grades. Overall, this suggests that Doppler observations from both positions will give the most comprehensive representation of bubble load.

Introduction

Decompression sickness (DCS) is thought to arise due to the formation and growth of inert gas bubbles from supersaturated blood and tissues during or after decompression. For many years Doppler audio ultrasound monitoring has been used to detect moving venous bubbles (often referred to as venous gas emboli [VGE]) and thereby derive a measure of ‘decompression stress’ following a dive, i.e., how likely it is that DCS might develop.[1] This technique uses a transducer to transmit sound waves into the body, with the resulting echo allowing determination of moving objects in the blood vessels and heart. Bubbles interact strongly with sound waves and so can be detected by this method.[1] In large datasets it has been observed that the higher the number of bubbles, or ‘bubble load’, the greater the correlation with the incidence of DCS;[1] therefore, a reliable measure of bubble load, such as Doppler monitoring, is of great use in scientific diving studies.

Doppler monitoring for diving research generally takes place at two positions on the body. In the precordial (PC) site the probe is positioned over the heart and more specifically, over the right ventricle and pulmonary artery, thus measuring the blood that comes back to the heart from the whole body.[1] The second position is over the subclavian (SC) veins that are positioned under the clavicle on both the left and right shoulders. These veins return blood to the heart from the upper body only and are not representative of the whole. However, they do have the advantage of providing an unambiguous signal, as bubble sounds in the SC vein are very distinctive against the quiet venous blood flow sound.[1] Bubbles monitored in the precordium can be difficult to differentiate from the turbulent sound of the heart, so grading them accurately can be problematic, particularly for inexperienced graders. In addition, varying anatomy, for example in a person with a very deep chest, can make it hard to hear clear heart sounds. Given these factors, it is apparent that PC and SC Doppler grades have the potential to be substantially different.

At the advent of the technique, it was recommended that both sites should be monitored following a dive and it was found that this appeared to improve the relationship between bubble load and DCS given that on occasion, no bubbles could be observed in the precordium but were apparent in the SC veins.[1] The most recent consensus on ultrasound measurements in diving research recommended that the PC site should be used as standard, with SC monitoring useful in providing additional information.[2] Generally, because the SC position does not report whole body venous return, this has led to the PC site becoming preferable in studies and often monitored alone. One retrospective study has compared resting only PC and SC Doppler data with respect to the probability of DCS (pDCS) associated with high bubble grades.[3] It found a high level of correlation between SC and PC resting grades (R = 0.66) and pDCS increased with increasing grade. They also noted that the DCS risk ratio was higher for SC data than PC though only when the exposure severity was considered. They concluded that perhaps the potential of SC Doppler had been underestimated,[3] although on reflection, this must be tempered by the higher severity of the dive profile used to reach this finding.

Since then, products such as the O'Dive™, which draws on the simplicity of SC Doppler monitoring have entered the market. They allow divers to perform their own measurements in the field without training to try and determine their own DCS risk using a novel severity index, and this has brought the validity and usefulness of SC measurements into question. Bubble monitoring can also be carried out using echocardiography, which is becoming more popular in research versus Doppler, as this technique is easier to learn with visible bubbles very apparent.[2] In one study it has been reported that SC Doppler measurements can correlate highly with echocardiography measurements in the heart.[4] However, this is contentious, with some suggestion that the correlation might have been due to the use of an extreme dive profile that caused a high incidence of high bubble grades (mean depth of 97.3 msw) and a small sample size (n = 6) so not dissimilar to the drawback of the Hugon study.[3–5] In contrast, another study has shown that SC grades had only fair to poor agreement with 2D echocardiography, with the SC site yielding lower bubble grades generally,[6] and this was corroborated in a study by Karimpour et al.[5] If SC measurements often underreport bubble load, then their use as an indicator of DCS risk should be treated with caution. Overall, it seems that the value of SC Doppler monitoring is equivocal and bears further investigation.

With renewed interest in travelling to the moon, establishing a lunar base, and performing further research and exploration (NASA Artemis program), remote Doppler monitoring for astronauts might be of benefit to assess DCS risk. NASA has recognised that such technology would be useful in understanding the risk of DCS in extra-vehicular activities for many years, although an operational system was not realised despite relatively successful research and development.[7] With improvements in technology, including new spacesuit designs, monitoring equipment, and the possibility of automated bubble grading systems for quick and consistent VGE assessment,[8] in-suit Doppler monitoring might now be a possibility, so determination of the most optimal monitoring position/s might be of benefit. Echocardiography is another often used measured of quantifying bubble loads but is too complex and bulky for under-suit deployment.

As part of a funded Office of Naval Research project initiated in 2020, the University of California at San Diego (UCSD) along with other partners including the University of North Carolina at Chapel Hill, the Divers Alert Network, Duke University (all US), and QinetiQ, UK, are currently curating a large database of Doppler audio recordings and metadata acquired previously, which at present holds around 6,700 individual Doppler recordings. This UCSD database 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 recordings available to the diving community. Most of these data include PC and SC rest and movement measurements for each diver as recommended at that time, so an opportunity to compare the Doppler grades from each site became apparent. The aim of this study was to make a retrospective comparison of PC and SC bubble grades in this large collection of data to determine the level of agreement between Doppler signals measured at both sites.

Methods

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).

Data were drawn from Doppler recordings included in the UCSD database and originally made during the Mark 15 and Mark 16 air algorithm decompression trials carried out at the Naval Experimental Diving Unit (NEDU) of the US Navy in the 1980s. All subjects were male of age range 17–44 years. These dives were performed to a range of depths from 59 ft (18 m) to 300 ft (91 m), with total dive times varying from six minutes to 90 minutes. All were made using either heliox gas (helium and oxygen) or an oxygen/nitrogen mix, with a constant oxygen partial pressure of 71 kPa (0.7 atmospheres absolute [atm abs]). Doppler grading was carried out by experienced NEDU staff, and a selection of the grades were assessed and corroborated on their inclusion to the database for quality control by one of the authors (SLB) who has over 20 years of experience of grading Doppler bubbles. A note of any cases of DCS in the data included in this analysis was also reported.

DOPPLER GRADING

All Doppler measurements were graded using the Kisman Masurel (KM) Doppler grading system,[9] which was developed in 1984 to succeed the more basic Spencer scale[10] with the idea that the greater detail afforded would provide a system that could be used by a computer program. It also provides larger scope for classification of the bubble signals and allows measurements to be made following movement, which is often used to 'flush bubbles out' if they cannot be heard at rest.[1]

The KM system is made up of a three-part code representing the frequency, percentage/duration, and amplitude of any bubbles that are audible to the Doppler grader. This code is then translated into a KM grade between 0–IV. The system is subjective to the individual grader, though training helps to standardise measurements. The scale is non-linear; a grade of KM I may be derived if a listener hears only one bubble pass through a vessel over 10 heartbeats, and so essentially the diver can be thought of as nearly bubble free and close to KM 0. However, a KM II represents 3–8 bubbles, a KM III 9–40 bubbles, and KM IV a continuous stream of bubbles. Therefore, the low KM grades (0–I) can be said to be much closer to each other in terms of numbers of detected bubbles. The ordinal nature of the grading scale means that any statistical analysis should be made using non-parametric tools.

COMPOSITION OF MEASUREMENT SETS

Following each dive, Doppler measurements were made at the PC and SC sites (Figure 1) as per the following protocol:
- One precordial (PC) measurement at rest, followed by three movement measurements (deep knee bend) ($n = 4$)
- One resting measurement at the left subclavian (SC) vein site, followed by three movement measurements ($n = 4$) (squeezing hand into a fist)
- As for the left SC, one resting measurement at the right subclavian vein, followed by three movement measurements ($n = 4$)

Therefore, the total number of measurements for each site were PC $n = 4$ and SC $n = 8$, so for each diver at each time point this protocol provided 12 Doppler measurements.

ANALYSIS OF SETS

For the present retrospective analysis, all records held in the database that had complete sets of 12 measurements were included. Each set was assessed to see:
- If the resting PC KM grade matched the highest resting SC KM grade
- If the highest movement PC KM grade matched the highest movement SC KM grade
- If not matching, was the SC KM grade higher or lower than the PC grade
- If the right SC grade matched the left SC grade

In addition, we determined the number of sets where:
- Both PC and SC matched
- There were matching measurements of KM 0
- The SC and PC grades did not match but were close

With regards to match analysis, as there were two resting SC grades (left and right) corresponding to one PC grade, and six movement SC grades corresponding three PC grades, the highest overall SC grade was compared to PC. Thus, a PC resting grade of KM I was said to match when compared with two SC resting grades made up of KM 0 and KM I grades, with the KM grade I counting in this case; conversely a PC resting grade of 0 was said not to match with SC grades KM 0 and KM I, as the highest SC grade recorded was KM I.

With respect to the final assessment point above, in many cases where low KM grades (KM 0 and I) had been recorded, the 'overall picture' of the bubble load between PC and SC grades may have looked very similar despite not being a definitive match (see the KM 0 and I examples above) and these were worthy of note.

Figure 1
Doppler monitoring sites; A – right subclavian; B – left subclavian; C – precordial

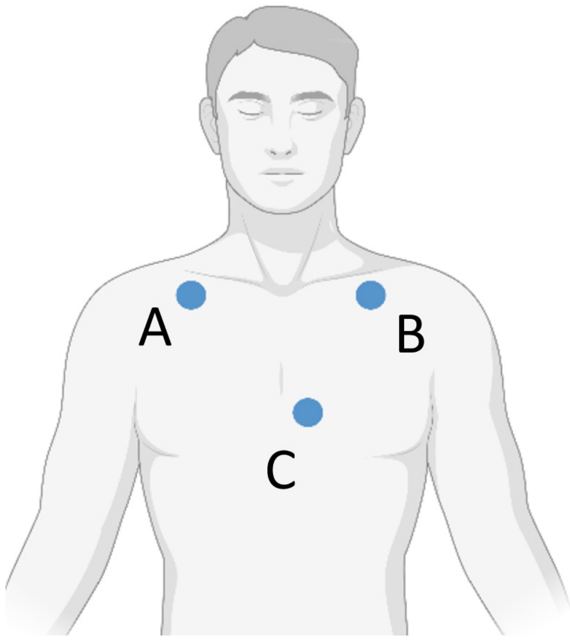

Table 1
Kappa statistic interpretation (adapted from Landis et. al 1977)[11]

Kappa coefficient	Interpretation
Below 0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

Table 2
Assessment of precordial (PC) and subclavian (SC) agreement; KM – Kisman Masurel; *Percentages are derived from the total unmatched, not the total number of sets. KM, Kisman Masurel; PC, precordial; SC, subclavian

A – Total number of data sets, n = 453	Matched n (%)	Unmatched n (%)
Resting	281 (62)	172 (38)
After movement	176 (39)	277 (61)
Zero grades (PC and SC)	144 (32)	–
Sets where both PC and SC matched	155 (34)	–

B – Total number of data sets, n = 453	Unmatched* n (%)
Resting SC higher (%)	121 (70)
Resting SC lower (%)	51 (30)
After movement SC higher (%)	127 (46)
After movement SC lower (%)	150 (54)
Overall grades rest and movement KM 0 or 1 (%)	56 (12)

STATISTICS

The PC and SC sets were compared using weighted kappa statistics with quadratic weights, which deal with ordinal data more effectively than Cohen's kappa statistic for which the agreement is binary.[5] The weighted treatment deals better with the greater disagreement between a KM I and KM IV than the smaller disagreement of a KM 0 and I for example, which occurs when using this non-linear scale as described in the previous section. A proposed interpretation of the kappa statistic is provided in Table 1.[11] Descriptive statistics were also used to illustrate the distributions where appropriate.

Results

Precordial and SC Doppler (rest and movement) measurements were compared, drawing data from the UCSD database. At the time of the analysis, the database contained 6,735 Doppler recordings/metadata. Of these, 453 complete sets of 12 measurements were available (5,436 Doppler recording clips) from 129 subjects (Table 2).

There were ten individual DCS cases, nine with Type I DCS (eight pain only, one pain and mild sensory symptoms), and one Type II case (sensory) (Table 3). The DCS incidence in the sample population (n = 129) was 7%. Kisman Masurel grades associated with the DCS cases ranged from KM 0 at both sites to the highest grade, KM IV. The distribution of cases across the grades was fairly even (Table 4).

There were 281 (62.0%) matching PC and SC grades at rest (weighted kappa agreement 0.33, 95% CI ± 0.04), and only 176 (38.9%) matching PC and SC grades following movement (0.29 ± 0.02) (Tables 2, 5 and 6, and

Table 3
Decompression sickness (DCS) cases and Kisman Masurel (KM) bubble grades at each site; PC – precordial; SC – subclavian

DCS case	DCS type	Symptom	Max PC KM grade	Max SC KM grade
1	Type I	Pain	**II**	0
2	Type I	Pain	I	**III**
3	Type II	Sensory	I	II
4	Type I	Pain	0	**IV**
5	Type I	Pain	0	**I**
6	Type I	Pain	0	0
7	Type I	Pain	**IV**	III
8	Type I	Pain	0	**III**
9	Type I	Pain	**II**	I
10	Type I	Pain and sensory	0	**I**

Table 4
Distribution of decompression sickness (DCS) cases across Kisman Masurel (KM) grades and sites; PC – precordial; SC – subclavian

Maximum KM Grade	DCS cases	Site
0	1	–
I	2	2 SC
II	3	2 PC, 1 SC
III	2	2 SC
IV	2	1 PC, 1 SC

Table 5
Contingency table for precordial (PC) vs subclavian (SC) at rest; the weighted kappa of agreement was calculated as 0.33 ± 0.04. KM – Kisman Masurel

Monitored site/grade		SC grade					Totals
		KM 0	KM I	KM II	KM III	KM IV	
PC grade	KM 0	259	61	20	21	0	361
	KM I	16	8	4	7	1	36
	KM II	8	4	5	5	1	23
	KM III	14	2	7	8	1	32
	KM IV	0	0	0	0	1	1
Totals		297	75	36	41	4	**453**

Table 6
Contingency table for precordial (PC) vs subclavian (SC) after movement; the weighted kappa was calculated as 0.29 ± 0.02. KM – Kisman Masurel

Monitored site/grade		SC grade					Totals
		KM 0	KM I	KM II	KM III	KM IV	
PC grade	KM 0	133	90	19	12	1	255
	KM I	19	21	9	7	1	57
	KM II	23	19	12	7	1	62
	KM III	18	24	12	9	3	66
	KM IV	2	3	4	3	1	13
Totals		195	157	56	38	7	**453**

Figure 2

Bland-Altman plot for precordial (PC) vs subclavian (SC) at rest; showing a small bias (SC overestimating PC by 0.23 grades on average) and 95% confidence intervals of -2.39 to 1.93 Spencer grades

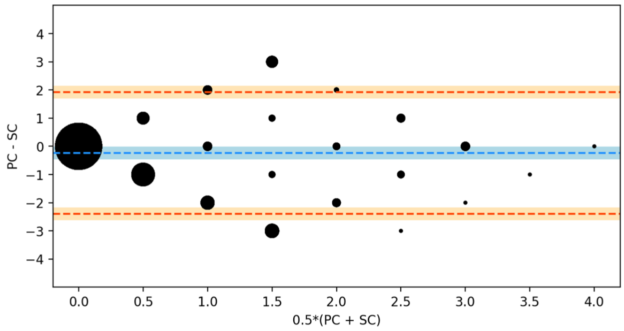

Figure 3

Bland-Altman plot for precordial (PC) vs subclavian (SC) after movement showing negligible bias (0.044 Spencer grades in favour of PC) and 95% limits of agreement from -2.6 to 2.69 Spencer grades

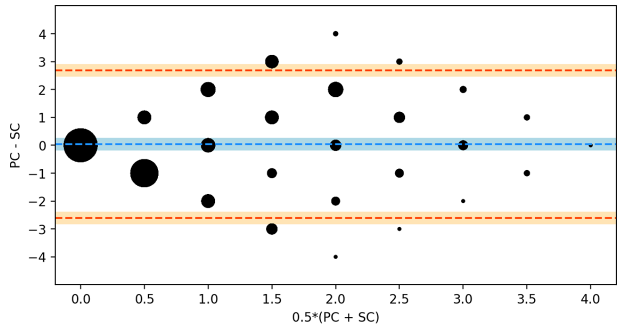

Table 7

Contingency table for right subclavian (SC) vs left SC at rest; KM – Kisman Masurel

Monitored site/grade		Left SC grade					Totals
		KM 0	KM I	KM II	KM III	KM IV	
Right SC grade	KM 0	297	31	12	7	0	347
	KM I	36	8	1	0	0	45
	KM II	14	7	2	4	0	27
	KM III	19	3	3	5	0	30
	KM IV	0	0	2	1	1	4
Totals		366	49	20	17	1	**453**

Table 8

Contingency table for right subclavian (SC) vs left SC after movement; KM – Kisman Masurel

Monitored site/grade		Left SC grade					Totals
		KM 0	KM I	KM II	KM III	KM IV	
Right SC grade	KM 0	195	49	11	3	2	260
	KM I	77	31	8	1	0	117
	KM II	20	10	7	7	0	44
	KM III	7	12	4	4	0	27
	KM IV	0	1	0	2	2	5
Totals		299	103	30	17	4	**453**

Figures 2–3). One hundred and fifty-five data sets matched both at rest and after movement, and 144 of these were grade KM 0 with no bubbles detected in either site. There were 56 sets of data that did not match but had grades no higher than KM I.

Of the unmatched data (rest n = 172; movement n = 277), resting SC grades were higher than the corresponding PC grade in 121 (70.3%) data sets and lower in 51 (29.6%). After movement, SC grades were higher in 127 (45.8%) and lower in 150 (54.2%).

The degree of agreement between the left and right subclavian measurements was also assessed. At rest, the overall agreement was 69% between left and right SC (Table 7), and after movement this reduced to 53% (Table 8).

Discussion

This retrospective study used a large post-dive Doppler dataset to compare the KM grade agreement between measurements made in the PC and SC measurement positions, finding that there was a large discrepancy between the two. At rest, 62% of measurements matched, while after movement this correlation was reduced greatly to only 39%. The present agreement at rest is considerably higher than that found in one study comparing SC Doppler (using the O'Dive™ device) to PC echocardiography, which found perfect agreement in only 34% (n = 1,113) of its measurements, however both studies note a considerable discrepancy between the two sites.[6] The weighted kappa coefficients indicated fair agreement between PC and SC (0.33 at rest and 0.29 after movement) indicating overall reasonable agreement. This divide between PC and SC measurements represents a challenge for diving research given there is general agreement that the highest bubble loads align with the greatest risk of DCS, and in the field workers rely generally on one site or the other from which to measure their data.[1,12,13] With this level of disagreement, which site is the most beneficial?

It should be said that historically, it was noted that the optimal way to gain the best prediction of DCS occurrence was to combine the maximum bubble grades from both sites (SC and PC) as per Nishi et al, where the relatively large number of DCS cases (69 cases: 35 after air dives, 34 after heliox dives) gave further clarity to this approach.[1] Following the air dives, DCS occurred when there were no observable bubbles in the precordial region, however, bubbles were found in the SC veins.[1] Thus, in this large set of air dive data (1,726 subjects) the occurrence of DCS was always accompanied by bubbles, so it was suggested for completeness both sites should be monitored.[1] One case of DCS was noted without the presence of bubbles but this was following heliox dives.[1] Their data also showed that the incidence of DCS increased with higher KM grades III and IV; of the 69 cases, 38 (55%) were accompanied by a KM III, and 24 (35%) a KM IV.[1]

In the present study, there were 10 cases (10 subjects) of DCS noted and interestingly, the associated maximum KM grades varied considerably (Table 3) ranging from KM 0 to KM IV at both sites, with a reasonably even distribution of cases across the KM grade range (Table 4). This pattern is not reflective of the Nishi results, but our findings should be tempered by noting there were only 10 DCS cases observed in the present data, which may be too small to reflect trends accurately. However, on calculation of DCS incidence within the sample population, this value was found to be higher (7.8% [n = 129]) than the Nishi study (2.0% [n = 1,726] for air dives, and 1.9% [n = 1,773] for heliox dives respectively), which confounds the small sample size argument somewhat.[1] Another point to note is that in the one DCS case where no bubbles were observed in the present study, the breathing gas was air, not heliox as in the Nishi data. That DCS was observed in the absence of detected bubbles is very unusual, with a general agreement that the condition does not occur without the presence of venous gas emboli post-dive. However, in this dataset, only two measurements were made after the exposure, at 34 and 300 minutes after return to surface. Thus, we should be careful and not say that bubbles were not present, but rather bubbles were not detected in this individual at these two timepoints, as in fact they could have evolved at other points post-dive. It is for this reason that the 2016 consensus recommended that measurements should be made within 15 min following decompression and at intervals no greater than 20 mins for the first 2 h post-dive.[2] Indeed, the more measurements made then the better we are able to say with any confidence that bubbles are present or not.[14]

Despite the slight disparities between the present study and the Nishi data, and the further limitation that we do not have access to all metadata for the individual dives in our dataset, given the larger size of the Nishi dataset perhaps the more conservative approach to bubble monitoring would be to measure at both sites. However, this is not always practicable, particularly in the field as it requires different Doppler equipment (probes of different frequencies) and much longer monitoring sessions, making the technique slightly limiting.

If this technology is to be used effectively in the future, the option to monitor subjects remotely and even grade the Doppler signals in real-time is an attractive prospect. As mentioned previously, NASA is currently renewing its interest in lunar exploration and DCS does pose a problem in the space environment. A real-time, remote monitoring system would be of great benefit in this setting. Current work across many research and development centres is proceeding to streamline and reduce the size of essential physiological life-support monitoring sensors to measure parameters such as heart rate, hypoxia, pulmonary barotrauma/arterial gas embolism, hypercapnia, and hyperoxia, in order to allow in-suit use. It would not be ideal to have to attach three relatively large Doppler probes to the torso as body space is at a premium, therefore a reductive approach to bubble monitoring is of prime importance. If a single site was confirmed as providing an acceptable estimation of DCS risk, all the better. On consideration of the data assessed in the present study it was noted that of the unmatched resting measurements, maximal SC grades were higher than PC grades in 70% of cases, while following movement, maximal SC grades were higher in only 46%; this equivocal finding is as expected given the results shown in the Bland Altman plots depicted in Figures 2 and 3. In the Plogmark study comparing Doppler SC to PC echocardiography, only 8% of SC measurements were higher than PC values, representing an even greater skew towards the capacity of the PC site to report the higher grades.[6] Importantly in our study, the large 95% limits of agreement between PC and SC and negligible bias suggest that one site cannot be favoured over another.

Of course, bubble grades could vary at the PC and SC sites for reasons other than those already mentioned. For example, a measurement is only a snapshot of a moment in time;

dependent on the dive profile used, post-dive bubbles may be constantly evolving and moving back to the heart in the venous circulation, or only develop at certain time points that means they can be missed, as noted earlier in the discussion.[13] Graders making audio Doppler measurements generally listen to at least 10 heartbeats for each measurement and often more, particularly if bubble sounds are rare and it is suspected that no bubbles are present. Precordial measurements including rest and movement could take two to three minutes to complete, with the grader then moving on to monitor the SC site. With these delays between measurements, bubbles could evolve or disappear in that time and so cause discrepancies. In the Plogmark study, timing of measurements was considered in 850 paired grades that had no more than five minutes between PC and SC grading. Although this could also be said to be too long a delay, analysis of these timed data found the same poor level of agreement.[6]

An additional confounder to PC versus SC is that the PC site is notoriously more difficult to monitor, often due to cardiac noise artefacts and to differences in anatomy between subjects, with deep chested individuals being notoriously difficult to optimise probe placement, so monitoring can be less accurate. However, despite these limitations the data considered in the present study although equivocal in terms of PC or SC reporting maximal grades more frequently, was of good quality.

Conclusions

The 2016 consensus on ultrasound monitoring for diving research advised that the PC site should be used as standard for Doppler monitoring given that it reports whole body venous return and that SC measurements could be useful to provide additional information. The current collection of Doppler data that form the UCSD database has allowed a retrospective investigation to verify or disprove this recommendation. Overall, our findings regarding maximal bubble grades suggest that differences between the two are equivocal, and dependent on many factors including resting/movement, timing of measurements etc. If remote monitoring of bubbles proceeds in the future, we suggest that if a site must be preferred, it be the PC position, given bubbles from the whole body can be examined from this site, while noting that SC measurements cannot be discarded as they provide additional information. A definitive study conducting a head-to-head assessment of different monitoring sites after separate limb movements with recent devices is perhaps necessary for a definitive finding.

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Conflicts of interest and funding

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Longitudinal study of changes in pulmonary function among inside attendants of hyperbaric oxygen therapy

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Hyperbaric oxygen treatment; Long-term effects; Nursing; Pulmonary function; Respiratory

Abstract
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Introduction: Hyperbaric oxygen therapy (HBOT) administers 100% oxygen in a pressurised chamber at pressures above 1 atmosphere absolute. Inside hyperbaric personnel accompany patients during sessions and breathe compressed air, exposing them to risks like decompression illness and respiratory changes. This study investigated whether hyperbaric exposure affects the long-term lung function of inside hyperbaric personnel.
Methods: An analysis was conducted on spirometry data from 14 personnel working between 2012 and 2023. Lung function tests measured forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), mid breath forced expiratory flow ($FEF_{25–75}$), and peak expiratory flow (PEF) before and after hyperbaric exposure. Participants were categorised based on age, body mass index, number of HBOT sessions, and duration of employment.
Results: No clinically or statistically significant differences were found in FVC, FEV_1, or PEF measurements before and after hyperbaric exposures ($P > 0.05$). However, $FEF_{25–75}$, an indicator of small airway function, showed a (mean) 16% reduction in personnel with more than 150 HBOT sessions ($P = 0.038$). A post-hoc analysis confirmed a significant difference in $FEF_{25–75}$ between personnel with fewer than 74 sessions and those with 150 or more sessions ($P = 0.015$). No clinically significant symptoms such as dyspnoea were reported during the study period.
Conclusions: The $FEF_{25–75}$ reduction, without changes in FEV_1, FVC, or PEF, could be due to improper performance of the FVC manoeuvre. Maintaining pulmonary health in inside hyperbaric personnel is essential, emphasising the importance of accurate FVC execution in assessments. Further studies are recommended to explore the long-term implications of these findings and the effects of repeated hyperbaric exposure on respiratory health.

Introduction

Hyperbaric oxygen therapy (HBOT) is the administration of 100% oxygen in a closed chamber at pressures higher than 101.3 kPa (1 atmosphere absolute [atm abs]).[1] There are more than 50 active HBO_2 centres in more than 20 cities in Turkey. Typically, sessions last two hours and operate at a pressure of 243 kPa (2.4 atm abs), although the indication may dictate different pressures and durations.

Inside attendant healthcare personnel (IHP) accompany patients throughout all sessions to assist with pressure equalisation manoeuvres, proper mask-wearing, and prompt action in any potential emergencies that may arise. Inside attendant healthcare personnel only breathe the compressed air in the chamber during sessions; unlike patients, they do not breathe 100% oxygen. Consequently, they are at risk of decompression illness and the adverse effects of pressure changes on various systems and organs of the body. In addition, respiratory function may be affected by exposure to the pressurised environment.[2]

There are many factors that affect respiratory functions. These can be related to genetics, environmental influences, physical conditions, and diseases. The initial circumstances that may impact pulmonary function in IHP are the risk of microbubble formation and the elevated partial pressure of oxygen during sessions. Exposure to high oxygen partial pressure can trigger inflammatory processes in the respiratory system by increasing oxidative stress.[2] Venous gas microbubbles are created during decompression and are expelled from the lungs by exhaling after being transported from nitrogensaturated tissues. Impaired gas exchange, temporary pulmonary hypertension, and pulmonary microvascular inflammation can be triggered by these microbubbles.[3,4]

Furthermore, breathing compressed air in a hyperbaric environment causes an increase in inspiratory effort and airway resistance, as well as a decrease in lung compliance.[5] These could have an impact on respiratory function, particularly airway function.[5,6] However, almost all of what is known about these potentially harmful processes comes from studies of divers rather than hyperbaric chamber exposures.

Airway obstruction is a relative contraindication for working in pressurised environments. Thus, it is crucial for IHP to maintain a healthy respiratory system in order to perform their duties. To make sure they are fit for work, IHP in Turkey have to undergo periodic exams, which include spirometry, to check for any anomalies in lung function.

In our literature review, we found only one study with longitudinal results on changes in lung function in IHP.[7] Nevertheless, there are more studies on changes in pulmonary function in commercial divers due to exposure to a hyperbaric environment.[8–17] The results from these studies have yielded different conclusions regarding pressure-induced changes in lung function in diver and IHP populations.

The objective of this study was to determine whether there has been a change in the lung function (primarily spirometry) of healthcare professionals working at the Akyurt Hyperbaric Oxygen Therapy Center from the time they began working as inside attendants and to examine the potential association between this change and hyperbaric exposure.

Methods

The study was approved by the Gulhane Ethics Board of the University of Health Sciences (02/24: 2024-106), and it was conducted in accordance with the Declaration of Helsinki.

PARTICIPANTS

An audit was conducted on the spirometry tests and postero-anterior chest radiographs of healthcare professionals who worked as IHP at the Akyurt Hyperbaric Oxygen Therapy Center from 2012 to 2023. Personnel who had stopped working prior to the periodic examination and those whose medical records were unavailable or incomplete were excluded from the study.

HYPERBARIC OXYGEN THERAPY PROTOCOL

In the 120-minute treatment protocol that constitutes the vast majority of IHP exposures, the chamber is pressurised with air to 243 kPa (2.4 atm abs) in about 15 minutes. After maintaining this treatment pressure for 90 minutes, decompression is performed over 15 minutes. Patients begin breathing oxygen through a mask or hood at the 10th minute of the treatment. The three 30-minute oxygen periods are separated by two 5-minute air breathing breaks. The accompanying IHP breathe 100% oxygen during the last 10 minutes of the final oxygen period (Figure 1).

DATA

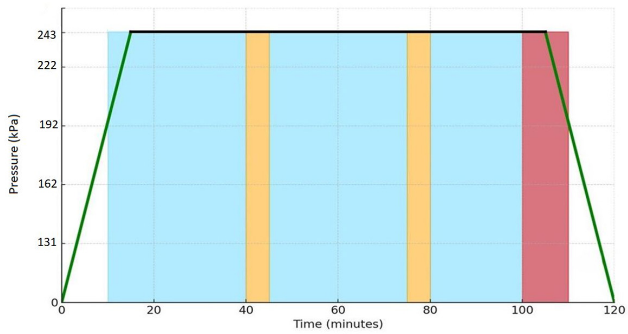
The following information was taken from IHP annual examination records: age, height, weight, medical history, smoking history, history of underwater activities (including recreational and professional diving), sports history, and pulmonary function test (PFT) results (forced vital capacity [FVC], forced expiratory volume at one second [FEV_1], forced expiratory flow at 25%–75% of FVC [$FEF_{25–75}$], peak expiratory flow [PEF], and the FEV_1/FVC ratio). The total number of sessions and the duration of working as an IHP were calculated from the session records.

SPIROMETRY TESTS

In our hospital's spirometry laboratory, spirometry tests were conducted on IHP using the CareFusion Vmax® Encore system (CareFusion, 22745 Savi Ranch Parkway, Yorba Linda, CA 92887). The tests were performed by technicians who had received standardised training in this field. All measurements were performed according to European Respiratory Society/American Thoracic Society task force guidelines. Parameters as above were recorded. The evaluated parameters were compared to the predicted normal values based on the patient's age, gender, height, weight, and ethnicity, expressed as a percentage. The expected values were derived using the Global Lung Initiative (GLI) reference system.[18] Calibration was carried out in accordance with the guidelines provided by the manufacturer.

Figure 1

Hyperbaric oxygen therapy protocol; green lines – compression and decompression phases; black line – constant treatment pressure (243 kPa); blue shading – oxygen breathing periods (mask/hood); orange shading – air breaks (5 minutes); red shading – IHP oxygen breathing during the last 10 minutes of final O_2 period



GROUPS

Age, body mass index (BMI), number of sessions, and the duration of working as an IHP were categorised in the analyses. Age was categorised into two groups: < 34 and ≥ 34 years, based on the median age of 34. Body mass index ($kg \cdot m^{-2}$) was categorised into three groups: 18.5–24.9 (normal), 25.0–29.9 (overweight), and 30.0–39.9 (obese). The duration of working as an IHP was divided into three categories: ≤ 10 months, 10–25 months, and ≥ 25 months. The number of sessions was categorised as ≤ 75, 75–150, and ≥ 150. In addition, a percentage change variable was generated by utilising the baseline and final measurements of PFT parameters. The fractional change was calculated as ((last value - first value) / first value)) and multiplied by 100 to derive percentage change.

STATISTICS

The analyses were assessed using the SPSS (Statistical Package for Social Sciences; SPSS Inc., Chicago, IL, version 25) software program. Descriptive data were reported as frequency (*n*) and percentage (%) for categorical variables, mean and standard deviation (SD) for continuous variables, and median with interquartile range (IQR) for continuous variables that were not normally distributed. The conformity of continuous variables to a normal distribution was evaluated by the Shapiro-Wilk test and visual methods (histograms and probability plots). The paired sample *t*-test was employed to assess the comparison between two dependent groups that conform to a normal distribution. In the independent two-group comparisons, the Student *t*-test was used for the data that had a normal distribution, and the Mann-Whitney U test was used for the data that did not conform to a normal distribution. In independent comparisons of more than two groups, the Kruskal-Wallis test was used for data that did not conform to a normal distribution. *Post-hoc* testing with Bonferroni correction (Mann-Whitney U test) was used for more than two significant within group comparisons. The analyses accepted a statistical significance level of $P < 0.05$ (in Bonferroni-adjusted Mann-Whitney U tests, $P < 0.017$).

Results

Fourteen inside attendant healthcare personnel were included in the study. The medical records did not reveal any history of disease associated with pulmonary function. No sports activities that could have an impact on pulmonary function, including diving, were identified. All postero-anterior chest X-rays were normal. The descriptive data are presented in Table 1.

The most recent spirometry tests of IHP and their tests prior to working in hyperbaric oxygen therapy were compared. There was no statistically significant difference between the baseline and final measures for FEV_1, FVC, FEV_1/FVC, $FEF_{25–75}$, or PEF values ($P > 0.05$ for each comparison) (Table 2).

From the baseline and final measurements of PFT parameters, fractional and percentage changes were computed according to the formula given in the method section. The changes were compared based on gender, age, BMI, duration of working,

Table 1
Descriptive data of inside attendants; SD – standard deviation

Parameter	*n* (%) or mean (SD) (min–max)
Gender	
Female	13 (92.9)
Male	1 (7.1)
Age (years)	33.7 (7.5) (22.0–45.0)
BMI ($kg \cdot m^{-2}$)	26.0 (3.4) (20.4–32.1)
Normal	5 (35.7)
Overweight	7 (50.0)
Obese	2 (14.3)
Smoking	
No	12 (85.7)
Yes	2 (14.3)
Smoking history (pack-year)	0.4 (1.2) (0.0–4.0)
Working duration (months)	25.4 (23.2) (6.0–92.0)
Number of sessions	141.4 (143.1) (30.0–579.0)
Number of sessions per year	83.3 (47.3) (15.0–154.0)

Table 2
Baseline and final spirometry tests values of inside attendants; $FEF_{25–75}$ – forced expiratory flow at 25%–75% of FVC; FVC – forced vital capacity; FEV_1 – forced expiratory volume at one second; PEF – peak expiratory flow; SD – standard deviation

Parameter		% of predicted Mean (SD)	*P*
FEV_1 (L)	Baseline	98.5 (13.2)	0.668
	Final	99.8 (11.6)	
FVC (L)	Baseline	94.1 (11.6)	0.619
	Final	96.0 (13.6)	
FEV_1/FVC (%)	Baseline	92.5 (6.1)	0.205
	Final	90.4 (5.7)	
$FEF_{25–75}$ ($L \cdot s^{-1}$)	Baseline	112.0 (30.4)	0.110
	Final	104.9 (23.5)	
PEF ($L \cdot s^{-1}$)	Baseline	93.1 (14.4)	0.972
	Final	93.3 (23.2)	

Table 3

Fractional changes (x100 for percentages) in spirometry tests parameters by categories; values annotated 'a' are significantly greater than 'b'; *Mann-Whitney U; **Kruskal Wallis; †Bonferroni corrected P value = 0.015; $FEF_{25–75}$ – forced expiratory flow at 25%–75% of FVC; FVC – forced vital capacity; FEV_1 – forced expiratory volume at one second; PEF – peak expiratory flow

Parameter	Fractional change				
	FEV_1	FVC	FEV_1 / FVC	$FEF_{25–75}$	PEF
	Median (min–max)	Median (min–max)	Median (min–max)	Median (min–max)	Median (min–max)
Gender					
Female	0.02 (-0.19–0.39)	0.02 (-0.16–0.57)	0.00 (-0.12–0.13)	-0.04 (-0.26–0.23)	0.06 (-0.36–0.33)
Male	0.02 (0.02–0.02)	0.11 (0.11–0.11)	-0.09 (-0.09–[-0.09])	-0.13 (-0.13–[-0.13])	0.13 (0.13–0.13)
*P**	0.901	0.172	0.172	0.385	0.535
Age (years)					
< 34 (*n* = 8)	0.03 (-0.06–0.39)	0.03 (-0.15–0.57)	-0.02 (-0.12–0.06)	-0.03 (-0.19–0.09)	0.05 (-0.36–0.24)
≥ 34 (*n* = 6)	-0.00 (-0.19–0.05)	-0.00 (-0.16–0.11)	-0.02 (-0.09–0.13)	-0.08 (-0.26–0.23)	0.06 (-0.32–0.33)
*P**	0.366	0.699	0.747	0.606	0.796
Body mass index					
Normal (*n* = 5)	0.03 (-0.05–0.39)	0.06 (0.02–0.57)	-0.07 (-0.12–0.01)	-0.01 (-0.19–0.09)	0.14 (-0.14–0.24)
Overweight or obese (*n* = 9)	0.02 (-0.19–0.11)	-0.04 (-0.16–0.11)	0.00 (-0.09–0.13)	-0.07 (-0.26–0.23)	0.06 (-0.36–0.33)
*P**	0,463	0.096	0.161	0.641	0.257
Working duration					
< 10 months (*n* = 4)	0.03 (-0.19–0.11)	-0.06 (-0.16–0.03)	0.0 (-0.04–0.01)	-0.02 (-0.09–0.09)	0.05 (-0.36–0.06)
10–25 months (*n* = 5)	-0.0 1 (-0.06–0.03)	0.04 (-0.11–0.08)	-0.03 (-0.07–0.13)	0.01 (-0.17–0.23)	0.19 (-0.20–0.33)
> 25 months (*n* = 5)	0.02 (-0.05–0.39)	0.05 (-0.04–0.57)	-0.08 (-0.12–0.01)	-0.13 (-0.26–[-0.04])	-0.14 (-0.32–0.14)
*P***	0.761	0.188	0.339	0.065	0.188
Number of hyperbaric sessions					
≤ 74 (*n* = 5)	0.02 (-0.06–0.11)	-0.11 (-0.15–0.08)	0.01 (-0.03–0.13)[a]	0.01 (-0.07–0.23)[a]	0.06 (-0.20–0.19)
75–150 (*n* = 5)	-0.01 (-0.19–0.03)	0.03 (-0.16–0.06)	-0.04 (-0.07–0.01)	0.02 (-0.17–0.09)	0.06 (-0.36–0.33)
≥ 150 (*n* = 4)	0.03 (-0.05–0.39)	0.08 (0.02–0.57)	-0.08 (-0.12–0.0)[b]	-0.16 (-0.26–[-0.10])[b]	0.00 (-0.32–0.14)
*P***	0.607	0.139	***0.041***	***0.038***†	0.873

and number of sessions. In the analyses performed according to the number of sessions, FEV_1/FVC showed a 1% increase over time in those with ≤ 74 sessions, a 4% decrease in those with 75–150 sessions, and an 8% decrease in those with ≥ 150 sessions (P = 0.041). Bonferroni-adjusted *post-hoc* analyses to determine the source of the difference did not identify any significant pairwise differences (P > 0.017 for each comparison). As for $FEF_{25–75}$, there was a 1% increase in those with ≤ 74 sessions and a 2% increase in those with 75–150 sessions, whereas a 16% decrease was observed in those with ≥ 150 sessions (P = 0.038). Bonferroni-adjusted post-hoc analyses showed a significant difference between those with ≤ 74 sessions and those with ≥ 150 sessions (P = 0.015) (Table 3).

During the follow-up period, no respiratory tract disease findings were observed in any IHP, aside from occasional cases of acute upper respiratory tract infections.

Discussion

In this study, we investigated whether there has been a longitudinal alteration in the lung function of healthcare professionals working in our centre since they began working as inside attendant for hyperbaric oxygen therapy. Percentage changes in predicted values showed no significant spirometry differences pre- and post-hyperbaric exposure, but greater session numbers were associated with a larger $FEF_{25–75}$ decline over time.

One study reported a substantial decline in FEV_1, $FEF_{25–75}$, and FEV_1/FVC values over time after retrospectively analysing 51 IHP over an average of 9.26 years.[7] Another study comparing the 1-year lung function of 11 IHP with a control group of fifteen participants found a significant decrease of 2.3% in the predicted FEV_1 and 3.7% in the $FEF_{25–75}$ in IHP within a year.[19] In contrast, no difference was noticed in comparison to a control group.[19] Similar to the latter study, we did not find any significant differences in PFT parameters. Because of our shorter follow-up duration and fewer IHPs, our study's results may differ from those of Poolpol et al.[7]

Demir et al. examined spirometry tests of 68 IHP with no previous HBOT experience before and after single hyperbaric sessions.[20] Mean FVC was 3.56 (SD 0.66) L before hyperbaric exposure and decreased by 3.4% to 3.44 (0.62) L after exposure. The mean FEV_1 was 3.37 (0.63) L before the session and 3.24 (0.59) L after the session; a 3.9% decrease. There was no statistically significant difference between the mean FEV_1/FVC ratio, PEF, and $FEF_{25–75}$ measurements before and after hyperbaric exposure. The authors suggested that the measured changes of less than 5% were not likely clinically relevant.[20] While the results of that study were based on a single HBOT session, they are consistent with our findings in that no changes likely to be clinically significant were found.

Most studies on respiratory function have primarily focused on divers. Previous research has demonstrated that divers tend to have larger lung volumes, a finding attributed both to natural selection and to the repetitive breath-holding and respiratory resistance encountered during diving.[8,21,22] However, studies examining the long-term spirometric measurements of IHP are limited. In a longitudinal study of 51 IHP with a follow-up period of 9.26 years, no significant changes in FVC, expressed as a percentage of the predicted values, were observed. While our study showed a slight increase in mean FVC over time, this change was not statistically significant.[7] It is well-established that FVC decreases with age in individuals without known pulmonary disease.[23] Although IHP may exhibit some degree of physiological adaptation to repeated hyperbaric exposures, the slower descent and ascent rates used during HBOT (1.5–2.0 $msw \cdot min^{-1}$) compared to standard diving practices (10–18 $msw \cdot min^{-1}$), and the absence of breathing masks during HBOT, may reduce the extent of this adaptation compared to divers. These factors may modulate the effects of hyperbaric exposure on the natural aging process, underscoring the need for further research in this area.

Several investigations have shown a decrease in expiratory flows at low pulmonary volumes, which may be attributed to pathological changes in the lung periphery.[24] For three years, Skogstad et al. monitored 87 divers at a diving school.[13] They found a significant decline in the mean FEV_1, $FEF_{25–75}$, and FEF_{75} of divers following this period. The authors concluded that diving could lead to changes in PFTs, mostly affecting small airway conductance and dysfunction. In another study Skogstad and Skare reported a decrease in $FEF_{25–75}$ after 12 years of diving.[25] Shopov conducted an analysis of spirometry test results in a group of 52 military divers and compared them to a control group ($n = 48$) consisting of deck crew who had similar physiological features.[26] The divers had an average of 10.2 (SD 2.5) years of diving experience. There was a statistically significant increase in FVC (both in percentage and absolute volume), a decrease in $FEF_{25–75}$ (again, both in percentage and volume), and a decrease in FEV_1/FVC. However, there were no significant changes in FEV_1 and PEF. Shopov concluded that diving can lead to PFT changes consistent with small airway obstruction.[26] Pougnet et al. showed that the FEV_1/FVC ratio and FEF_{25} decreased significantly after 15 years of professional diving.[27] Poolpol et al. also demonstrated that lung function alterations were associated with average working depths, session lengths, and total working hours.[7] Kangal et al. conducted a study involving 64 divers with an average diving experience of 13.6 (SD 7.3) years. They found that both the FEV_1/FVC ratio and $FEF_{25–75}$ were significantly decreased in these divers. Additionally, a noteworthy negative correlation was seen between the FEV_1/FVC ratio and both the $FEF_{25–75}$ and the number of years of diving experience. The authors concluded that occupational diving creates clinically asymptomatic changes in spirometry tests due to small airway obstruction after many years of exposure.[28] In our study, the percentage change in $FEF_{25–75}$ among inside IHP demonstrated statistically significant variations based on the number of HBOT sessions. Although the changes in FEV_1/FVC were not statistically significant, a trend was observed where those with a higher number of sessions exhibited greater reductions in both FEV_1/FVC ratio and $FEF_{25–75}$ values. However, no clinical symptoms related to pulmonary system disease were observed in any of the IHP.

The $FEF_{25–75}$ does not contribute additional information already provided by the FVC and FEV_1.[29] The infrequent occurrence of abnormal expiratory flows in the presence of normal FEV_1 and FVC values may indicate measurement 'noise'. This suggests that maximum mid-expiratory flow and flow towards the end of a forced expiratory maneuver add limited value to clinical decision-making.[29] The absence of clinical symptoms related to pulmonary system disease in the IHP in our study also supports this.

Contrary to the above studies, some studies conducted in recent years have not detected any changes in the pulmonary functions of divers.

In a longitudinal cohort study, 8,149 spirometry tests from 1,260 navy divers were analysed. Long-term pulmonary function changes in professional navy divers were found to be no different from those in the non-diving population.[17] In another longitudinal study, 232 divers with data spanning 10 to 25 years were analysed. The PEF showed a greater decline than expected for age in long-term divers and was significantly correlated with the duration of diving and initial age. However, these changes were considered small and clinically insignificant.[16] In our study, only FEF_{25-75} showed a greater decline over time in those with a higher number of sessions compared to those with fewer sessions, but this change was also not clinically significant. However, the absence of clinical symptoms in IHP and the lack of significant differences in PFT changes other than FEF_{25-75} may be due to the FVC manoeuvre not being performed correctly.

Inside attendants breathe compressed air during the HBOT session, an experience similar to that of divers. These sessions occur at a pressure similar to being 10–15 metres underwater. During compression, nitrogen diffuses into tissues; then during decompression, if the partial pressure of accumulated nitrogen in tissue exceeds ambient pressure (supersaturation), the dissolved nitrogen may form bubbles. These bubbles can pass in the venous blood to the pulmonary microvasculature where they may incite inflammation. Potential, but uncertain adverse effects on pulmonary function may result.[2,30] Based on our data, any related effects in IHP appear minor or physiologically inconsequential because no significant changes were observed in longitudinal PFT measurements.

LIMITATIONS

There are certain limitations to this study. Our study was retrospective; nearly all of the participants were women, and all of them were Caucasian. The number of participants in the study was small. This limits the ability to generalise the results. Moreover, future research could investigate confounding variables like contact with undiscovered allergens and high air pollution, which can be challenging to investigate.

Conclusions

This study demonstrated that IHP did not exhibit significant changes in overall lung function as a result of hyperbaric exposures, although a notable decline in FEF_{25-75} was observed in those with a higher number of exposures. No clinically significant respiratory symptoms were identified in the study population. In the absence of changes in FEV_1, FVC, or PEF values, the observed decrease in FEF_{25-75} could be the result of improper FVC manoeuvre performance. Given the critical role of IHP in HBOT sessions, maintaining their pulmonary health is essential. Ensuring the accurate execution of the FVC manoeuvre during assessments is thus important. Our findings suggest that hyperbaric exposure may not have a significant negative impact on pulmonary function in IHP. Further prospective studies are necessary to investigate the long-term clinical significance of these findings and to better understand the effects of hyperbaric exposure on respiratory function over time.

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Divers with large or normal lungs: is the difference justified?

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Fitness to dive; Lung function; Medical conditions and problems; Military diving; Pulmonary barotrauma; Risk factors

Abstract
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Introduction: Measurements of forced vital capacity (FVC) have shown that divers have larger lungs than members of the general population. Bullae or decompression illness (DCI) secondary to pulmonary barotrauma is more likely to occur in large lungs (LLs) than in normal lungs (NLs). This study retrospectively compared lung function, high-resolution CT (HRCT) scan anomalies, the unfit-to-dive rate, and the prevalence of DCI in groups of divers with LLs and NLs.
Methods: The results of fitness examinations of divers with LLs (FVC z-score > 1.96) and NLs (FVC z-score ≤ 1.96) from 2011 to 2020 were retrospectively evaluated. Data were obtained from lung function tests, HRCT results, fitness examination outcomes, and whether the diver did or did not have DCI.
Results: The study included 1,069 divers, with 65 subjects, all male, fulfilling the requirements for LLs. Subjects with LLs had a significantly higher z-scores for FVC and FEV_1 but a significantly lower FEV_1/FVC ratio, than subjects with NLs. The rates of bullae, DCI, and unfit-to-dive did not differ significantly in the two groups.
Conclusions: Although FEV_1/FVC ratio was significantly lower in the LL than in the NL group, there were no between-group differences in the rates of bullae and DCI. These findings suggest that subjects with LLs are not at a higher risk of bullae and DCI than are subjects with NLs.

Introduction

Divers have large lungs (LLs), with a much higher forced vital capacity (FVC) than subjects in the general population.[1–5] Subjects with LLs have a disadvantage, however, as their forced expiratory volume in one second (FEV_1) often increases to a lesser degree than the increment of FVC. This may result in a lower FEV_1/FVC ratio. Although this could be interpreted as an obstructive airway disease, it is merely an effect of dysanapsis.[6]

Divers with obstructive lung diseases are at a higher risk for pulmonary barotrauma (PBt), which may cause arterial gas embolism (AGE).[7,8] Air trapping was found to be more frequent in divers with LLs,[9] suggesting the need for caution when assessing these divers. Yet, we must remember that 'trapped air' in that article was measured at a lower lung volume than may be relevant during ascent from a dive, where trapped lung gas cannot be exhaled from a large lung volume close to total lung capacity (TLC). Besides, the lower FEV_1/FVC ratio in subjects with LLs may not have a pathological cause,[10] but can be a physiological phenomenon, known as dynamic airway compression.[11]

Between 2009 and 2011, the Royal Netherlands Navy's Dive Medical Center (DMC) encountered six subjects with PBt. A retrospective analysis of their medical files revealed that all six had LLs based on the reference values at that time. Post-injury CT scans showed abnormalities, including air trapping, bullae and blebs in all six subjects, suggesting that the risk of PBt is higher in divers with LLs than NLs.[12] Since 2011, therefore, every diver found to have LLs has undergone additional lung function tests, such as body plethysmography and high-resolution computed tomography (HRCT) scans. Although divers with LLs are comprehensively assessed, it is unclear whether testing mitigates the risk of PBt in divers with LLs or results in a higher rate of diver rejection, with rejected subjects labelled as unfit to dive (UtD).

These findings suggested that divers with LLs would have higher rates of HRCT anomalies and UtD, but, a similar rate of decompression illness (DCI) when compared with divers with NLs. The primary objective of this retrospective study was therefore to compare the results of spirometry, body plethysmography, and HRCT, as well as the rates of DCI, defined as both decompression sickness (DCS) and PBt in divers with LLs and NLs.

Methods

As this study was a retrospective analysis of anonymous data gathered during divers' annual assessments, approval from a Medical Ethical Committee was not required. However, the Surgeon General of the Netherlands Armed Forces evaluated and granted permission for this study (reference number DOSCO 2024010072).

Divers belonging to the Netherlands Armed Forces undergo annual medical assessments. These assessments include biometric data, spirometry, and exercise testing, along with an interview and physical examination by the dive medical officer. Fitness-to-dive was assessed according to the European Diving Technology Committee (EDTC) guidelines.[13] Large lungs were defined as those with a FVC > 120% of the European Community for Steel and Coal (ECSC) reference value.[14] Since 2015, the ECSC reference value was replaced by the Global Lung Function Initiative (GLI) reference values, which use z-scores to compare the measured data to the reference value. The z-scores are corrected for height, age, sex and ethnicity; LLs were defined as those with FVC z-scores > 1.96.[15,16]

SPIROMETRY AND PLETHYSMOGRAPHY

Until 2005, the FVC, FEV_1, FEV_1/FVC ratio, and forced expiratory flow rate at 75% of FVC (FEF_{75}) were measured using the Vmax Legacy (SensorMedics, Milan, Italy); after 2005, these parameters were measured using the Vmax Encore (Care-Fusion, Houten, the Netherlands). Residual volume (RV) and functional residual capacity (FRC) were measured, and total lung capacity (TLC) plethysmography was performed, in a V62J Body box using the Vmax Encore. Current GLI reference values and their z-scores were used.[15,17] All measurements were performed by qualified respiratory technicians according to European Respiratory Society / American Thoracic Society task force guidelines. Instruments were calibrated before each test, according to the manufacturer's instructions.

HRCT IMAGING

As stated before, all divers classified as LL were referred to the respiratory physician of our military hospital for extensive lung function testing and HRCT imaging. When we switched from the ECSC reference value to the GLI reference value, some LL subjects were now classified as NL. Furthermore, when NL subjects had a decreased FEV_1/FVC ratio with normal FVC and FEV_1 reference values, and HRCT imaging was performed to exclude air trapping, parenchymal abnormalities or ventilation inhomogeneity.

DATA GATHERING

Demographic and respiratory data from all annual assessments of all divers who visited our centre between January 2011 and January 2021 were obtained from the Diving Medical Centre database. These medical files included HRCT results, as determined by radiologists, and determinations of any DCI, including DCS or PBt, during the study period. All data were anonymised prior to analysis. We divided the included subjects into two groups: those with normal lungs (NLs), defined as having FVC z-scores ≤ 1.96, and those with LLs, defined as having FVC z-scores > 1.96. Ex-smokers were considered non-smokers if they had abstained from smoking ≥1 year.[18]

STATISTICAL ANALYSIS

All data were tested for normality using the Shapiro-Wilk test. Normally distributed continuous data were expressed as mean and standard deviation (SD) and compared in the NL and LL groups using Student's *t*-tests. Non-normally distributed data were reported as median and interquartile range (IQR) and compared using Wilcoxon rank-sum tests. Dichotomous and categorical data were expressed as frequencies (%) and compared using Fisher's exact tests. Differences in successive z-scores of FVC, FEV_1, and FEV_1/FVC were compared by one-way ANOVA with Scheffé correction. All statistical analyses were performed using Stata BE software (version 18, StataCorp, USA), with P-values < 0.05 considered statistically significant.

Results

TOTAL GROUP

This study included 1,069 subjects, 21 (2%) women, and 1,048 (98%) men; of these subjects, 14.5% were smokers, and 85.5% were non-smokers or ex-smokers (Table 1). Sixty-five subjects (6.1%) were identified as having LLs (see Figure 1). Based on the reference population, this percentage was more than the expected 2.5%. All 65 subjects with LLs were male, constituting 6.2% of the male subjects in this study. The FVC z-scores of the study subjects obtained during their first assessment (median FVC z-score 0.422) were higher than those of the reference population (Figure 2). The UtD rate for the whole population was 10.9%, affecting 10.8% of male and 14.3% of female subjects. DCIs were observed only in male subjects. The overall DCI rate was 2.0%, including 1.1% of subjects with type 1 DCS, 0.2% with Type 2 DCS, and 0.7% with PBT.

'LARGE LUNG' VERSUS 'NORMAL LUNG'

A comparison of the 65 subjects with LLs and the 1,004 with NLs showed that subjects in the LL group were significantly older. Unsurprisingly, FVC, FVC z-score, FEV_1, and FEV_1 z-score were significantly higher, and FEV_1/FVC ratio and FEV_1/FVC z-score significantly lower, in the LL group

Table 1

Demographic characteristics of all included subjects and of males and females. Normally distributed data reported as mean (standard deviation) and non-normally distributed data reported as median (interquartile range). * = $P < 0.05$; † = $P < 0.01$; DCI – decompression illness; FVC – forced vital capacity; zFVC – z-score for FVC; FEV_1 – forced exhaled volume in one second; $zFEV_1$ – z-score for FEV_1; FEV_1/FVC – FEV_1/FVC ratio; $zFEV_1/FVC$ – z-score for FEV_1/FVC ratio; $FEF_{75\%}$ – forced expiratory flow rate at 75% of FVC; $zFEF_{75\%}$ – z-score for $FEF_{75\%}$

Parameter	Total group (*n* = 1,069)	Male (*n* = 1,048)	Female (*n* = 21)
Age (yrs)	28.2 (24.8–33.8)	28.2 (24.8–33.9)	28.1 (5.5)
Height (cm)	182.7 (6.6)	182.9 (6.4)	172.5 (6.6) †
Weight (kg)	84 (79–91)	84 (79–91)	69 (7) †
Fat (%)	14.6 (11.5–17.7)	14.5 (11.5–17.7)	25.0 (20.7–27.2) †
Smoking (%)	14.5	14.4	19
FVC (L)	6.22 (5.70–6.68)	6.24 (5.73–6.70)	4.55 (0.67) †
zFVC	0.637 (0.022–1.200)	0.639 (0.023–1.210)	0.409 (0.771)
FEV_1 (L)	4.80 (0.63)	4.83 (0.61)	3.67 (0.52) †
$zFEV_1$	0.144 (0.911)	0.146 (0.910)	0.067 (1.008)
FEV_1/FVC (%)	78 (74–82)	78 (74–81)	80 (7)*
z FEV_1/FVC	0.776 (0.057)	-0.734 (0.818)	-0.593 (0.935)
$FEF_{75\%}$ ($L.s^{-1}$)	1.8 (1.5–2.3)	1.8 (1.5–2.3)	1.8 (0.7)
$zFEF_{75\%}$	-0.296 (0.790)	-0.299 (0.781)	-0.138 (1.190)
Unfit to dive (%)	10.9 (*n* = 116)	10.8 (*n* = 113)	14.3 (*n* = 3)
DCI (%)	2.0 (*n* = 21)	2.0 (*n* = 21)	0.0

Figure 1

Data flow diagram; HRCT – high-resolution computed tomography

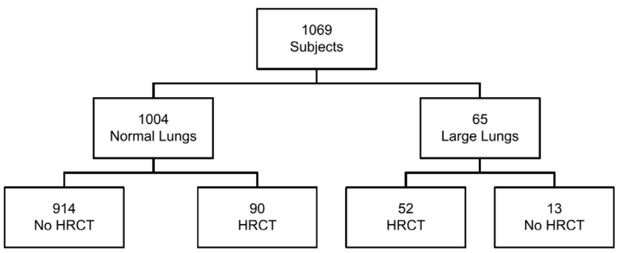
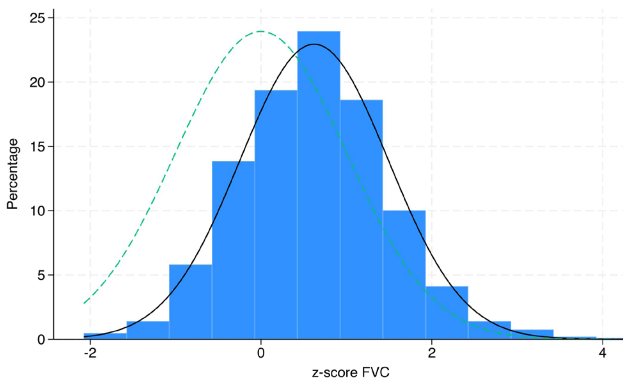


Figure 2

Histogram and normality curve of the z-score of the forced vital capacity (FVC) in the study population (black line) compared with the normality distribution curve (dashed green line); Percentage – percentages of subjects in a specific bin



than in the NL group (Table 2). The rates of UtD, DCS, and PBt did not differ significantly in these two groups. The predominant reasons for UtD in the NL group were based on lung function results (72.3%), followed by HRCT anomalies (19.6%) and other non-respiratory reasons (8.1%). For the LL group, it was 60%, 40% and 0%, respectively (see Table 3). The differences between the NL and LL groups were not significant.

‘LARGE LUNGS’ VERSUS ‘NORMAL LUNGS’ WITH HRCT IMAGING

Of these divers, 142 underwent HRCTs, 90 in the NL group and 52 in the LL group (Figure 2). Body plethysmography data were also available for 120 of these subjects. Age, height, weight, fat percentage and smoking rate did not differ significantly in NL and LL subjects who underwent HRCT. Similar to findings in the total male population, FVC, FVC z-score, FEV_1, and FEV_1 z-score were significantly higher, while FEV_1/FVC ratio and FEV_1/FVC z-score were significantly lower, in LL than in NL subjects who underwent HRCT (Table 4). Plethysmography showed that TLC, TLC z-score, and FRC z-score were significantly higher in subjects with LL, whereas RV, RV z-score, RV/TLC ratio and RV/TLC ratio z-score did not differ in the two groups. Surprisingly, the UtD rate was significantly lower

Table 2

Demographic characteristics of male subjects with normal and large lungs. Normally distributed data reported as mean (standard deviation) and non-normally distributed data reported as median (interquartile range). * = $P < 0.01$; FVC – forced vital capacity; zFVC – z-score for FVC; FEV1 – forced exhaled volume in one second; $zFEV_1$ – z-score for FEV_1; FEV_1/FVC – FEV_1/FVC ratio; $zFEV_1/FVC$ – z-score for FEV_1/FVC ratio; $FEF_{75\%}$ – forced expiratory flow rate at 75% of FVC; $zFEF_{75\%}$ – z-score for $FEF_{75\%}$; DCS – decompression sickness; PBt – Pulmonary barotrauma

Parameter	Normal lungs (n = 983)	Large lungs (n = 65)
Age (yrs)	28.0 (24.8–33.7)	30.2 (25.8–38.7)*
Height (cm)	183.0 (6.3)	182.0 (7.2)
Weight (kg)	84 (79-91)	87 (9)
Fat (%)	14.5 (11.5–17.7)	14.8 (4.2)
Smoking (%)	14	16
FVC (L)	6.16 (0.70)	7.37 (0.67)*
zFVC	0.559 (-0.014–1.088)	2.320 (2.105–2.686)*
FEV_1 (L)	4.78 (0.59)	5.44 (0.59)*
$zFEV_1$	0.054 (0.839)	1.469 (0.864)*
$FEV_1/FVC\%$ (%)	78 (74–82)	74 (6)*
z FEV_1/FVC	-0.698 (0.812)	-1.248 (0.734)*
$FEF_{75\%}$ ($L.s^{-1}$)	1.8 (1.5-2.3)	1.9 (0.7)
$zFEF_{75\%}$	-0.310 (0.781)	-0.144 (0.763)
Unfit to dive (%)	11.1 (n = 109)	6.2 (n = 4)
DCS (%)	1.2 (n = 12)	3.1 (n = 2)
PBt (%)	0.7 (n = 7)	0.0

Table 3

Reason for unfit to dive decision for normal and large lung groups; 'HRCT' are bullae, blebs, emphysematous change, air trapping, and other pulmonary HRCT findings; 'Lung' is lung function reasons, such as insufficient spirometry, positive bronchoprovocation test, etc; 'Other' is non-pulmonary reasons. There were no significant between-group differences. HRCT – high resolution computed tomography

Group	HRCT	Lung	Other	Total
Normal lungs	n = 22 (19.6%)	n = 82 (72.3%)	n = 8 (8.1%)	n = 112
Large lungs	n = 2 (40%)	n = 3 (60%)	0%	n = 5
Total	n = 24 (20.5%)	n = 85 (72.6%)	n = 8 (6.9%)	n = 117

in LL than in NL subjects who underwent HRCT, a result ascribed to the larger number of HRCT anomalies in the NL group (Table 5). Rates of bullae and blebs, however, did not differ significantly in these two groups, nor did the rates of DCS and PBt (Table 4).

'LARGE LUNGS' AND 'NORMAL LUNGS' OVER TIME

Divers undergo medical assessments once per year, with z-scores for spirometric data corrected by sex, age, and ethnicity. Over time, the FVC z-score decreased minimally in the NL group, but showed a greater decrease in the LL group (Figure 3). The FEV_1 z-scores decreased minimally in both groups (Figure 4), accompanied by increases in their z-scores for the FEV_1/FVC ratio (Figure 5). The $FEF_{75\%}$ z-scores did not differ significantly in the LL and NL (Figure 6). One-way ANOVA with Scheffé correction for multiple comparisons showed that neither group's changes were statistically significant.

Discussion

To our knowledge, this is the first study to compare HRCT anomalies, UtD rates, and the prevalence of DCI in groups of divers with LLs and NLs. The percentage of divers with LLs was higher than that of the GLI reference population. Although the FEV_1/FVC ratio was significantly lower in the LL group, the number of HRCT anomalies in the LL group was also significantly lower than in the NL group. In addition, rates of DCS and PBt did not differ in these two

Table 4

Demographic characteristics of male subjects with normal and large lungs evaluated by high resolution computed tomography (HRCT) imaging; normally distributed data are reported as mean (SD) and non-normally distributed data reported as median (IQR). * n = 80; † n = 40; ¶ = $P < 0.05$; ‡ = $P < 0.01$; FVC – forced vital capacity; zFVC – z-score for FVC; FEV_1 – forced exhaled volume in one second; $zFEV_1$ – z-score for FEV_1; FEV_1/FVC – FEV_1/FVC ratio; $zFEV_1$/FVC – z-score for FEV_1/FVC ratio; $FEF_{75\%}$ – forced expiratory flow rate at 75% of FVC; $zFEF_{75\%}$ – z-score for $FEF_{75\%}$; FRC – functional residual capacity; zFRC – z-score for FRC; TLC – total lung capacity; zTLC – z-score for TLC; RV – residual volume; zRV – z-score for RV; RV/TLC – RV/TLC ratio; zRV/TLC – z-score for RV/TLC ratio; DCS – decompression sickness; PBt – pulmonary barotrauma

Parameter	Normal Lungs (n = 90)	Large lung (n = 52)
Age (yrs)	30.5 (26.7–39.5)	30.2 (25.3–38.7)
Height (cm)	184.1 (6.5)	182.5 (9.2)
Weight (kg)	87 (9)	87 (9)
Fat (%)	15.1 (12.2–17.7)	15.0 (3.8)
Smoking (%)	14	16
FVC (L)	6.57 (0.71)	7.42 (0.66)‡
zFVC	0.559 (0.695–1.528)	2.325 (2.122–2.686) ‡
FEV_1 (L)	4.98 (0.68)	5.44 (0.55) ‡
$zFEV_1$	0.392 (-0,412–1.277)	1.172(0.862–1.957) ‡
FEV_1/FVC (%)	76 (6)	73 (5)¶
z FEV_1/FVC	-0.668 (-1.579– -0.183)	-1.312 (0.678) ‡
$FEF_{75\%}$ ($L.s^{-1}$)	1.8 (1.4–2.3)	1.9 (0.6)
$zFEF_{75\%}$	-0.273 (0.946)	-0.182 (0.710)
FRC (L)	3.73 (0.73)*	3.91 (0.72) †
zFRC	0.018 (0.738)*	0.393 (0.664) †,¶
TLC (L)	8.21 (0.90)*	8.86 (0.86) †,‡
zTLC	0.534 (0.658)*	1.468 (1.145–1.767) †,‡
RV (L)	1.62 (1.36–2.10)*	1.74 (0.29) †
zRV	-0.043 (0.663)*	0.127 (0.528) †
RV/TLC	0.21 (0.05)*	0.20 (0.04) †
zRV/TLC	-0.239 (0.625)*	-0.382 (0.502) †
Unfit to dive (%)	27.7 (n = 25)	3.8‡ (n = 2)
HRCT anomaly (%)	23.3 (n = 21)	3.8‡ (n = 2)
DCS (%)	1.1 (n = 1)	3.8 (n = 2)
PBt (%)	3.3 (n = 3)	0.0

Table 5

Comparison of high-resolution computed tomography (HRCT) anomalies in subjects with normal and large lungs. There were no significant between-group differences

Pulmonary finding	Normal lungs (n = 21)	Large lungs (n = 2)
Bullae and blebs	33.3% (n = 7)	100% (n = 2)
Emphysematous change	19.0% (n = 4)	0%
Air trapping	9.5% (n = 2)	0%
Cysts	9.5% (n = 2)	0%
Other	28.6% (n = 6)	0%

Figure 3
Time courses of z-scores for forced vital capacity (FVC)

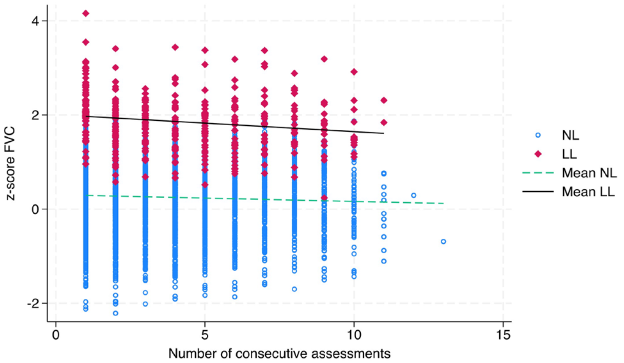


Figure 4
Time courses of z-scores for forced exhaled volume in one second (FEV_1)

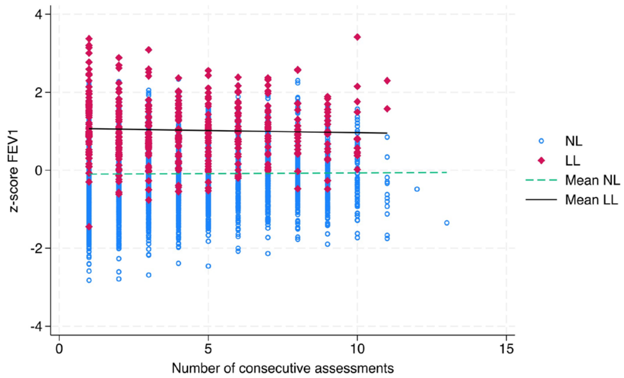


Figure 5
Time courses of z-scores for forced exhaled volume in one second to forced vital capacity (FEV_1/FVC) ratio

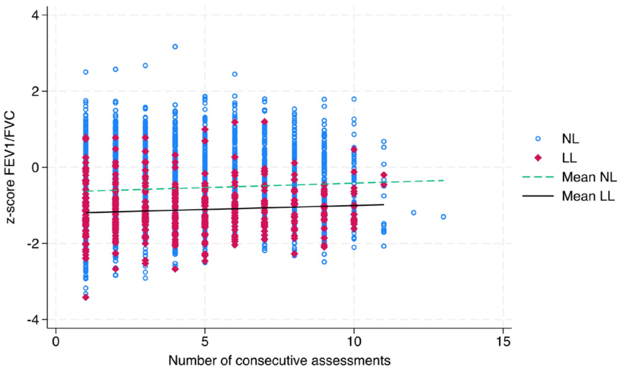
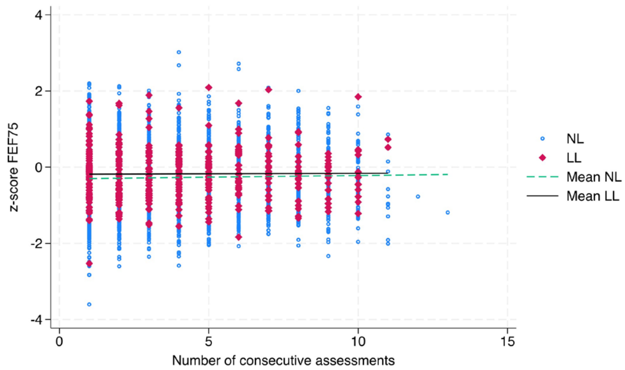


Figure 6
Time courses of z-scores for forced expiratory flow rate at 75% of FVC ($FEF_{75\%}$)



groups, suggesting that subjects with LL group were not at higher risk than those with NL.

Over the assessment period, the FVC, FEV_1, and FEV_1/FVC z-scores showed little change in both groups, in agreement with previous findings.[10,19] Although evaluations of older subjects showed significant changes over time,[20] the GLI introduced better age-corrected reference values, resulting in non-significant changes. This strongly supports the importance of using correct reference values.[21]

An international consensus conference in 1993 concluded that diving could affect pulmonary function by increasing the FVC and reducing the FEV_1/FVC ratio.[22] This is different from the results of the present study. Large lungs may not be a diving-related physiological phenomenon but rather a selection bias.[23,24] The median FVC z-score obtained during the first assessment of the subjects in the present study was 0.422, shifting the normality curve of the population to the right and supporting the likelihood of selection bias. Alternatively, it could also be that within the LL group, more subjects had already dived before being assessed as military divers, leading to higher FVC values. Indeed, 49.8% of the divers with large lungs had some diving experience, varying between one to 80 dives. However, we found that 77% of the subjects in the NL group had also been diving before the first assessment, ranging between one and 30 dives. Thus, we do not think that this biased our results.

Two results surprised us. First, the UtD rate did not differ significantly in males with LLs and NLs. The five subjects rejected in the LL group included two with anomalies on HRCT and three with abnormal lung function testing results. The predominant reasons for rejection in the NL group were mainly based on insufficient lung function values compared to the reference value. Although the reasons for this difference are not clear, the results of lung function tests may be more strictly interpreted in the NL group. Large lungs are not necessarily considered a pathological phenomenon, but an anatomical imbalance between the upper and lower airways, resulting in differences in FVC and FEV_1, also called dysanapsis.[10,11] Subjects with LL may undergo additional lung function testing to confirm this anatomical imbalance, which resulted in a lower UtD rate.

By contrast, subjects with NL may undergo lung function testing to exclude pathological bronchoconstriction, resulted in a higher rejection rate for diving.

Second, the percentage of subjects with HRCT anomalies was significantly higher in the NL (23.3%) than in the LL (3.8%) group. This difference was mainly due to the rates of anomalies other than bullae and blebs, as rates of bullae and blebs were similar in the two groups. However, the prevalence of bullae and blebs in the NL group (7.8%) was higher than previously reported (4.7%).[25] Other studies, however, have reported higher rates of bullae in healthy subjects aged ≤ 40 years (7.2%)[26] and in a population of military divers (7.0%).[27]

Despite the 'Large Lung Protocol', 13 subjects in the LL group did not undergo HRCT. All 13 subjects had z-scores for the FEV_1/FVC ratio within the normal range, which may explain the lack of HRCT in these subjects. Performing an HRCT may have increased the number of bullae detected. The exact rates of bullae and blebs in a military population and in subjects with LLs are unclear, but they could range between 2.3% and 7.8%. More importantly, these findings showed that subjects with LLs were not at higher risk of having bullae and blebs than those with NLs.

In contrast to the present findings, another study showed air trapping rates were higher in divers with LLs than NLs.[9] The amount of trapped air was calculated by subtracting total lung capacity (TLC), as measured by a helium dilution test, from TLC as measured by plethysmography. The volume of trapped air was found to increase when vital capacity (VC) was > 122% of reference. In the present study, subjects in the LL group had z-scores > 1.96, or > 123% of reference. Only two of these subjects had bullae, with none of the others having trapped air. Despite improvements in the resolution of HRCT, small areas of air trapping may be missed. A post-mortem study using high-dose total body CT found that the prevalence of bullae in a general population without any lung diseases was > 30%,[28] indicating that the current HRCT technique is not sufficiently sensitive to show all areas of trapped air. Further developments in HRCT techniques and models may enable the exact volume of trapped air to be measured. Yet, when assessing air trapping by comparing end-inspiratory to end-expiratory HRCT, one assesses at a lower lung volume than what may be relevant during ascent from a dive, as a diver will never breathe at expiratory reserve volume while diving. This raises the question of whether the methods used to detect air trapping, specifically end-inspiratory and end-expiratory HRCT imaging, are appropriate tools. Especially when air trapping diagnosed through HRCT could result in UtD, as was the case at our centre due to the interpretation of the former EDTC guidelines.[13]

Furthermore, in the Wuorimaa et al.[9] and the present studies, the RV was not significantly different between the LL and NL groups. This implies an increased functional capacity but no increase in RV to suggest air trapping, which may be reassuring when assessing a LL dive candidate. This might explain the present study's lack of abnormalities in HRCT.

STRENGTHS AND LIMITATIONS

The strengths of the present study include the size of the study population and its being the first study to compare pulmonary function, chest HRCT results, and UtD and DCI rates in military divers with LLs and NLs. Nevertheless, this study had several limitations. First, most of the study population was male. Only 2% were females, and none of these had LLs. Thus, the results of the present study are inapplicable to female divers. Furthermore, military diving differs from off-shore, in-shore and saturation diving. Thus, male military divers with LLs and NLs do not differ in UtD rate, the number of bullae and the risk of diving accidents. Research on other categories of professional divers, including off-shore and in-shore divers, may clarify whether findings in these divers are similar to those in military divers. Second, despite the longitudinal evaluation of some subjects, data on the exact diving exposure of each subject were not available. Although all of these divers had to dive for at least 360 minutes per month, information on dive depth and the diving gas used could not be determined, thus precluding the determination of any relationship between diving and changes in lung function parameters. Yet, as shown in Figure 3, the diving methods used in our military setting did not increase FVC over time in both LL and NL. Therefore, we do not think the missing diving data biased our study. Nevertheless, future studies could include these diving data to determine whether diving experience and diving gas have any effect on LLs in non-military diving settings. Third, few subjects had diving accidents during the 10-year study period. Although DCI rates did not differ significantly in the LL and NL groups, the numbers of diving accidents may have been too low to show any significant effect. *A posteriori* power analyses showed that the minimum number of DCI events in each arm required to show a significant between-group difference was > 1,000, a number too large for a single centre study. Multi-centre trials in allied countries are therefore needed to study the effects of NLs and LLs on DCI events (particularly PBt).

Conclusions

Previously, subjects with LLs were regarded as being at higher risk for bullae and DCI than subjects with NLs. The present study compared HRCT anomalies and UtD and DCI rates in military divers with LLs and NLs. Although the FEV_1/FVC ratio was significantly lower in the LL group, the number of bullae in the NL and LL groups did not differ. In addition, with the caveat that the study was underpowered to show a difference, rates of DCS and PBt did not differ in these two groups, suggesting that divers with LLs are not at higher risk of DCI.

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The influence of wetsuit thickness (≥ 7 mm) on lung volumes in scuba divers

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Keywords
Diving research; Equipment; Fitness to dive; Lung; Respiratory; Spirometry

Abstract
(Stevens G, Smart DR. The influence of wetsuit thickness (≥ 7 mm) on lung volumes in scuba divers. Diving and Hyperbaric Medicine. 2025 31 March;55(1):27–34. doi: 10.28920/dhm55.1.27-34. PMID: 40090023.)
Introduction: We hypothesised that although thicker (≥ 7 mm) wetsuits delay hypothermia and allow divers to dive in cooler waters, they may hinder pulmonary function. The aim of this study was to investigate whether thicker wetsuits worn by Tasmanian divers affected lung volumes, primarily the forced vital capacity (FVC) and forced expiratory volume, one second (FEV_1).
Methods: Sixty-two volunteer active divers were recruited from recreational dive clubs and Tasmania's occupational diving industry. After confirming fitness and that the divers were currently active, spirometry testing was performed with and without the divers' usual wet suits, in a controlled dry environment. Suits were of varying thickness, but all were ≥ 7 mm thickness.
Results: All divers had significantly reduced lung volumes when wearing ≥ 7 mm wetsuits. Recreational divers had greater decrements (-7% FVC and -5% FEV_1), compared to occupational divers (-3% FVC, -3% FEV_1). Males' lung volumes declined -4% FVC and -4 % FEV_1, whereas females declined -7 % FVC and -6 % FEV_1. Female recreational divers experienced the greatest negative impact from thicker wetsuits (up to 15% reduction in FVC), and this group also demonstrated an inverse relationship between increasing wetsuit thickness and declining lung volumes.
Conclusions: Wearing thicker wet suits aids in thermal protection in temperate water diving but this study suggests it has negative effects on lung volumes. The real-life impact of this negative effect may be minor in fit healthy divers but might add additional risk to a less fit, recreational diving population with medical comorbidities.

Introduction

Wetsuits are worn by divers for thermal protection to prevent conductive heat loss in the subaquatic environment and may offer some protection from marine hazards. Wetsuit thicknesses vary from 1 mm (or less) in tropical waters to 18 mm or more in colder waters. Previous authors have shown a detrimental effect from wearing wetsuits < 7 mm thickness on performance in spirometry in fit 'active' recreational divers.[1] The effect of thicker wet suits which are commonly used in colder waters on pulmonary function are, as far as we are aware, unknown.

In Tasmania, Australia, sea temperatures range from 9–21°C which are consistent with temperate waters in other countries.[2] To prevent hypothermia, divers routinely use ≥ 7 mm (single layer and sometimes double layer) neoprene wetsuits, or dry suits. Double layer suits are in 'long john' (singlet shoulders) and vest with attached hood configuration. The double layer covers the thorax, abdomen and pelvis. Tasmania has more than 20,000 divers among its 570,000+ population, including recreational and occupational divers; the latter supporting multi-million-dollar seafood and aquaculture industries and offshore work.[3,4] Occupational divers are subject to legislated higher level commercial training, annual full diver health assessments, and they dive all year round. Recreational divers have minimal governance over health assessments, and tend to dive less frequently. Based on the above it is possible that there may be a difference between these diver groups.

A previous study demonstrated reduced forced vital capacity (FVC) of 4% and forced expiratory volume in one second (FEV_1) of 3.6% in recreational divers wearing thinner wetsuits of mean thickness 3.8 mm.[1] We hypothesised that wetsuits of ≥ 7 mm thickness may have a greater negative impact on pulmonary function.

The aim of this study was to investigate whether (≥ 7 mm thickness) wetsuits worn by Tasmanian divers affected lung volumes, primarily FVC and FEV_1. Secondary aims were to assess the influence of body mass index (BMI), age, sex, and recreational versus occupational status of the diver on lung volumes.

Methods

Ethics approval was obtained from the University of Tasmania Human Research Ethics Committee (UTasHREC) and the Department of Health Research Governance Office [Protocol number H0024772]. The study was registered with the Australian and New Zealand Clinical Trials Registry (382180).

Volunteer active divers were recruited through poster advertising in dive shops, dive clubs and via occupational dive companies over 15 months from 21 July 2021 to 24 October 2022. Study exclusions were pregnancy, age < 18 years, respiratory illness less than four weeks prior (including COVID-19), symptomatic cardiovascular disease, dived < 24 hours before evaluation and non-active divers. Active divers were defined as performing ≥ 20 dives per year and as having dived in the last three months. Included divers then provided written consent to enter the study.

Divers were asked to complete a basic health triage questionnaire (developed by the authors) to confirm absence of major illnesses affecting fitness to dive. The results of the triage questionnaire were not further analysed in this study. Data for each diver were recorded: age, height, weight, sex, body mass index (BMI), number of total dives, recreational qualification or occupational qualification, and wetsuit(s) thickness.

Divers were assessed in the Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, at the workplace or dive site (pre-dive) by the first author. Subjects were assessed when wearing their personal wetsuit(s) in a dry room or office. It was assumed that these personal wetsuits were appropriate 'fit' as they had been self-selected, and were in regular use by the subjects. Ages of the wetsuits were variable and not documented. Wetsuit thicknesses were recorded as stated from the manufacturer label. Wetsuits of 14 mm and 18 mm thickness had double layers covering the thorax and abdomen.

Randomisation of the order in which measurements were performed (in wetsuit, out of wetsuit, thicker suit first) was generated using R Software (R Foundation for Statistical Computing, Vienna, Austria) just prior to the measurement to mitigate potential learning effect.[5] The assessor was blinded to the order of testing until just before the test was performed.

The Spirolab III spirometer (MIR, Rome, Italy) was calibrated in accordance with manufacturer's instructions. Each test was performed with subjects exhaling through disposable mouth pieces. The device was cleaned fully between subjects. Individual subjects completed all their tests in a single session, same day. It was initially planned to complete testing when subjects achieved three category A quality spirometry samples (assessed by the spirometer internal algorithm) for each of the wetsuit states: wetsuit off, wetsuit on (thick or thin).[6,7] Subjects were expected to require multiple blows to achieve each quality A sample (minimum two). For a full data set, subjects with one wetsuit therefore provided six samples to the database (three with wetsuit on and three with wetsuit off, and subjects with two wetsuits (thick and thin) had nine samples taken. Allowances were made if some subjects became exhausted and were unable to achieve the three samples of acceptable quality. On that basis two samples were regarded as acceptable.[6,7] Spirometry included: forced vital capacity (FVC), and forced expiratory volume in one second (FEV_1), as measures of pulmonary function, previously used by other authors.[1] Full spirometry curves were available for each subject but not analysed in this study.

Spirometry and anonymised biometric data (sex, height, weight, BMI, number of dives, and diver status – recreational or occupational) were extracted from our data pool and analysed. Wetsuit thickness was stratified into three groups for analysis: ≤ 7 mm, > 7 mm but < 14 mm, and ≥ 14 mm.

STATISTICS

R software was used, and a sample size of 60 was calculated to provide 95% power to detect a 4% difference in FEV_1 or FVC at alpha = 0.05 by two-tailed *t*-test.[5] The estimates were based on previously published data.[1,5] To investigate the relationship between lung volumes (FEV_1 and FVC) and suit thickness, a linear mixed-effect model was also used in R Software.[5] This modelling approach enabled us to account for population level variance using the random effects of the subject, and fixed effects of suit-type. Additional fixed effects that may influence pulmonary function (age, sex, height, weight, BMI, and recreational vs occupational diving background) were also included which enabled us to control for these variables and avoid confounding changes in pulmonary function due to suit effect interaction with other variables. Additional data analysis was performed using GraphPad Prism software (version 7.03) for tests of normality (Shapiro-Wilk and Kolmogorov-Smirnov), paired Student *t*-testing, contingency tables with Chi-square analysis and Bland-Altman analysis.[8]

Results

Recruitment was hampered by the COVID-19 pandemic. We recruited 62 divers over a 15-month period, who provided 364 samples. Five divers provided samples in two different wetsuit thicknesses, which meant the ideal sample number should have been 387. Thirteen divers were unable to provide more than two category A samples for their assigned wetsuit states (off, on ± thin or thick). Because they produced a minimum of two samples of sufficient quality, their data was accepted for analysis. In our 62 subjects, 47% were female, and 47% were occupational divers (of these 14/29 were female, Table 1). Samples were collected mostly (71%) in the morning and less (29%) in the afternoon. The distribution of sampling times was not significantly different for occupational versus recreational samples (P = 0.58 Fishers exact test).

Height, weight, BMI, FEV_1 and FVC data were normally distributed, but age was not (skewed by a small group of older recreational divers). Mean BMI of all the divers was 25.1 $kg \cdot m^{-2}$. The BMI in occupational and recreational divers was not different (P = 0.67, two-tailed unpaired t-test). Wetsuit thicknesses were 7 mm, 8 mm, 10 mm, 14 mm (double thickness 7 mm) and 18 mm (double thickness 9 mm). Median thickness for recreational divers was 10 mm (range 7–14 mm), and for occupational divers 14 mm (range 7–18 mm).

Occupational divers had significantly greater diving experience compared to recreational divers, Figure 1 (P = 0.0002, χ^2 test). Table 1 summarises baseline data for the divers. Occupational and female divers were generally younger in this study. Lung volumes were not significantly different when occupational and recreational divers were compared in this sample (P = 0.29 for FEV_1, and P = 0.10 for FVC (two tailed t-test)).

Table 1 also documents the reductions in FVC and FEV_1 when wearing any thickness of wetsuits. All diver groups demonstrated statistically significant reductions in lung volumes when wearing a wetsuit versus no wetsuit (t-test). Recreational divers had greater reductions when wearing a wetsuit compared to occupational divers; recreational divers exhibited a reduction of FVC and FEV_1 by 0.350 L (7%) and 0.210 L (5%) respectively in comparison to occupational divers where the reduction was 0.140 L (3%) and 0.100 L (3%) respectively. Occupational divers generally were wearing thicker wetsuits (Table 1). For males, FVC

Figure 1
Distribution of diving experience for the study cohort

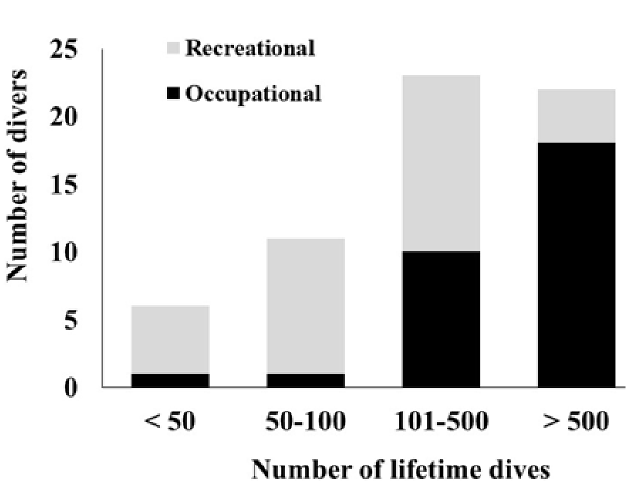


Table 1
Diver age, height, body mass index (BMI) and mean reductions of forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) by diver sub-group; F – female; IQR – interquartile range; M – male; SD – standard deviation

Diver group	Median (IQR) age (y)	Mean (SD) height (cm)	Mean (SD) BMI ($kg \cdot m^{-2}$)	Median wetsuit thickness (mm)	Mean (SD) Baseline FEV_1 (L)	Mean (SD) Baseline FVC (L)	Mean reduction FEV_1 wearing any wetsuit			Mean reduction FVC wearing any wetsuit		
							L	%	P-value	L	%	P-value
All (n = 62)	31.5 (26.0, 46.5)	173.9 (9.1)	25.1 (3.5)	10	4.2 (1.0)	5.4 (1.4)	-0.16	-4	< 0.001	-0.25	-5	< 0.001
Male (n = 33)	36 (28.0, 50.0)	180.7 (4.6)	26.3 (3.4)	14	4.8 (0.7)	6.1 (0.8)	-0.16	-4	< 0.001	-0.25	-4	0.0019
Female (n = 29)	28 (22.5, 35.0)	166.6 (5.9)	23.8 (3.3)	10	3.3 (0.5)	4.1 (0.7)	-0.17	-6	0.0052	-0.26	-7	0.0126
Occupational (M = 15, F = 14)	30 (26.0, 37.0)	173.3 (9.8)	24.9 (3.6)	14	4.1 (1.0)	5.0 (1.3)	-0.10	-3	0.0068	-0.14	-3	0.0044
Recreational (M = 18, F = 15)	32 (26.5, 48.5)	174.1 (8.2)	25.3 (3.5)	10	4.3 (1.0)	5.6 (1.5)	-0.21	-5	< 0.001	-0.35	-7	0.0017

Table 2
Reductions in forced vital capacity (FVC) in the female recreational diver group

Suit	FVC (L)	% baseline in sample	% negative change
Baseline	4.26	100	0.0
7 mm	3.99	93.7	-6.3%
7–14 mm	3.78	88.7	-11.3%
> 14 mm	3.63	85.2	-14.8%

Table 3
The effect of suit type, sex, age, and height on forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1); the parameter estimates for the optimum (AICc selected) model;[9–11] M – male

Variable	FEV_1			FVC		
	Estimate change (L)	95% confidence interval	*P*-value	Estimate change (L)	95% confidence interval	*P*-value
Intercept (includes baseline, i.e., no suit)	-0.20	-4.26, 3.86	0.923	-0.75	-5.96, 4.45	0.776
Suit (7 mm)	-0.16	-0.24, -0.07	< 0.001	-0.27	-0.40, -0.13	< 0.001
Suit (7 to14 mm)	-0.19	-0.29, -0.09	< 0.001	-0.48	-0.64, -0.32	< 0.001
Suit (> 14 mm)	-0.17	-0.23, -0.11	< 0.001	-0.19	-0.29, -0.10	< 0.001
Sex (M)	1.42	0.99, 1.86	< 0.001	1.86	1.30, 2.42	< 0.001
Age centre	-0.03	-0.04, -0.02	< 0.001	-0.02	-0.03, -0.01	0.002
Height cm	0.02	-0.00, 0.04	0.104	0.03	-0.00, 0.06	0.075
Random Effects						
σ^2	0.05			0.12		
Number of subjects	62			62		
Observations	364			364		
Conditional R^2-Marginal R^2	0.95 – 0.72 = 0.23 (23%)			0.93 – 0.71 = 0.22 (22%)		

and FEV_1 declined 0.240 L and 0.160 L respectively, a 4% fall for both compared to females where FVC and FEV_1 declined 0.258 L (7%) and 0.165 L (6%) respectively. Although absolute values of the male vs female FVC and FEV_1 reductions were similar, the percentage decrements for females were greater due to smaller baseline spirometry values in females.

Female recreational divers had reductions of almost 15% in FVC when wearing 14 mm or greater wet suits (Table 2). Even the 7–14 mm and 7 mm suits recorded FVC decrements of 11.3% and 6.3% respectively. For this subset of our study population, there was an inverse relationship of declining lung volumes as wetsuit thickness increased. The same relationship was not confirmed for other diver subsets.

Controlling for other variables such as age, sex and height, the reduction in lung volumes was statistically significant in our multivariate analysis (Table 3). This model, using Akaike Information Criterion, (AIC)c, provided the best fit for analysis of small groups with multiple variables.[9–11] Our multivariate analyses confirmed that there was a negative effect on FEV_1 and FVC when wearing a wetsuit, which was statistically significant in all categories. The reduction in FEV_1 was greatest in the 7 to 14 mm suit thickness category, followed by > 14 mm thickness, then 7 mm thickness suits. The reduction in FVC was greatest for 7–14 mm wetsuits, followed by ≤ 7 mm wetsuits and ≥ 14 mm thickness. These results are depicted graphically in Figures 2 and 3.

Effect of suit type, age, sex, and height were treated as explanatory variables. Males had significantly greater FEV_1 and FVC in this population; a known characteristic which is incorporated into normative spirometry databases. Lung volumes reduced significantly with age in all categories. The effect of BMI was not significant as an independent variable (Bland-Altman analysis, $P = 0.48$ for FEV_1 and $P = 0.80$ for FVC). There was a trend towards statistical significance for height as an independent variable (also a known effect incorporated into spirometry databases).

Table 3 also provides marginal R2/conditional R2 values for the two parameters. The marginal is the variation explained by the model fixed effects and conditional is the variation

Figure 2
Wetsuit thickness effect on mean forced expiratory volume in one second (FEV_1); error bars represent mean (2 standard deviations)

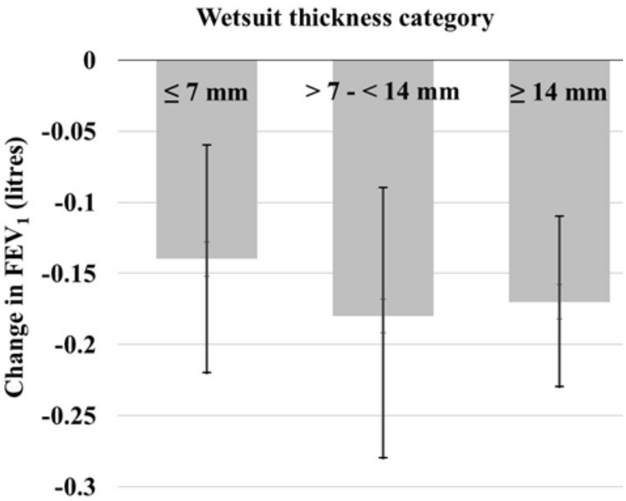
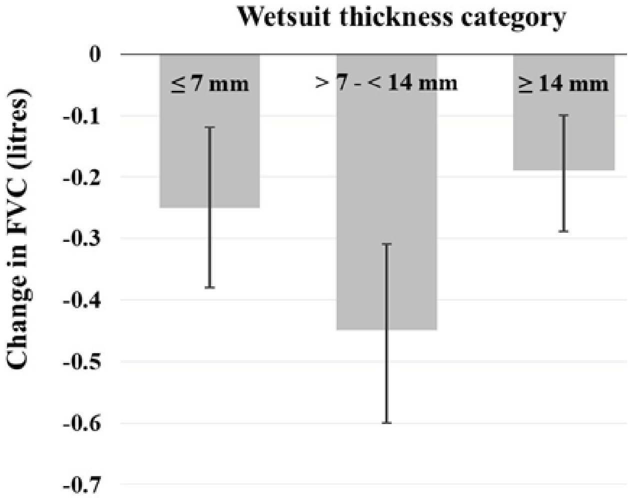


Figure 3
Wetsuit thickness effect on mean forced vital capacity (FVC); error bars represent mean (2 standard deviations)



explained by the random and fixed effects. The random effect demonstrates some variance not specified in the fixed effects. Hence, some of the study population variance is not fully explained by our chosen parameters. Using a mixed effects model such as this, we had the opportunity to account for greater population-level variability than a standard (fixed effect) linear model. In the fitted models, the inclusion of a random effect of subject increased the variability explained (calculated as conditional R2 minus marginal R2) in pulmonary function 23% for FEV_1 and by 22% for FVC.

Discussion

We have shown that there is a statistically significant reduction in lung volumes when wearing temperate water wetsuits, but what does this mean in the real world? Is a 3–7% reduction in FVC and FEV_1 physiologically significant? In a young, fit, healthy population of divers, free of medical illness, we would assert that this order of decrement is unlikely to have any functionally consequential effect on physical performance when diving.

An earlier study demonstrated that tropical thickness wetsuits have negative effects on measurable lung volumes in recreational divers.[1] Mean suit thickness in our study was greater than in that study, and our recreational diver subset had a greater decrement in lung volumes.[1] The largest reductions of FVC (greater than 10%) were observed in female recreational divers. This may be explained by a smaller baseline FVC and FEV_1 in females, but could also be related to suit fit, baseline physical fitness or technique. This effect was independent of other variables and our data model correlated well with previous work on age and pulmonary function.[12]

It is possible that specific diver groups could experience greater negative physiological effects from wetsuits. Increasing age can be associated with reduced fitness, obesity, hypertension, underlying cardiac and pulmonary disease. These effects may also evolve without detection in recreational divers who dive less frequently. Recreational divers in Australia have no mandated health monitoring. This contrasts with occupational divers who have mandatory annual medical assessments. Medical assessments are likely to detect and correct heath issues, weight gain, and ensure fitness in this group. In addition, regular diving may improve occupational divers' adaptation and strength when wearing wetsuits.[13]

An individual sustaining weight gain but still using the same wetsuit, could experience greater impaired pulmonary function. All divers in our study were in relatively good physical condition and BMI did not influence lung volumes. Our population mean BMI was 25.1, within a narrow range. Our data showed insufficient variance in BMI to accurately detect relevant effects.

Median wetsuit thicknesses were greater in the occupational group. This was counter-intuitive, particularly when considering the lesser impact on FVC (Figure 3). Occupational divers may have had better quality wetsuits, fitted specifically for work, more flexible due to frequent use, and their wetsuits may be replaced more frequently. In addition, occupational divers are likely to be fitter and stronger, physically compensating for the restrictive effect of the wetsuit. Wetsuits which are used less frequently may become stiff and less flexible.

An additional important factor could be the wetsuit 'fit' which was not independently assessed in this study. Subjects were all assessed when wearing their personal wetsuits.

We made an assumption that these wetsuits would be close to ideal 'fit' because they were personally selected, and in regular use. This may be valid for occupational divers who dive regularly at work. Recreational divers in this study dived less frequently and had less overall experience than occupational divers. It is possible that recreational divers may not update their wetsuit if the wetsuit ages or stiffens, they gain weight or fail to maintain their fitness levels.

Other than for the female recreational diver subset, our data did not confirm a stepwise inverse relationship between wetsuit thickness and lung volumes. For the total cohort, there were smaller reductions in FEV_1 and FVC when wearing wetsuits > 14 mm thickness. There are some possible explanations for this:

(1) A significantly greater proportion of occupational divers were wearing wetsuits ≥ 14 mm thickness.Occupational divers as a group had lesser reductions in pulmonary function when wearing wetsuits. For the reasons outlined above, the impact of wetsuit thickness may have been attenuated for that sub-group, reducing the effect in the whole cohort wearing wetsuits ≥ 14mm thickness. We had insufficient numbers to investigate subgroups in this study.

(2) The lack of consistency across subgroups makes it possible that the chosen statistical model has over-fitted the data from an insufficient number of samples. In a mixed effects linear model with six explanatory variables, and 22–23% random effects, this is possible.

(3) The effect was greater on FVC than FEV_1. This could have resulted from individuals not inhaling fully when wearing the thickest wetsuit, due to impaired thoracic expansion. Hence the inspired vital capacity was reduced, and subsequently the measured expired FVC and FEV_1.

Males and females were almost equally distributed in both occupational divers, and recreational divers; hence this cannot be implicated in causation. The sampling times for occupational and recreational divers were not significantly different (morning vs afternoon), so diurnal variation was not a factor. A practice effect for individual samples was minimised by randomisation.

Tasmania has recently observed a trend towards older divers being more represented in fatalities.[3] Other authors have confirmed this trend.[14] The reduction in pulmonary function from wetsuits could further add to negative impacts from cold water immersion, in particular the effects on cardiovascular physiology, hypothermia and wetsuit compression, buoyancy and any concomitant health issues. Adding more neoprene helps delay hypothermia but at a cost of decreased pulmonary function.

Despite a publicly available medical risk assessment, Australian recreational divers have no mandatory regular medical fitness assessments.[15] This means recreational divers may accumulate health and fitness risks over many years without medical assessment or intervention, and the sum of these risks could compromise their safety in the water. For these individuals, detailed medical assessments and achievement of high levels of fitness might help offset the pulmonary effects of wearing wetsuits. It could be argued that diving fitness and medical requirements should be greater for cold water versus warm water diving. We are concerned that negative effects on pulmonary function from thicker wet suits may impact more on older divers and could represent a further safety factor to consider when appraising fitness to dive.

Some of the risk factors in a recent review of immersion pulmonary oedema (IPO) were female sex, fifty years or older, diving in cold water and tight-fitting wet suits.[16] In addition, female open water swimmers had a much greater risk of developing IPO, but wetsuit tightness was not considered in the study or 30-month follow-up.[17,18] Our study has identified a relationship between reduced lung volumes and thicker suits in recreational female divers and this could be explored further in future studies of IPO.

LIMITATIONS

This study was limited by several factors. A key confounder was that we had no method of assessing wet suit 'fit'. We relied on the divers to provide their own suits, and confirmation that they were active, regular divers. Wetsuit thickness was not directly measured but assumed as per manufacturer stated labelling. In addition, we did not record the age of subjects' wetsuits. It is possible that older wetsuits were thinner, due to wear and tear, or stiffer due to neoprene collapse. Both factors could have influenced lung volumes. Our inclusion of occupational divers who used thicker wetsuits may also have biased against detecting greater effects on lung volumes in subjects with the thickest wetsuits.

Testing of non-immersed divers may not accurately reflect performance during immersion. Further limitations include the fact that good technique is required to produce accurate spirometry. Thirteen divers (21%) were unable to provide three samples for each of their wetsuit states due to exhaustion. All produced a minimum of two 'A' quality samples for each state, and hence their available data were used. This should not have biased the results, and should have been compensated for by randomisation. We did not standardise the time of day that data was collected, which could have influenced measurements because there is a significant diurnal variation in spirometry.[19] There was however, no significant difference between sampling times for recreational and occupational divers.

It is likely that we had insufficient numbers to adequately assess the relationship of incremental wet suit thickness and lung volumes, at a more detailed level. Our initial power study was undertaken for a single variable, wetsuit versus no wetsuit, and we achieved the required sample size. We stratified the wetsuits into three thickness groups for statistical analysis. It does appear that occupational divers and recreational divers are different with respect to impact on lung volumes from wetsuits when diving, and future studies will need to separate these groups, with sufficient numbers for statistical analysis. To assess this greater detail using a multivariate model, may require upwards of 1,000 subjects for adequate power (depending on numbers of variables analysed).

This study has raised areas for future research. Measuring body metrics, respiratory parameters and effect on inspiratory pressures at rest and when exercising might be useful in assessing wetsuit 'fit'. Precise tailoring of wetsuits may further improve 'fit'. A recent paper reported that 3-dimensional printed polycarbonate panels in a 3 mm neoprene wetsuit had superior thermal properties when compared to a 7 mm neoprene wet suit. Future technologies may reduce wetsuit effect on pulmonary function.[20]

This study could be repeated with divers immersed in a pool; potential volunteers wearing (or not wearing) a wetsuit, or when wearing dry suits. All options are technically possible using smart device-based spirometers.[21] Wearing full scuba gear including buoyancy control device and weights would also add realistic variables to the data collection.

Conclusions

Scuba diving has many variables that create an additional risk for the diver. This study has found that thicker temperate water wetsuits produce significant reductions in pulmonary function and that the effect was greater on recreational divers than occupational divers. Female divers had a greater percentage decrement from their wetsuits, than male divers. The real-life impact of this negative effect may be minor in fit healthy divers but might add additional risk to a less healthy, unfit, older recreational diving population in deeper and colder waters. For dive physicians, an awareness of the increased demands of cold-water diving, and the negative effect on lung volumes when wearing a thicker wetsuit is relevant to providing advice about the health risks to each individual diver.

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Diving-related fatalities in Victoria, Australia, 2000 to 2022

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Keywords
Diving deaths; Obesity; Scuba diving; Seafood collection; Snorkelling; Surface supplied breathing apparatus (SSBA)

Abstract
(Lippmann J. Diving-related fatalities in Victoria, Australia, 2000 to 2022. Diving and Hyperbaric Medicine. 2025 31 March;55(1):35–43. doi: 10.28920/dhm55.1.35-43. PMID: 40090024.)
Introduction: The aim was to examine the diving-related fatalities in Victoria, Australia from 2000 to 2022, identify trends and assess existing and potential countermeasures.
Methods: The National Coronial Information System and the Australasian Diving Safety Foundation (ADSF) database were searched to identify compressed gas diving and snorkelling/breath-hold diving deaths in Victoria for 2000–2022, inclusive. Data were extracted and analysed, and chain of events analyses conducted.
Results: Thirty-six scuba divers, one diver using surface supplied breathing apparatus (SSBA) and 25 snorkellers/breath-hold divers were identified. Compressed gas divers were older than snorkellers (medians 47 vs 36 years) with a higher proportion being overweight or obese (89% vs 61%), half with pre-existing medical conditions which likely contributed to their deaths. Most snorkellers died from primary drowning, often associated with inexperience. Half of all victims were inexperienced, and more than half of the accidents occurred while diving for seafood, often in rough conditions. Only one third of victims were with a buddy at the time of their accident. Of those known to be wearing weights, three-quarters were still wearing them when found.
Conclusions: Diving medical assessment in divers aged 45 years or older needs to be strengthened and obesity should trigger medical assessment in older divers. Other identified risks included seafood collection, diving in adverse conditions, ineffective or no buddy system, overweighting, poor buoyancy control and failure to ditch weights. Many are longstanding problems, so relevant messages are still not penetrating the community. Constant reinforcement through formal training, internet forums and targeted educational campaigns is required.

Introduction

With more than 2,500 km of coastline and its rich temperate marine environment, Victoria, Australia offers a wide variety of opportunities for divers, from scuba diving on shipwrecks, to snorkelling for abalone in the shallows on rocky, often kelp-covered reefs. With water temperatures ranging from around 11 to 21ºC, 5 to 7 mm wetsuits are common fare, with increasing drysuit usage, especially in technical divers.

Most of the boat charter diving occurs around the heads of Port Phillip Bay where the reef can drop off from depths as shallow as five metres of seawater (msw) to over 90 msw with currents ranging from none during the short 'slack water' period between tides, to over 6 knots. There are more than 300 located historic shipwrecks in Victorian waters, many of which have become popular dive sites. This is especially true for what has become known as the 'Ship's Graveyard' which has over 40 known wrecks generally located at depths between 25 to 45 msw. These include tugs, dredges, barges, World War 1 submarines, a paddle steamer and more recently a scuttled warship specifically prepared as a dive site. The shore diving occurs all around the coastline, including within the two main bays and from ocean beaches.

As in most places, it is difficult to gauge diving activity. A Victorian tank fill survey conducted in 1993–94, estimated that around 80,000 scuba dives were performed that year.[1] However, the early 1990s were likely around the peak of diving activity in Australia, with certifications decreasing since then.[2] Data from the largest Victorian dive charter operator from 2007–14 estimated an average annual fatality rate of 1.64 deaths per 100,000 dives for that operator, which is comparable to estimates from other locations with similar conditions.[3]

Inevitably with diving and snorkelling, fatalities occur for a variety of reasons which include inexperience, conditions and health factors. The aim of this study was to examine the diving-related fatalities in Victoria from 2000 to 2022 to examine trends and assess existing and potential countermeasures.

Methods

Ethics approval for the collection and reporting of these data was received from the Victorian Justice Human Research Ethics Committee to access the National Coronial Information System (NCIS; Approval Number CF/21/18434).[4]

This represents a complete, or near-complete, case series of scuba diving and snorkelling/breath-hold diving fatalities in Victorian waters from 1 January 2000 to 31 December 2022. For inclusion, the scuba diver must have been wearing a scuba set and a snorkeller/breath-hold diver generally must have been wearing at least a snorkelling mask. However, an exception to the latter is a person who partakes in breath-hold diving and who is specifically practicing extending their breath-holding in water to increase their diving limits. In this paper, the term snorkeller is generally used throughout to include both surface snorkellers and breath-hold divers.

SEARCH

A comprehensive key-word search was made of the NCIS for diving-related deaths in Victoria for the period 1 July 2000 (the inception of the database) to 31 December 2022. Key words included scuba, compressed air, compressed gas and div*, snorkel*, breath-hold and div*, and underwater fishing. Data obtained from the NCIS was matched with that listed on the Australasian Diving Safety Foundation (ADSF) fatality database.[5] Additional reports were obtained directly from the office of the Victorian State Coroner. Information gathered during previous published investigations for 2000 to 2018[6–10] was reviewed and relevant further data extracted from these, and, where necessary the underpinning coronial documents.

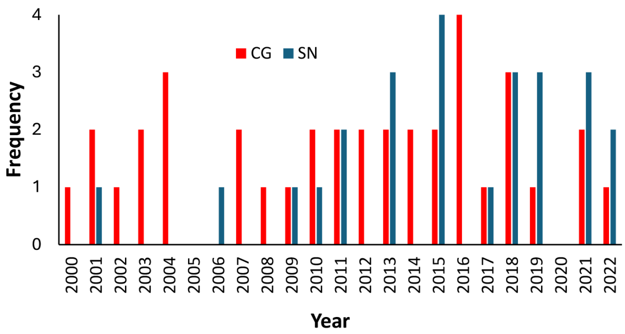
REVIEW PROCEDURE AND OUTCOME MEASURES

The investigator reviewed all datasets. Outcome measures were extracted for each case and entered into a specially created and protected Microsoft Excel® spreadsheet. Where available, these data included demographics, health factors, training and experience, origin of victims, dive location and conditions, buddy circumstances and oversight, dive purpose and depth, equipment used and resuscitation factors.

ANALYSIS

A chain of events analysis (CEA) was performed for each case using existing templates.[11] Descriptive analyses based on means and standard deviations or medians and ranges, and Mann-Whitney tests for comparisons of age or body mass index (BMI), as appropriate, were conducted using SPSS Version 29 (IBM Armonk, NY; 2022). The level of statistical significance assumed was $P = 0.05$.

Figure 1
Annual compressed gas diving (CG) and snorkelling (SN) fatalities in Victoria, 2000–2022



Results

Sixty-two deaths were identified, comprising 36 scuba divers, two of whom were using closed circuit rebreathers (CCR), 25 snorkellers (mainly breath-hold divers) and one diver using surface supplied breathing apparatus (SSBA – hookah). This gives averages of 1.6 compressed gas and 1.1 snorkel deaths per year with a rise in snorkelling deaths over the final decade or so. The annual deaths are shown in Figure 1. The Victorian fatalities comprised 18% (36/204), 4% (1/28) and 8% (25/323) of the national fatalities for scuba, SSBA and snorkelling, respectively during that period.

DEMOGRAPHICS

There were six females (five scuba and one snorkeller) and 56 males (31 scuba, 24 snorkellers and one SSBA diver). The median (IQR) age for the compressed gas divers (i.e., scuba and SSBA) was 47 (39, 52) years and for snorkellers 36 (29, 42) with ranges of 25–67 and 19–65 years, respectively.

The BMI was not available in two cases due to missing bodies. The mean (SD) BMI for the compressed gas divers was 30.6 (5.6) $kg.m^{-2}$ and, although females had a higher BMI (35.2 vs 30.0), this was not significant ($P = 0.19$). Twelve victims were overweight (25–29.9 $kg.m^{-2}$), 11 obese (30–34.9 $kg.m^{-2}$) and eight severely obese (> 35 $kg.m^{-2}$) There was no significant difference in age of victims who were obese (mean 47.5 years) or not (47.3 years) ($P = 0.632$).

The snorkel victims had a mean (SD) BMI of 27 (5.7) $kg.m^{-2}$ with six overweight, seven obese and one severely obese. The BMI was unavailable for two cases.

CERTIFICATION AND EXPERIENCE

At least 29/36 scuba divers were certified, two were untrained, four were undergoing Open Water Diver (OWD) training, and, in one case, it was unreported. Eighteen of the victims were classified as 'novices' (0–30 dives), 10 'experienced' (31–200 dives), six 'very experienced' (> 200 dives), and experience was unknown in one victim. The SSBA diver was a certified, albeit novice, scuba diver but had no additional training in the use of SSBA which he had used up to six times, all at shallower depths. One of the scuba trainees was a very weak swimmer who had in fact failed his swim test in the pool but was allowed to progress to an open water dive (in rough conditions) through an organisational oversight.

Three of the snorkel victims were known to have had scuba certification. Ten had little or no experience, seven appear to have been experienced and, in seven cases, there was no indication of experience. Three of the snorkellers were reported to have been teaching themselves through the internet. This included one who was also using an apnoea App to extend his breath-hold. At least five of the snorkel victims were reported to have been weak swimmers. None of the victims had any additional buoyancy aids.

SETTING AND LOCATION

Twenty-two compressed gas victims were diving privately and 15 were on commercial dive charters or under training. Two of the snorkelling accidents occurred under the oversight of a commercial operator. One was with a school group overseen by an adventure tour company, and the other on a wildlife snorkel experience. The remainder occurred during private snorkelling events. The locations are shown in Figure 2.

Six scuba divers and one snorkeller died while diving shipwrecks, which included two on the *Coogee* (35 msw) and one each on the *Rotomahana* (39 msw), *J4 Submarine* (28 msw), *Ex-HMAS Canberra* (28 msw), the *SS Alert* (75 msw), and the *HMVS Cerberus* (6 msw).

ORIGIN OF VICTIMS

The countries of birth of the compressed gas victims were Australia (28), Asia (3), New Zealand/Pacific (2), United Kingdom/Europe (2) and the Americas (1). Many snorkelling victims were born in Asia (16), others in Australia (6), the Balkans (1) with two unknowns.

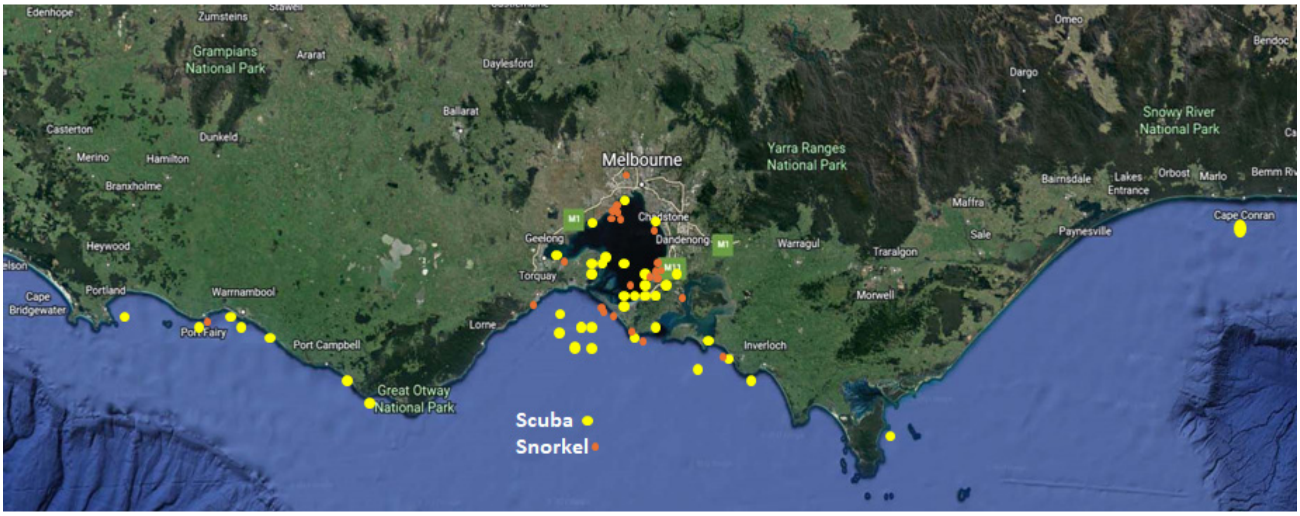
All but one of the compressed gas divers were Victorian residents, the exception being an international tourist. All the snorkellers were currently living in Victoria although at least two were on international student visas.

ACTIVITY

Fifteen of the compressed gas victims were collecting seafood including crayfish (9), abalone (4) and scallops (2). Twelve were sightseeing and eight died during training activities. The training deaths included a double fatality involving an instructor and student during OWD training, three other OWD student deaths, one death during Advanced Open Water Diver (AOWD) training, one during wreck diving training and one during rescue training. Four of the deaths during training involved diving in rough conditions and/or strong current with associated separation and probable panic. One diver was diving a wreck using a relatively unfamiliar closed-circuit rebreather (CCR) and the other CCR death involved intentional self-harm.

Fifteen of the snorkellers were looking for abalone, one for crabs and four were spearfishing. Three victims were just sightseeing, and two died while practicing extended breath-holding in pools without direct supervision.

Figure 2
Locations of the fatal accidents

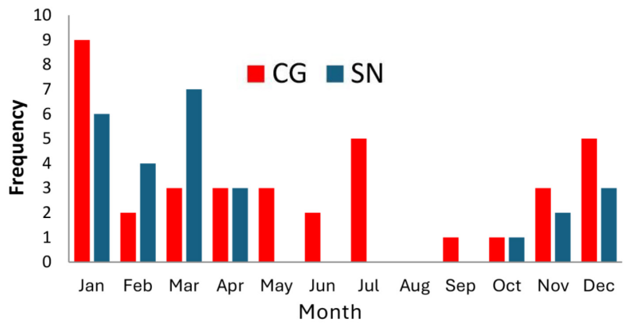


Overall, 35/62 (56%) of victims were hunting or harvesting seafood. Of note, two scuba divers and one snorkeller were found on the seabed with heavy catch bags attached to their un-ditched weight belts. Both scuba divers had no remaining air in their tanks.

MONTH OF ACCIDENT

The compressed gas accidents occurred throughout the year with a peak in January, a popular time for diving in Victoria. The snorkel accidents were largely confined to warmer months and, unsurprisingly, to the abalone season, which occurs from mid-November to the end of April (Figure 3).

Figure 3
Months during which the fatal diving accidents occurred; CG – compressed gas diving; SN – snorkelling



BUDDY SITUATION

Thirteen compressed gas divers were with a buddy when the accident occurred, five of these becoming separated during the event. Another 16 victims set out with a buddy or group but were separated before their accident, and eight victims were solo diving from the outset. Similarly, eight of the snorkellers were with a buddy when their accident occurred, with three separating during it. Another nine set out with a buddy or group but were separated before their accident. Eight snorkellers set out solo. Overall, only 21/62 (34%) of divers were with a buddy at the time of their demise.

DEPTH

The depth of the compressed gas dives ranged from 1–74 msw with a median (IQR) depth of 7.5 (4, 23) msw. At least one half of these accidents were at depths from 0 to 10 msw with more than one third occurring on or near the surface.

Water depth was only reported in 11 of the snorkelling cases with a median (IQR) of 3 (2, 5) msw and range from 1 to 7.5 msw. From the locations involved, it appears likely that most of the remaining accidents would have occurred at depths between 2 to 4 msw.

WEIGHTS

Twenty-six of the 37 compressed gas victims were found with their weights in situ, eight had ditched some or all their weights. Fourteen victims were found with weights in place and an uninflated buoyancy control device (BCD), 16 had either ditched weights or inflated their BCD, and three had done both. There was no relevant information in three cases. Of the 12 snorkellers who were known to have been wearing weights, 11 were still wearing them when found.

RESUSCITATION

Cardiopulmonary resuscitation (CPR) was performed in 26 of the compressed gas cases and was not attempted in 10 due to delays in body recovery or absence of a body. In another case, it wasn't performed as the sole buddy was unable to lift the victim aboard the boat. An automatic external defibrillator (AED) was available and promptly used in one incident, where two shocks were given without success. Supplemental oxygen was administered to only five victims although equipment was available and unused in at least three other cases due to lack of confidence of the first aiders.

CPR was attempted on 15 snorkelling victims, was not appropriate in eight due to long delays to recovery, and, in two cases, there was no indication whether CPR was performed. There were no reports of readily available AED use or oxygen first aid with the snorkellers.

CHAIN OF EVENTS ANALYSIS

Predisposing factors

A predisposing factor is defined as a relevant factor that was present prior to the dive, and/or prior to the trigger occurring, and which is believed to have predisposed to the incident and/or to key components in the accident chain (e.g., the trigger or disabling agent).

Compressed gas divers:
Eighty pre-existing risk factors were identified in the 37 compressed gas divers. Twenty-three divers had pre-existing health risk factors, including many with multiple conditions, with at least 12 of these divers receiving some medical treatment or oversight. The health factors included obesity (19), left ventricular hypertrophy (LVH, 9), severe ischaemic heart disease (IHD, 8), cardiomegaly (5), hypertension (5), anxiety/depression (3), diabetes (3), tachycardias (2), asthma (1) and pre-dive use of amphetamines and alcohol (2). These health risk factors appear to have been directly contributory in 19 deaths.

Planning shortcomings were identified as likely contributors to 18 deaths. Seven of these were associated with decisions to dive in challenging conditions and included the deaths of three OWD students, one who panicked in a strong current and another likely disabled by strong surge. Decisions to dive solo, planned buddy separations and poor buddy systems were associated with 11 accidents, most of these involving seafood harvesting.

Inexperience and/or poor skills likely contributed to 17 deaths and pre-existing equipment shortcomings to twelve. The latter included high-reading gauges (leading to out-of-gas situations), overweighting, absence of a knife when diving in and becoming entangled in kelp, diving in cold water without an exposure suit (and wearing a weight belt!) and a poorly configured and over-complicated multi-tank system. As mentioned earlier, one CCR diver set off with inappropriate diluent gas for the planned dive.

Supervision shortcomings were associated with three compressed gas accidents, two of which involved students under instruction, and one involved a divemaster's oversight of a very inexperienced diver, allowing him to enter the water with his mask on his forehead, his demand valve out, his BCD inflator hose detached, and BCD deflated.

Snorkellers:
The most common predisposing factors in the snorkelling victims were planning-related shortcomings, identified in 20 cases. The majority involved decisions to dive in unsuitable conditions, often compounded by an inadequate appreciation of the potential for conditions to change (e.g., current). Planning issues also involved decisions to snorkel solo or with a loose buddy system.

Lack of experience and poor skills were identified as likely contributory in 11 cases, and equipment shortcomings in nine, the latter largely associated with inexperience. For example, at least five of the snorkel victims were not wearing fins (in another five cases fin use was unrecorded so there might have been more). Two of these were weak swimmers and inexperienced snorkellers who were wearing weights, one without a wetsuit. Health-related factors, including obesity and/or severe IHD, as well as the combination of methamphetamine use in a person with epilepsy, appear to have contributed to six snorkelling fatalities.

Three higher risk activity-related predisposing factors were identified and included two victims who were practicing extended apnoea in pools without appropriate supervision. Both succumbed to apnoeic hypoxia and there were substantial delays before the problem was identified. The other case involved a victim who went snorkelling alone inside a wreck at night.

Supervision shortcomings were associated with two fatalities and included very poor oversight from an adventure tour operator supervising a school snorkelling expedition, and poor oversight of a highly inexperienced snorkeller by their companions.

Triggers

A trigger is the earliest identifiable event that appeared to transform the dive into an emergency.

Compressed gas divers:
Fifty-three likely or possible triggers were identified in 34 accidents with multiple possible triggers in some of these. Insufficient information was available in three cases to postulate on triggers. Environmental triggers, including rough seas, strong currents, kelp entanglement and nitrogen narcosis were identified as likely contributors in 14 cases. Additionally, the effects of immersion (also an environmental trigger) combined with exertion was identified in six accidents in divers with pre-existing cardiac disease. Ten accidents were likely triggered by problems with the breathing gas supply, and substantial exertion just before or during a dive, and, in one case, exiting the water at the end of a dive, likely triggered seven events. Two of these victims were dragging heavy catch bags attached to them. Diver errors triggered at least four events and included unfamiliarity and/or errors in equipment use, entering the water without the demand valve in place and with an uninflated BCD and failing to open the cylinder valve before entry (again with an uninflated BCD). Poor buoyancy control was a probable trigger in three accidents.

Snorkellers:
Twenty-seven likely or possible triggers were identified in 22 of the snorkelling accidents, the majority of which were environmental. These included 11 accidents which were likely triggered by adverse sea conditions, four by the effects of immersion and/or exertion on cardiac function, and one from impact with a passing boat. Three deaths in novices were likely the result of water aspiration through the snorkel and two, in more experienced divers, by extended apnoea. One accident was triggered by entanglement in a speargun cord, and one was triggered when the victim erred by prematurely jumping from the back of a reversing boat and being hit by the propellor.

Disabling agents

A disabling agent is an action or circumstance (associated with the trigger) that caused injury or illness.

Compressed gas divers:
Likely disabling agents were identified in 31 of the compressed gas accidents. The main disabling agents were medical factors, predominantly cardiac-related, but also included at least one case each of immersion pulmonary oedema (IPO), oxygen toxicity and asthma. The other disabling agents were ascent-related (6), gas supply-related (5), environmental (4), buoyancy-related (3) and equipment-related (1).

Snorkellers:
Likely disabling agents were identified in 22 of the snorkelling accidents. These included environmental factors (7), mainly adverse sea conditions but also two boat propellor injuries. Others were buoyancy issues (7), medical conditions (4), water aspiration/laryngospasm (3), apnoeic hypoxia (2), and equipment-related (1).

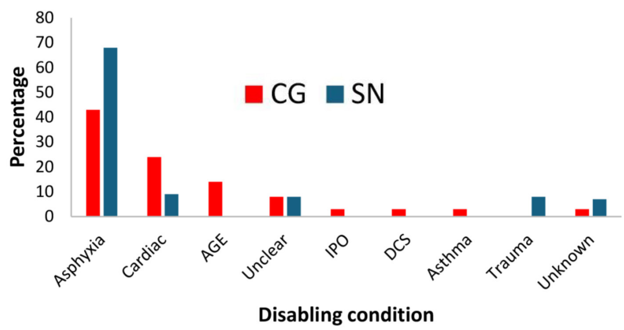
Disabling conditions

The disabling condition is directly responsible for death or incapacitation followed by death from drowning.

The most common disabling conditions in the compressed gas divers were asphyxia (i.e., primary drowning), cardiac causes (predominantly arrhythmias), and arterial gas embolism (AGE). In two cases, it was unclear if the disabling condition was asphyxia or IPO, and, in another, asphyxia or cardiac.

In the vast majority (17) of snorkellers the disabling condition was asphyxia. There were two likely cardiac arrhythmias, two traumas, two where it was unclear whether the disabling condition was asphyxia or cardiac, and another two where the likely disabling condition couldn't be identified (Figure 4).

Figure 4
Disabling conditions for scuba and snorkel victims of diving fatalities in Victoria 2000–2022. AGE – arterial gas embolism, CG – compressed gas diving; DCS – decompression sickness; IPO – immersion pulmonary oedema; SN – snorkelling



Discussion

Over the 23-year period there was an average of 2.7 diving-related deaths per year in Victoria, 90% of whom were males. Compressed gas diving victims were older than the snorkellers with a higher proportion being overweight or obese. Almost all victims were locals, half were inexperienced, many deaths were associated with adverse sea conditions, and more than half of the accidents occurred while diving for seafood. A high proportion of the snorkel victims were seafood gatherers of Asian descent. As in earlier studies, a lack of, or poor buddy system was common and likely contributed to many deaths, especially those from primary drowning. Overweighting was apparent in both cohorts of divers and many victims were found with their weights *in situ*.

DEMOGRAPHICS

With a median age of 47 years, the compressed gas divers were substantially older than the snorkelling cohort. With age comes an increasing prevalence of chronic disease. As reported previously: "… *Australian data for 2001 to 2018 reveals that 92 (56%) of the 164 scuba victims were 45 years or older, with 84% of this subgroup likely to have suffered a cardiac-related disabling condition*".[9] These Victorian data are consistent with the National trend with almost one quarter of scuba victims likely being disabled by a cardiac condition, and is supports the advice for diving medical assessment with close consideration of cardiac health for divers or prospective divers aged 45 years or more.[12] On the other hand, a far higher proportion of snorkellers succumbed to primary drowning, unsurprising with this younger, and often inexperienced cohort.

A higher proportion of compressed gas divers were overweight or obese. Indeed, at 51%, the proportion of compressed gas divers who were obese or severely obese is similar to divers nationally[9] and is very concerning, being higher than that of the general Australian population of a similar age, reported to be 37.4%.[13] Given the relationship between obesity and chronic disease such as hypertension, diabetes and chronic obstructive sleep apnoea,[14,15] as well as cardiac arrhythmias[16] and sudden cardiac death,[17,18] it should be a serious consideration with fitness-to-dive assessments. Although BMI *per se* and waist circumference measures may only provide an indirect association with sudden cardiac death,[19] they should trigger further investigations for cardiac risk. Accordingly, it may be appropriate for a question about BMI/obesity to be included in diver medical participant questionnaires[20] with appropriate medical referral. Diver training and education should include information about the risks associated with obesity and diving.

Unlike the situation in Queensland where only 20% of victims lived locally,[21] almost all the victims in Victoria were residents in the state. Three-quarters of the compressed gas divers were born in Australia compared to only one quarter of the snorkellers. At least two-thirds of the snorkel victims were Asian nationals.

ACTIVITY AND INEXPERIENCE

Again, unlike Queensland where few victims were involved in seafood collection, more than half the Victorian victims were hunting or harvesting seafood, including three quarters of the snorkellers, the latter being predominantly of Asian descent. The Victorian lifesaving and fishing authorities have been trying to target the culturally and linguistically diverse (CALD) communities with education campaigns aimed at improving awareness of the potential hazards of diving for seafood. This includes advice on adequate swimming ability, choosing suitable conditions and being with a buddy. However, the fatalities in this series indicate that such advice does not extend far enough. Recurring issues include lack of snorkelling experience, inadequate or inappropriate equipment (such as absence of fins and/or overweighting) and lack of knowledge about reasonably predicable tidal and weather changes. Inflatable buoyancy vests or tubes can be lifesaving for weak swimmers and inexperienced snorkellers and should be encouraged for such persons. Of note, a Victorian fisheries information brochure includes an image suggesting that divers attach their catch bags to their weight belts, a practice that contributed to the demise of several divers in this series.

As mentioned earlier, at least three of the snorkellers were teaching themselves through the internet, which is no substitute for undergoing practical training under the guidance of an instructor or experienced guide. Historically, prospective snorkellers often bought their equipment from a dive shop where they had the opportunity to interact and get advice from generally experienced staff. However, many now purchase equipment online or in general stores, and so miss this potentially valuable opportunity for personal advice, including equipment choice and local knowledge. The hookah diver was untrained in the use of his equipment, and this has become increasingly common.[22] There are currently no basic hookah diving training courses readily available in Australia and there is a need and opportunity for this to be addressed.

BUDDY SITUATION

As is often the case,[6–9,23,24] despite ongoing education, many of the victims, in this case two-thirds, were alone at the time of their accident either from setting out solo or having an inadequate buddy system. Absence of a buddy and/or close observer reduces the likelihood of prompt rescue and the chances of survival. This was particularly highlighted in the two victims who were practicing extended apnoea in swimming pools without direct supervision. Both remained unnoticed for an extended period, despite others being nearby, in one case, only metres away.

PREDISPOSING FACTORS

Poor pre-dive planning decisions were a commonly identified predisposing factor affecting both cohorts of divers, the most common being the decision to dive in unsuitable conditions. Victoria's weather can be notoriously variable and many of the dive sites can be exposed to strong winds, large swells and, in some places, strong currents. If divers have inadequate local knowledge, insufficient experience, or poor fitness (physical or medical), they can struggle to cope with challenging conditions with which they are ill-equipped to deal. The incentive to conduct a particular dive on the day often overrides common sense. Divers and their supervisors need to be prepared to abandon the day's diving or find a safer site. This is an important part of a dive plan.

Pre-existing health factors including ischaemic heart disease, hypertension, epilepsy, asthma, diabetes, exercise tachycardia in addition to obesity, as highlighted earlier, were again contributors to the fatalities. This supports the advice for existing or prospective divers or snorkellers with chronic health conditions to seek diving medical advice, especially those aged 45 years or older, and particularly if obese.[25]

BUOYANCY

Problems with buoyancy control were apparent with five of the compressed diving victims, all of whom were overweighted and ran low on breathing gas. Victorian dive sites include some sheer drop-offs and wrecks in deeper waters so correct weighting and good buoyancy control is an important part of safe diving.

As well as consuming more gas through exertion, an overweighted diver needs to divert more gas into their BCD or drysuit, more rapidly depleting the supply. Exertion also adds strain on a heart that may already be challenged by the effects of immersion and other potential cardiac stimulants from diving.[26]

Overweighting was a very common problem with the snorkellers. For most diving and snorkelling, weights should be chosen to attain 'neutral buoyancy' at about 1.5 to 2 m below the surface, which means being slightly buoyant at or near the surface. Consistent with previous reports,[6,8,24] a large proportion of both compressed gas divers and snorkellers in this series who were known to have set off wearing weights, were still wearing these when found. Divers and snorkellers must frequently remind themselves of the importance of reaching or staying on the surface in situations where unconsciousness is likely. They need to be very familiar with their weight system and practice releasing these periodically to embed the skill so it is second nature in an emergency. Despite ever-increasing evidence of the need, this is clearly not being done effectively.

BOATS

Two snorkellers in this series died from boat propellor injuries. In addition, according to Victorian marine accident reports, there were at least another five serious, albeit non-fatal, boat propellor injuries involving three scuba divers and two snorkellers during this study period.

Nationwide, from 2000 to 2022, there were at least eight fatalities in divers resulting from boat and or propellor contact. Five were snorkellers and three were using SSBA. Two of the SSBA divers and one snorkeller (the later included in this series) jumped from the rear of a boat which was reversing and/or had its propellor engaged. Two victims were snorkelling in areas of high boat activity without towing a float and dive flag. The others were towing a float with flag or in very close proximity to a buddy with one (one in this series) but were unseen by an approaching boat. The reality is that some flags are too small and difficult to see in choppy seas, so 'size is important' when selecting a suitable float and flag.

In Victoria, a vessel is required to slow to a maximum speed of 5 knots (9 $km.hr^{-1}$) within 100 m of a diver below flag (50 m in some States). Sadly, this is often not adhered to as some boat and jet ski drivers ignore or fail to notice the flag, or don't understand its meaning. Ongoing education is important for boaters and divers alike about the meaning of the *Diver Below* flag and its importance. In some jurisdictions, legislation more easily enables criminal prosecution of a boat operator considered to have been acting in a dangerous manner (including failure to keep a proper lookout) in the event of serious injury or death. The Victorian State Coroner has recommended to government that existing Victorian legislation be strengthened in this respect.

Owners of boats used for diving-related activities should seriously consider fitting a propellor guard to reduce the likelihood of propellor injury.

LIMITATIONS

Even using multiple sources, it is possible that some fatalities were not recorded due to limitations in recording and NCIS searches. As with any uncontrolled case series, the collection and analysis of the fatality data are subject to inevitable limitations and uncertainties associated with the investigations. Witness reports varied in their likely reliability. Police reports varied in their content, often related to the expertise of the investigators. Given that many incidents were unwitnessed, some of the assertions in the reports are speculative. Many data items were not available which rendered the study data incomplete, thus limiting the conclusions that can be drawn. The CEA attempts to identify the predominant features of each case, but there always remains an element of uncertainty.

Conclusions

Compressed gas diving victims were predominantly middle-aged and many were obese or severely obese with pre-existing medical conditions likely contributing to one half of deaths. Diving medical assessment in divers aged 45 years or older needs to be strengthened and obesity should trigger a targeted medical assessment in older divers. Care must be taken when assessing the suitability of conditions for training activities.

A high proportion of the snorkel victims were inexperienced, seafood gatherers of Asian descent and safety education campaigns to this demographic need to be broadened and better targeted. Diving in adverse conditions, ineffective or no buddy system, overweighting, poor buoyancy control and failure to ditch weights are longstanding problems and constant reinforcement through formal training, internet forums and invigorated and targeted educational campaigns is required. Supplemental oxygen and rapid access to an AED can play important roles in the resuscitation of diver and snorkellers and effort is needed to increase their availability and associated training and use.

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Venous gas emboli (VGE) in 2-D echocardiographic images following movement: grading and association with cumulative incidence of decompression sickness

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Abstract
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Introduction: Venous gas emboli (VGE) are a common surrogate experimental endpoint for decompression sickness (DCS). VGE numbers are graded, and the peak post-dive grade is associated with the probability of DCS (P_{DCS}). VGE are typically graded with the subject at rest when bubble numbers are stable, and again after limb flexions which elicit a transient shower of bubbles. Detection of VGE using two-dimensional (2-D) echocardiography has become common, but the principal grading scales do not specify how to grade VGE after limb movement.

Methods: This was a retrospective analysis of 1,196 man-dives following which VGE were detected using 2-D echocardiography and graded on a scale 0–4 and 41 cases of DCS occurred. P_{DCS} was estimated for each peak post-dive VGE grade from the cumulative incidence of DCS. Two different definitions of movement VGE grades were assessed in 84 measurements; the grade was either the maximum VGE number sustained for one diastole (1-cycle) or for six cardiac cycles (6-cycle).

Results: For each peak post-dive VGE grade (maximum of rest or movement) the cumulative incidences of DCS (%) were: grade 0 (0%); grade 1 (1.3%); grade 2 (2.5%); grade 3 (4.6%); grade 4 (5.7%). When grading movement VGE, 57% of 1-cycle grade 4 were reduced to grade 3 using the 6-cycle definition.

Conclusions: There is a need for consensus in the research community on how to assign movement VGE grades when using 2-D echocardiography. Publications should carefully explain methodology for assigning VGE grades and consider differences in methodologies when comparing historical data sets.

Introduction

Decompression sickness (DCS) is caused by intracorporeal bubble formation from supersaturated dissolved gas. Ultrasonically detected venous gas bubbles (venous gas emboli: VGE) are widely used as a surrogate endpoint instead of DCS in studies of decompression procedures because VGE occur commonly after diving whereas DCS is rare.[1] Commonly, VGE numbers are graded on an ordinal scale and the peak post-dive grade is used as the endpoint. For experimental designs that compare interventions, VGE grades may be used to order the interventions in accord with different risks of DCS without directly estimating the probability of DCS (P_{DCS}).[1,2] However, estimating P_{DCS} is required for the development, validation, and fielding of decompression procedures. To estimate the P_{DCS} of decompression procedures using VGE outcomes, it is necessary to have a prior distribution of P_{DCS} given the VGE grade.[3,4] P_{DCS} can be estimated from the cumulative incidence of DCS associated with each VGE grade in a large data set of diving data with both DCS and VGE outcomes. The gold standard data defining the cumulative incidence of DCS associated with peak post-dive VGE grades are from development of Canadian Armed Forces decompression tables at the Defence and Civil Institute of Environmental Medicine (DCIEM).[5,6] In the DCIEM dive trials, VGE were detected using ultrasonic Doppler bubble detectors with which audible bubble signals can be heard in the Doppler flow signal. Bubble signals were graded using the Kisman-Masurel (KM) scale.[6]

Two-dimensional (2-D) echocardiography is now a popular method of VGE detection and grading.[7] VGE appear as bright spots in the 2-D echocardiographic images. The

VGE images are commonly graded using the Eftedal-Brubakk (EB) scale, and this scale was recommended by a 2015 consensus guidelines development conference.[8] The largest published data set defining the cumulative incidence of DCS associated with peak post-dive VGE grades in 2-D echocardiographic images is from the Navy Experimental Diving Unit (NEDU).[1] In those data, VGE were graded using a NEDU scale comparable to the EB scale. Since that publication, NEDU has added substantially to the data set and has graded VGE using a modified EB scale that is backward compatible with the NEDU scale.[9]

VGE are typically graded with the subject at rest and VGE numbers are stable, and again after limb flexion which elicits a transient shower of bubbles. The peak post-dive grade of both conditions has the best association with the cumulative incidence of DCS.[5] The KM scale specifies how to grade VGE both at rest and after limb movement. The movement grade is based on the number and amplitude of the bubble signals and number of cardiac cycles over which the maximum signal persists. The EB scale was originally designed for anaesthetised animals, and it does not specify how to grade VGE after a movement. It follows from the definitions of the EB grades (Table 1) that VGE must be counted for at least five cardiac cycles to distinguish between grades 1, 2 and 3, but the definitions provide no clues for assigning higher grades following movement. Many 2-D echocardiographic VGE studies assign EB grades to the VGE shower following limb flexion, but few studies define how this grade was assigned. One group writes that the grade is the highest achieved following the movement, implying the grade is based on the highest number seen irrespective of duration.[10,11] NEDU assigns EB movement grades 4 and 5 based on the highest number of VGE sustained for at least 0.5 s (approximately one diastole).[9] Another group assigns EB movement 4 and 5 based on the highest number of VGE sustained for at least two cardiac cycles.[4] None of these methods for assigning EB movement grades 4 and 5 require the signal to be sustained as long as the comparable highest grades in the KM scale, which requires the signal to be sustained for at least six cardiac cycles.[6]

This paper presents an expanded NEDU data set defining the cumulative incidence of DCS associated with peak post-dive VGE grades in 2-D echocardiographic images. This is followed by an evaluation in a smaller data set of 2-D echocardiographic movement grading using the original NEDU definition of higher grades (highest number of VGE sustained for one diastole) and a more KM-like method (highest number of VGE sustained for at least six cardiac cycles). We show the correspondence between VGE grades in the NEDU, EB, and KM grading scales and provide suggestions for comparing VGE grades collected using different methodologies.

Methods

PEAK POST-DIVE VGE AND DCS

Data analysed were collected during four man-dive trials approved by the NEDU Institutional Review Board.[12–15] Informed consent for each study included consent for de-identified data to be used in future research without additional consent. Full details of the dive trials are available in the original reports and only relevant details are summarised here.[12–15] All diving occurred in the NEDU Ocean Simulation Facility hyperbaric chamber and wet pot complex. Most of the dives were wet, working air decompression dives with the divers fully submerged in the wet pot. One trial was of dry, resting nitrox dives with oxygen decompression. Maximum depths ranged from 113 to 170 feet of sea water (35 to 52 metres of sea water; 448 to 622 kPa absolute)

Table 1

Approximate equivalency across common venous gas emboli (VGE) grading scales based on references 6 and 9; MEB – modified Eftedal-Brubakk grade

<table>
<tr><th>KM</th><th>MEB</th><th>Semantic</th><th>NEDU</th><th>Semantic</th></tr>
<tr><td>0</td><td>0</td><td>No bubbles</td><td>0</td><td>No bubbles</td></tr>
<tr><td>I-
I
I+</td><td>1</td><td>Occasional bubbles</td><td>1</td><td>Rare (fewer 1/s) bubbles; < 1 audio signal per cycle</td></tr>
<tr><td>II-
II
II+</td><td>2</td><td>≥ 1 bubble / 4 heart cycles</td><td rowspan="2">2</td><td rowspan="2">Several discrete bubbles visible; frequent discrete audio signals</td></tr>
<tr><td rowspan="2">III-
III
III+</td><td>3</td><td>≥ 1 bubble / heart cycle</td></tr>
<tr><td>4a</td><td>≥ 1 bubble/cm^2 in all frames</td><td>3</td><td>Multiple bubbles/cycle, not obscuring image; audio signals most cycles</td></tr>
<tr><td rowspan="2">IV-
IV</td><td>4b</td><td>≥ 3 bubble/cm^2 in all frames</td><td rowspan="2">4</td><td rowspan="2">Bubbles dominate image, may blur chamber outlines; audio signals all cycles, may obscure heart sounds</td></tr>
<tr><td>5</td><td>Whiteout, individual bubbles cannot be discerned</td></tr>
</table>

and bottom times ranged from 20 to 166 minutes. Divers refrained from any hyperbaric or hypobaric exposure for two or three days before and after each experimental dive. The four dive trials comprised 1,199 dives resulting in 44 diagnosed cases of DCS. However, three cases of DCS were diagnosed and treated before VGE monitoring and these were excluded from the present data set. Initial diagnoses of DCS and treatment decisions were made by the on duty Undersea Medical Officer. For research purposes the outcome of each man-dive were subsequently re-evaluated according to the Weathersby et al. 1988 criteria (reprinted in references[5,13–15]) and categorised as definite DCS requiring recompression; definite DCS not requiring recompression ('marginal DCS' or 'niggles'); or not DCS. No diagnoses were revised in the present data set. For the present study, marginal DCS (typically pain resolving spontaneously within a few minutes) were considered not DCS. Full case descriptions of marginal and DCS cases are available in the original reports.[12–14] The final data set analysed was 1,196 man-dives with peak post-dive VGE grades including 41 cases of DCS.

After surfacing from a dive, divers were periodically monitored (at intervals ranging from 20 to 80 minutes) for VGE for two to four hours. For each VGE examination, the diver reclined in the left lateral decubital position while the heart chambers were imaged (apical long-axis four-chamber view) for at least 10 cardiac cycles with transthoracic 2-D echocardiography. VGE in the right heart chambers were graded at the time of the examination. For the earlier two trials VGE were graded according to the NEDU scale (Table 1).[12,13] For the latter two trials[14,15] VGE were graded according to the modified EB scale (Table 1).[8,16,17]

At each examination, VGE were graded three times in the following order: after the diver had been at rest on the examination table for approximately one minute; immediately after three forceful limb flexions around the right elbow; and immediately after three forceful limb flexions around the right knee. The earliest trial was not performed by the current authors and less detail about the VGE grading is available.[12] For the latter three trials the intent was to capture the maximum post-flexion signal. Grades higher than three are based on VGE density in all frames (Table 1) and we assigned these grades as the highest signal sustained for about 0.5 s (one diastole). Lower grades are based on the proportion of heart cycles with VGE (Table 1). Grade 3 was assigned if four consecutive heart cycles had VGE, grade 2 was assigned if at least two of five consecutive heart cycles had VGE, and grade 1 was assigned if only one of five or more heart cycles had VGE. For each man-dive, the peak grades of all resting examinations or of all resting and limb flexion examinations were analysed; for compactness these are hereafter denoted as resting or movement VGE grades, respectively.

To combine data graded with different scales, modified EB and NEDU grades 0–2 were considered equivalent, and modified EB grades 3–4a and grades 4b–5 were collapsed to single grades equivalent to NEDU grades 3 and 4, respectively (see Table 1). The dives were binned according to peak post-dive VGE grade and the cumulative incidence of DCS in each bin was calculated.

VGE GRADING AFTER MOVEMENT

Two different definitions of EB movement grading were assessed. The first was the standard NEDU definition described in the preceding section, hereafter denoted the '1-cycle' definition. The second definition was that the grade assigned was the highest signal sustained for at least six consecutive cardiac cycles for all grades. This '6-cycle' definition was chosen because it was similar to the existing NEDU definition for grades 1–3 and because it was comparable to the KM scale definitions for higher grades.

KM movement grades are based on the number of bubble sounds per cardiac cycle, the amplitude of the bubble sounds relative to the cardiac sounds, and the number of cardiac cycles over which the maximum signal persists ('duration').[6] Each of these three components are assigned a code and different combinations of these codes map to the 12 KM grades (Table 1). The duration code break points are 0, 1–2, 3–5, 6–10, and > 10 cardiac cycles. With few exceptions, combinations with the 1–2 and 3–5 duration codes map to KM grades I- through II+ and combinations with the 6–10 and > 10 codes map to KM grades -III through IV.

The 1-cycle and 6-cycle definitions of EB movement grades were assessed in two data sets. There were no DCS cases in either data set. One data set was from one of the trials described above for which video clips of the 2-D echocardiographic measurements were saved.[15] Video clips of measurements that were prospectively assigned 1-cycle EB movement grades 4a, 4b, and 5 and that were suitable for reassessment were identified ($n = 29$). These video clips were retrospectively graded using the 6-cycle definition. The other data set was an unpublished trial approved by the NEDU Institutional Review Board. Informed consent for the study included consent for de-identified data to be used in future research without additional consent. The VGE measurements were graded prospectively with both the 1-cycle and 6-cycle definitions. This data set contained 55 measurements with 1-cycle EB movement grades 4a, 4b, and 5. In both data sets, any examination time or limb flexion that resulted in a modified EB grade 4a, 4b or 5 was reassessed, not just the peak post-dive grade. The retrospectively and prospectively graded data sets were pooled for comparison of the two grading definitions.

Results

PEAK POST-DIVE VGE AND DCS

Table 2 presents the number of dives and number of DCS, and the resulting cumulative incidence and 95% confidence

Table 2

Resting venous gas emboli (VGE) grades (Naval Experimental Diving Unit [NEDU] 2-D echocardiography) and decompression sickness (DCS) outcomes; CL – confidence limits

Grade	Dives *n*	DCS *n*	DCS %	95% CL
0	329	4	1.2	0,3
1	274	8	2.9	1,6
2	262	12	4.6	2,8
3	306	15	4.9	3,8
4	25	2	8	1,26
Total	1,196	41	3.4	2,5

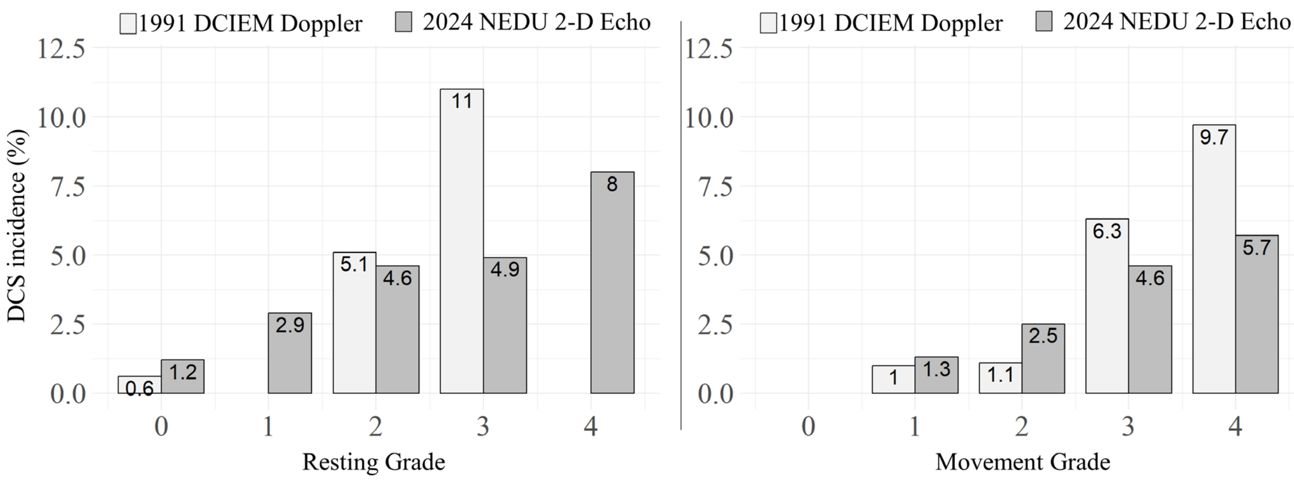
Table 3

Movement venous gas emboli (VGE) grades (Naval Experimental Diving Unit [NEDU] 2-D echocardiography) and decompression sickness (DCS) outcomes; CL - confidence limits

Grade	Dives *n*	DCS *n*	DCS %	95% CL
0	177	0	0	0,2
1	157	2	1.3	0,5
2	197	5	2.5	1,6
3	348	16	4.6	3,7
4	317	18	5.7	3,9
Total	1,196	41	3.4	2,5

Figure 1

Cumulative incidence of decompression sickness (DCS) and peak post-dive VGE grade after rest (left panel) and movement (right panel) in the Naval Experimental Diving Unit (NEDU) 2-D echocardiography data set and the Defence and Civil Institute of Environmental Medicine (DCIEM) Doppler air diving data set. The bars are labelled with the cumulative incidence of DCS. The DCIEM air diving data from reference [6] are the maximum grade observed between precordial and subclavian monitoring sites and the 12 KM grades are collapsed to five grades by eliminating the plus/minus modifiers (e.g., grades II-, II, II+ collapse to grade 2)



limits (CL) of DCS, for each peak post-dive resting VGE grade and the totals for the 1,196 dives irrespective of grade. Table 3 presents the same data for each peak post-dive movement VGE grade (1-cycle definition). It is notable that there was an order of magnitude fewer resting VGE grade 4 observations than any other grade, and a correspondingly wide 95% confidence interval around the cumulative incidence of DCS. The number of observations of each movement VGE grade are more evenly distributed than the resting VGE grades and there are correspondingly narrower 95% confidence intervals around cumulative incidences of DCS for all movement grades (Table 3) than for resting grades.

Figure 1 illustrates the cumulative incidence of DCS and peak post-dive VGE grades for the present NEDU 2-D echocardiography data set and the DCIEM Doppler air diving data set.[5,6] Comparable VGE and DCS data has been published for DCIEM helium-oxygen diving[5,6] but these data are not considered in this paper.

VGE GRADING AFTER MOVEMENT

Figure 2 shows the distribution of modified EB grades assigned using the 1-cycle and 6-cycle definitions for movement grades from the 84 measurements. Forty-nine 1-cycle measurements were decreased by one grade when the 6-cycle definition was applied (24 grade 4a became grade 3; 23 grade 4b became grade 4a; 2 grade 5 became 4b). There was a single instance of a two-grade decrease from grade 5 to 4a. There were 34 the measurements in which the grades were the same using the 1-cycle and 6-cycle definitions. Figure 3 shows the same data as Figure 2 but with the modified EB grades collapsed to NEDU grades.

Figure 2

Comparison of 1-cycle and 6-cycle definitions for modified (Eftedal-Brubakk)movement VGE grades for the same 84 examinations

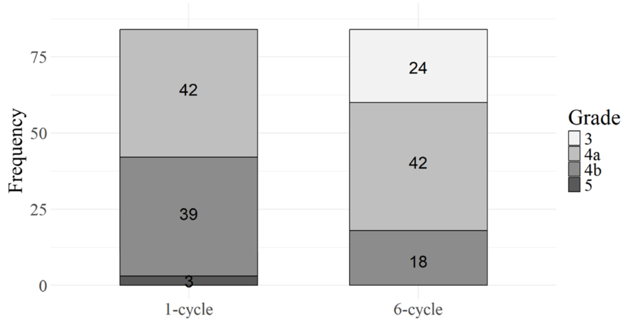


Figure 3

Comparison of 1-cycle and 6-cycle definitions for modified Eftedal-Brukbakk movement VGE grades collapsed to Naval Experimental Diving Unit (NEDU) grades for the same 84 examinations

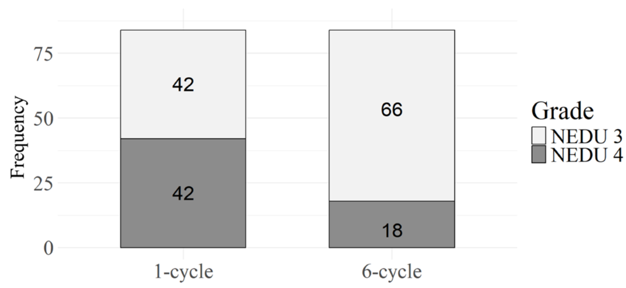
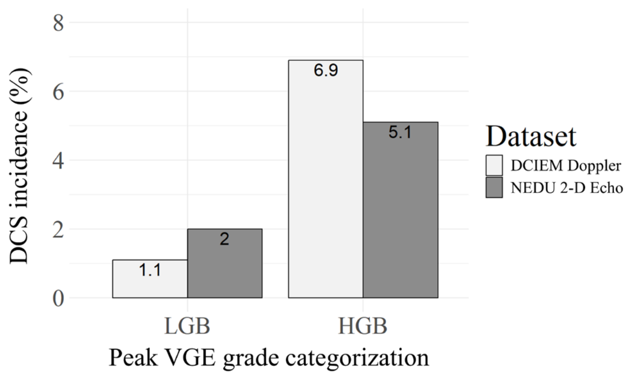


Figure 4

Cumulative incidence of decompression sickness (DCS) and peak post- dive movement venous gas emboli (VGE) grade in the Naval Experimental Diving Unit (NEDU) 2-D echocardiography data and the Defence and Civil Institute of Environmental Medicine (DCIEM) Doppler air diving data set. Data are the same as in Figure 1 (right panel), but with low VGE grades 1 and 2 collapsed and high VGE grades 3 and 4 collapsed. Grade zero VGE are not illustrated because the cumulative incidence of DCS is zero for both data sets. LGB – low grade bubbles; HGB – high grade bubbles



Approximately 57% (24 of 42) of 1-cycle NEDU movement grade 4 measurements were decreased to grade 3 when the 6-cycle definition was applied. The distribution of NEDU VGE grades 3 and 4 is statistically different between 1-cycle and 6-cycle definitions (two-sided χ-squared $P = 0.0002$).

2-D ECHOCARDIOGRAPHY AND DOPPLER DATA SET COMPATIBILITY

The preceding analysis indicates that the NEDU 2-D echocardiography and the DCIEM Doppler movement VGE data sets illustrated in Figure 1 (right panel) may not be compatible for the higher grades because of differences in the definition of higher grades in the NEDU, EB, and KM scales. However, it is possible to remove ambiguity and make the NEDU and DCIEM air diving data similar by collapsing the higher grades. Figure 4 illustrates the relationship between peak movement VGE grade and DCS with VGE grades 1 and 2 collapsed (LGB: low grade bubbles) and 3 and 4 collapsed (HGB: high grade bubbles).

Discussion

PEAK POST-DIVE VGE AND DCS

The present data are a superset of those previously published.[1] The previously reported subset had a higher cumulative incidence of DCS in movement VGE grade 3 than in grade 4. This present data set shows a more credible, consistent increase in DCS cumulative incidence with VGE grade. We propose that, compared to the resting data, the movement VGE data set is the more useful distribution for P_{DCS} based on VGE. In the resting data there were few VGE grade 4 observations and although these data indicate a high P_{DCS} for resting VGE grade 4, the point estimate is imprecise because of the wide 95% confidence interval around the cumulative incidence of DCS. Compared to the resting VGE data set, the movement VGE data set has narrower confidence interval around DCS cumulative incidence for all grades. The movement VGE data set demonstrates a 100% negative predictive value of movement VGE grade zero. It was similar features that lead Sawatzky to conclude that the DCIEM movement VGE data set has a better association with DCS than the resting data set.[5]

The most notable difference between the DCIEM and NEDU movement VGE data sets is the apparently higher cumulative incidence of DCS for grade 4 VGE in the DCIEM data set. However, the proportion of DCS cases in the movement VGE grade 4 bins in the DCIEM and NEDU data are not statistically different (two-sided χ-squared $P = 0.319$). The DCIEM data set arises from development of decompression tables and the dives were intended to have a low incidence of DCS and low VGE grades; of the 1,726 dives in the data set, only 72 (4%) resulted in movement VGE grade 4 and seven of these resulted in DCS.[5,6] As a result, there is a wide 95% confidence interval for the cumulative incidence of DCS for movement VGE grade 4 (5–19%). The NEDU data is predominantly from experiments designed to have a measurable incidence of DCS and the data set has correspondingly high VGE grades; 27% of dives resulted in movement VGE grade 4. The NEDU cumulative incidence of DCS for movement VGE grade 4 may be a more accurate point estimate of P_{DCS} than the corresponding DCIEM data.

However, the present analysis of 1-cycle and 6-cycle definitions for movement VGE grades suggests the apparently higher cumulative incidence of DCS for movement VGE grade 4 in the DCIEM than in the NEDU data set may be due to differences in the methods of grading. The 6-cycle definition resembles the definition of movement VGE grades 3 and 4 in the KM scale used to generate the DCIEM Doppler data. The present analysis indicates that a large fraction of 1-cycle NEDU movement VGE grade 4 dives would be downgraded to grade 3 if a 6-cycle definition had been used. However, the data are not available to apply a 6-cycle definition for movement VGE grades to all the NEDU data and make this reallocation, so it is unknown how this reallocation would change the cumulative incidence of DCS for movement VGE grades 3 and 4.

VGE GRADING AFTER MOVEMENT

It is not surprising that the 1-cycle and 6-cycle definition of movement VGE grades resulted in a different distribution of grades assigned to the same data. This difference illustrates that care must be taken in comparing 2-D echocardiographic (EB or NEDU) movement VGE grades reported by different groups and comparing EB or NEDU movement VGE grades to KM movement VGE grades. One option is to only ever compare resting grades, for which the definitions are unambiguous. However, movement VGE grades have a better association with DCS than resting grades.

Examples of using disparate data sets would be meta-analysis combining historical data sets of KM Doppler data and 2-D echocardiography data or using either the NEDU or DCIEM movement VGE data as prior distributions when estimating P_{DCS} of a different set of dives evaluated using peak post-dive VGE grades. Such data are only combinable as published (grades 0–4) if the definitions for the movement grades are similar. However, for both examples, appropriate collapsing of grades can allow comparison of data using different definitions of movement grades. For instance, collapsing VGE grades 3 and above into a single high grade bubble bin will make many data sets comparable.

Conclusions

There is a need for the diving research community to reach a consensus on how to assign movement VGE grades when using the EB scale. Publications should carefully explain the methodology for assigning movement VGE grades and consider differences in methodologies when comparing historical data sets.

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Guideline

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)

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Decompression illness; Decompression sickness; Echocardiography; Fitness to dive; Health surveillance; PFO; Right-to-left shunt

Abstract

(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 and the United Kingdom Diving Medical Committee. Diving and Hyperbaric Medicine. 2025 31 March;55(1):51–55. doi: 10.28920/dhm55.1.51-55. PMID: 40090026.)

This consensus statement is the product of a workshop at the South Pacific Underwater Medicine Society Annual Scientific Meeting 2024 with representation of the United Kingdom Diving Medical Committee (UKDMC) present, and subsequent discussions included the entire UKDMC. A large right-to-left shunt across a persistent (patent) foramen ovale (PFO), an atrial septal defect (ASD) or a pulmonary shunt is a risk factor for some types of decompression sickness (DCS). It is agreed that routine screening for a right-to-left shunt is not currently justifiable, but certain high risk sub-groups can be identified. Individuals with a history of cerebral, spinal, vestibulocochlear, cardiovascular or cutaneous DCS, migraine with aura or cryptogenic stroke; a family history of PFO or ASD and individuals with other forms of congenital heart disease have a higher prevalence, and for those individuals screening should be considered. If screening is undertaken, it should be by bubble contrast transthoracic echocardiography with provocative manoeuvres (including Valsalva release and sniffing). Appropriate quality control is important. If a shunt is present, advice should be provided by an experienced diving physician taking into account the clinical context and the size of shunt. If shunt-mediated DCS is diagnosed, the safest option is to stop diving. Another is to perform dives with restrictions to reduce the inert gas load, which is facilitated by limiting depth and duration of dives, breathing a gas with a lower percentage of nitrogen and reducing repetitive diving. Divers may consider transcatheter device closure of the PFO or ASD in order to return to normal diving. If transcatheter PFO or ASD closure is undertaken, repeat bubble contrast echocardiography must be performed to confirm adequate reduction or abolition of the right-to-left shunt, and the diver should have stopped taking potent anti-platelet therapy (low dose aspirin is acceptable) before resuming diving.

Introduction

This position statement is a revision of the 2015 Joint position statement on persistent (patent) foramen ovale (PFO) and diving.[1] It is the product of a workshop held at the 52nd Annual Scientific Meeting of the South Pacific Underwater Medicine Society (SPUMS) in May 2024, and followed consultation with the United Kingdom Diving Medical Committee (UKDMC), three members of which attended the meeting. The statement must be interpreted in consultation with a medical practitioner experienced in diving medicine and will be subject to periodic review when new evidence becomes available.

The levels of evidence defined for the position statement are those promulgated in the 2013 ACCF/AHA Clinical Practice Guideline Methodology Summit Report:[2]

Ia Evidence from meta-analysis of randomised controlled trials.
Ib Evidence from at least one randomised controlled trial.
IIa Evidence from at least one well designed controlled trial which is not randomised.
IIb Evidence from at least one well designed experimental trial.
III Evidence from case, correlation, and comparative studies.
IV Evidence from a panel of experts.

Each statement is followed by identification of the level of evidence in the literature for that statement and the supporting references.

The participants who attended the PFO workshop held at the SPUMS 52nd ASM, May 2024 agreed on the principle of each statement and gave approval for the named authors to agree on the final wording.

Statement 1

Routine screening for a right-to-left shunt (PFO, atrial septal defect [ASD] and pulmonary shunts) at the time of dive medical fitness assessment (either initial or periodic) is not indicated. (IV – consensus of SPUMS/UKDMC).

Statement 2

Consideration should be given to investigating for a right-to-left shunt under any of the following circumstances:

- A history of cerebral, spinal, vestibulocochlear, cardiovascular or cutaneous decompression sickness (DCS) (IIa);[3–11]
- A history of migraine with aura (IIa);[12–18]
- A history of cryptogenic stroke (IIa);[19,20]
- A history of PFO or ASD in a first degree relative (IIa);[21,22]
- A history of congenital heart disease (III).[23]

Statement 3

If screening for a right-to-left shunt is undertaken, the following is recommended:

- When obtaining informed consent, there should be discussion of the consequences of a positive finding (IV – consensus of SPUMS/UKDMC);
- Testing should be undertaken by centres well practiced in the technique. See online Appendix 1* (IV – consensus of SPUMS/UKDMC);
- Testing must include bubble contrast, ideally combined with trans-thoracic echocardiogram (TTE), because subjects do not require sedation and this best facilitates cooperation with provocation manoeuvres. Use of two-dimensional and colour-flow Doppler echocardiography without bubble contrast is not adequate (IIa);[7,8,24]
- Testing must include the use of provocation manoeuvres to promote right-to-left shunt including Valsalva release (where the Valsalva causes a reduction in size of the left ventricle) and sniffing as described in the supporting references and online Appendix 1* (both undertaken when the right atrium is densely opacified by bubble contrast) (IIa);[7,8,25]
- The degree of shunting is defined by the number of bubbles seen in the left heart in the frame with the largest number of bubbles:[4,5,7,8,15,20]
  < 6 = small;
  6–20 = medium;
  > 20 = large.

Statement 4

Interpreting a positive bubble contrast echocardiogram result:

- A spontaneous shunt without provocation or a large, provoked shunt is recognised as an unequivocal risk factor for those forms of DCS listed in statement 2 (IIa);[7–9,25]
- Medium shunts are associated with a lower but poorly defined risk of DCS. The significance of small degrees of shunting needs to be interpreted in the clinical setting that led to testing (IIa);[7–9,25]
- In those with a history of DCS as per Statement 2, a small shunt may require further investigation to confirm that the shunt really is small (IV – consensus of SPUMS/UKDMC).

Those interpreting bubble contrast echocardiograms in divers who had DCS should be aware that pulmonary shunts account for a much greater proportion of cases of shunt-mediated DCS (i.e., the result of paradoxical gas embolism) than the proportion of cases of stroke resulting from paradoxical thromboembolism that are via a pulmonary shunt (IIb).[26]

*** Footnote:** Appendix 1 can be found on the DHM Journal website: https://www.dhmjournal.com/index.php/journals?id=351

Statement 5

Following diagnosis of a right-to-left shunt that is considered likely to be associated with increased DCS risk, the diver should be advised of the following options in consultation with a diving physician:

- Stop diving; It is self-evident that DCS cannot occur without pressure reduction that causes bubble nucleation in the body;
- Close the right-to-left shunt if it is atrial (III);[8,14,27–30]
- Dive more conservatively (III).[31]

Diving deeper than 15 metres increases the risk of developing bubbles and hence shunt-mediated DCS (IV – consensus of SPUMS/UKDMC).

There are various strategies that can be employed to reduce the risk of significant venous bubble formation after diving and to reduce the inert gas load in tissues able to amplify any arriving arterial bubble emboli. Examples include: reducing dive times to well inside accepted no-decompression stop limits; restricting dive depths to less than 15 metres; performing only one dive per day; use of nitrox with air dive planning tools; intentional lengthening of a safety stop or decompression time at shallow stops.

There are other precautions with a less established basis which may reduce the right-to-left shunting of bubbles across an atrial shunt after diving, (examples include: avoiding heavy exercise and unnecessary lifting or straining and forceful Valsalva for at least three hours after diving) (IV – consensus of SPUMS/UKDMC).

Statement 6

The options outlined in Statement 5 require careful consideration of the risks and benefits and the clinical setting that led to screening, and the diver's stated plans for future diving (IV – consensus of SPUMS/UKDMC);[30]

The risks and consequences of recurrent DCS in a diver should be considered and taken into account when advice is given, with acceptance of such risk by the diver (IV – consensus of SPUMS/UKDMC).

Statement 7

Before return to diving following closure of a PFO or ASD, the diver requires a repeat transthoracic bubble contrast echocardiogram with provocation manoeuvres as described, that demonstrates adequate reduction or abolition of the right-to-left shunt, a minimum of three months after the closure (III).[14,26,28,30]

Statement 8

Diving should not be resumed until satisfactory closure of the right-to-left shunt is confirmed, and the diver has ceased potent antiplatelet medication (low dose aspirin is acceptable) (III).[14,27,28,30]

Statement 9

Advice about pulmonary shunts should be from a cardiologist with expertise in diving medicine (IV – consensus of SPUMS/UKDMC).

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Dr Turner acts as a consultant and proctor for St Jude Medical, Medtronic and Edwards Lifesciences, as a consultant and lecturer for Gore Medical and performs PFO closures on private patients. Professor Mitchell is the editor of Diving and Hyperbaric Medicine Journal. However, as a societal position statement this manuscript did not require peer review or a related decision regarding publication. The other authors declare that they have no conflicts of interest.

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Case reports

A case of facial vascular occlusion after hyaluronic acid cosmetic filler injection treated with adjunctive hyperbaric oxygen

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Keywords
Case report; Hyperbaric oxygen treatment; Ischaemia; Skin

Abstract

(Stevens G, Lewis I. A case of facial vascular occlusion after hyaluronidase cosmetic filler injection treated with adjunctive hyperbaric oxygen. Diving and Hyperbaric Medicine. 2025 31 March;55(1):56–58. doi: 10.28920/dhm55.1.56-58. PMID: 40090027.)
Treatment of suspected upper lip area vascular occlusion caused by facial hyaluronic acid filler injections with hyperbaric oxygen is reported. The patient was initially treated with hyaluronidase injections in the cosmetic clinic then again in the emergency department. Persistent symptoms and signs of occlusion prompted hyperbaric oxygen treatment at 284 kPa (nine treatments over seven days). The outcome was positive for this patient and adds supportive evidence to the sparse literature, which are mainly case studies.

Introduction

Soft tissue injuries have been reported from vascular obstruction caused by the injection of hyaluronic acid filler. The standard initial approach to treatment is with the injection of hyaluronidase to dissolve the filler.[1] Persisting vascular occlusion has been treated with hyperbaric oxygen in several reported case studies.[2–4] Here we report another case of vascular occlusion treated with hyaluronidase and hyperbaric oxygen treatment (HBOT).

Case report

The patient reported in this case report approved the publication of clinical details and photographs.

A 36-year-old female non-smoker with no significant past medical history was referred by medical staff at a cosmetic clinic after developing pain, swelling, and dusky colouration in her upper lip 12 hours after receiving hyaluronic acid filler injections (0.15 ml Stylage Medium; crosslinked hyaluronic acid in mannitol) into this same area. Vascular occlusion by the dermal filler was suspected. Initial management by the clinic involved regional injection of hyaluronidase 1,500 IU x five boluses plus aspirin.[1] Although there was a minor improvement, persisting discolouration and pain prompted the decision to transport to the Emergency Department of the local public hospital for presumed continued upper lip vascular occlusion (see Figure 1).

During her emergency admission she was given further injections of hyaluronidase (two x 1,500 IU) and was assessed by the hyperbaric physician on call. The patient had no contra-indications to HBOT and was initially treated at 284 kPa (2.8 atmospheres absolute [atm abs]) in a regimen involving three twenty minute oxygen breathing periods separated by five minute air breaks, followed by a 30 minute decompression. Initial treatment took place in a multiplace chamber with similar follow-up treatments twice daily for two days and once daily for four days in a monoplace chamber. A total of nine HBOT treatments were given.

The patient reported improved pain and objectively had some resolution of the swelling after the first treatment, and by treatment six she had normal capillary refill and reported subjectively normal skin temperature in the affected region (Figure 2). At the end of the treatments the physical appearance of the facial area was perceived to be back to normal by both the patient and the medical staff.

The patient was followed up at two weeks by hyperbaric staff with total resolution of all the symptoms (Figure 3).

Figure 1
Appearance of the upper lip before any hyperbaric oxygen treatment

Figure 2
Appearance of upper lips after five hyperbaric oxygen treatments

Figure 3
Appearance of lips two weeks after completion of hyperbaric oxygen treatments

Discussion

Injection of filler in cosmetic clinics is a multi-billion-dollar industry and becoming more accessible and acceptable.[5] Case reports of vascular occlusion following dermal filler or autologous fat injection vary from pain and localised skin necrosis to retinal artery occlusion, sensorineural deafness, stroke and even death.[6–9] Most of the literature pertaining to acute vascular occlusions in the head and neck and hyperbaric oxygen have historically referenced central retinal artery occlusion (CRAO) or branch retinal artery occlusion (BRAO).[10]

In Australia, the Australian Health Practitioner Regulation Agency publishes guidelines for non-surgical cosmetic procedures performed by medical professionals.[11] However, there is a significant unregulated industry including black-market injectables and home injectors.[12] There is no impediment to buying hyaluronic acid online and self-injecting. There is a broad range of target areas in the face for dermal fillers, including jaw line, chin, infra-orbital, and glabella.

The primary medical emergency response to vascular occlusion is injection of pulsed high dose hyaluronidase in the affected area to dissolve the hyaluronic acid filler material.[1] This can be repeated up to four cycles of 1,500 IU hourly. If this fails, anecdotal evidence supports the use of HBOT in achieving better outcomes, but treatment times and pressures vary.[2–4] The presumed beneficial mechanism is supporting tissue oxygenation during the initial hypoxic event, reduction in swelling, and down-regulation of triggered inflammatory mediators.[13] Longer term benefits may include modulation of angiogenesis and connective tissue formation/repair. There are no large randomised controlled trials regarding HBOT and cosmetic vascular occlusion but extrapolation of the data supporting HBOT for CRAO/BRAO would appear to present a solid pathophysiological model base for arguing the benefits.[14,15] Hyperbaric oxygen treatment has been used successfully in other soft tissue injuries of the face.[16] The potential long-term harm caused by vascular occlusion in the face such as scarring, facial distortion, mastication and speech issues, psychological harm and permanent disfigurement or sensory impairment should encourage research into mitigating these harmful outcomes. In Tasmania, HBOT was included in the earlier CRAO/BRAO protocol (guidelines for management of soft tissue filler-induced vision loss) but was left out of the 2022/3 guidelines because they referred to the National guidelines (RANZCO Filler Blindness Guidelines).[17] We are currently working to rectify this omission.

Conclusions

Consideration should be given to treating vascular occlusion caused by dermal fillers such as HA, with HBOT as an adjunct to hyaluronidase injections. This is supported by pathophysiological models and by limited case studies. Larger trials would be ideal although the low prevalence would create difficulties in recruitment. However, this cosmetic procedure is becoming more common therefore we may yet see an increase in complications.

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Severe neurological decompression sickness associated with right ventricular dilatation and a persistent foramen ovale

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Keywords
Arterial gas embolism; Case reports; Decompression illness; Diving incidents; Persistent (patent) foramen ovale (PFO); Scuba diving; Right-to-left shunt

Abstract

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We present the case of a 28-year-old female diver who performed a scuba air dive with significant omitted decompression obligation. She developed constitutional and neurological symptoms. Brain magnetic resonance imaging post treatment demonstrated multifocal embolic infarcts and transthoracic echocardiogram with bubble contrast on day three revealed a persistent foramen ovale (PFO) and severe right ventricular (RV) dilatation. We postulate that the high venous bubble load from the provocative decompression caused an increase in pulmonary artery pressure, leading to RV dilatation and increased right to left shunting of bubbles across her PFO, resulting in significant neurological deficits. This mechanism is analogous to that seen in acute thromboembolic pulmonary embolism.

Introduction

Right-to-left shunt is promoted by increased pulmonary artery pressures in patients with submassive or massive pulmonary thromboembolism (PE) and a persistent (patent) foramen ovale (PFO).[1] We report a patient with severe right ventricular (RV) dilatation and PFO-associated neurological and constitutional decompression sickness (DCS).

Case report

Written consent for publication of the history and images was obtained from the patient, and approval was obtained for data review and extraction by Governance, Evidence, Knowledge and Outcomes (GEKO) at Fiona Stanley Hospital (Approval Number 46996).

A 28-year-old woman, who had performed 44 previous dives and had no significant past medical history or medications except combined oral contraceptive, performed a scuba air dive to 35 metres of seawater (msw) for 44 minutes (min). She had performed a single dive to 12 msw for 89 min 24 hours (h) earlier. Therefore, according to The Defence and Civil Institute of Environmental Medicine (DCIEM) air diving tables, the deeper dive was a non-repetetive dive.[2] There was no rapid ascent but she omitted a significant decompression obligation, surfacing with a nitrogen loading of 122% according to her dive computer as calculated by the Bühlmann ZHL-16C algorithm. During the surface interval of 1 h 48 min, the patient developed progressive nausea and bilateral lower limb paraesthesia. Despite this, she completed a second dive to 26 msw for 30 min with her symptoms improving slightly at depth. The dive profiles are shown in Figure 1. The conservatism level on the dive computer was set to high for dive 1 and medium for dive 2.

After surfacing from the second dive her symptoms worsened, with vomiting, thoracic back pain and neurological symptoms including headache, unsteadiness, bilateral upper and lower limb paraesthesia and leg weakness. She denied chest pain, breathlessness or syncope. The patient was taken to shore by police boat with face mask oxygen, where she was met by an ambulance 2 h 45 min after surfacing from the second dive. Her observations on shore were respiratory rate 22 breaths·min^{-1}, oxyhaemoglobin saturation 98% with 15 L·min^{-1} oxygen via non-rebreather face mask, pulse 120 beats·min^{-1}, blood pressure 116/76 mmHg and temperature 36.5°C. She had clear lungs on auscultation with mildly

Figure 1

Dive profiles downloaded from patient's Garmin dive computer. X axis – time (minutes:seconds), Y axis – depth (metres); red shaded area – decompression ceiling as per Bühlmann ZHL-16C algorithm

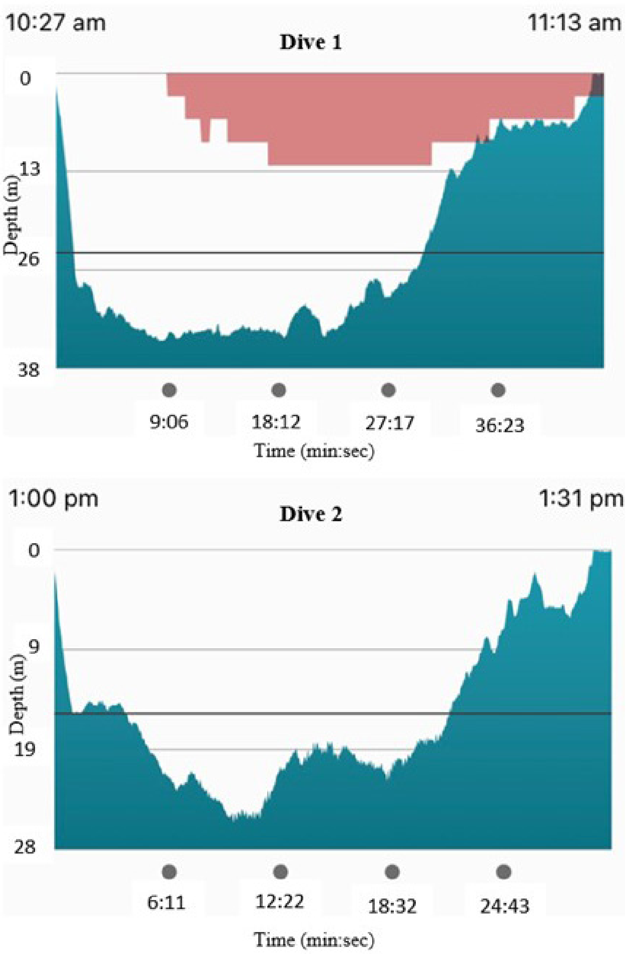


Table 1

Initial blood results upon arrival to hospital; CRP – c-reative protein; hs-TnI – high sensitivity troponin I levels

Test	Result	Normal range	Units
Haemoglobin	188	115–160	g·L^{-1}
Haematocrit	0.57	0.37–0.47	L·L^{-1}
White cell count	32.89	4–11	x10^{9}·L^{-1}
Neutrophils	29.95	2.0–7.5	x10^{9}·L^{-1}
CRP	6.7	< 5	mg·L^{-1}
Sodium	138	135–145	mmol·L^{-1}
Potassium	4.2	3.5–5.2	mmol·L^{-1}
Bicarbonate	18	22–32	mmol·L^{-1}
Urea	4.3	3.0–8.0	Mmol·L^{-1}
Creatinine	96	45–90	Umol·L^{-1}
Troponin I (Abbot hs-TnI)	6	< 16	Ng·L^{-1}

increased work of breathing. She was transported by road to Fiona Stanley Hospital, the State Referral Centre for Diving and Hyperbaric Medicine in Western Australia.

Upon arrival to hospital, 3 h 40 min from surfacing, she reported ongoing nausea, thoracic back pain, headache and progressive paraesthesia to her legs and fingers. Examination revealed bidirectional end gaze nystagmus and reduced power (4/5) to the left leg, with equal and symmetrical limb reflexes. Tympanic membranes were normal and there was no rash. Blood tests revealed haemoconcentration consistent with dehydration and a leucocytosis (Table 1). Electrocardiogram (ECG) showed normal sinus rhythm without T-wave abnormalities or signs of right heart strain and a chest X-ray was normal. Bedside lung ultrasound excluded pneumothorax and pulmonary oedema. The patient was treated with intravenous (IV) antiemetics and 2 L of crystalloid fluid.

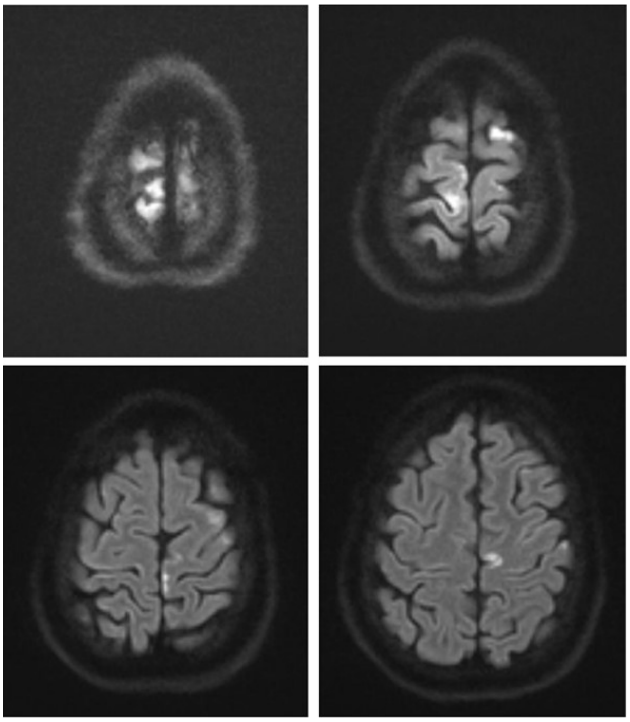
The patient received hyperbaric oxygen treatment (HBOT) with a modified United States Navy Treatment Table 6 (USN TT6) without extensions in a monoplace chamber. She vomited during the treatment, however her nausea settled as the treatment progressed. When reviewed after completing her initial recompression her symptoms had improved, but she had ongoing paraesthesia, nausea and ataxia. The patient developed a fever of 38.1°C after the treatment, with rapid antigen test for COVID negative and urinalysis showing a trace of leucocytes. She had no sick contacts nor focal infective symptoms and was treated with further IV fluids and commenced on IV antibiotics (piperacillin with tazobactam). The following morning she had persistent ataxia, nystagmus and lower limb paraesthesia and she received further HBOT with United States Navy Treatment Table 5 (USN TT5).

Brain magnetic resonance imaging (MRI) with angiogram on day one post-dive showed multifocal areas of cortical diffusion restriction in the supratentorial brain, including the right parafalcine motor strip, consistent with multiple embolic infarcts, without intracranial arterial stenosis (Figure 2). Spinal MRI was normal. The patient was commenced on aspirin and admitted by the neurology service. The patient completed twice daily HBOT for two days after her initial USN TT6, then daily until symptom plateau plus one for a total of 22 treatments (Table 2). Thrombophilia screening was normal. The oral contraceptive was stopped due to potential pro-coagulant effect.

A transthoracic echocardiogram (TTE) with bubble contrast was performed on day three post-dive. This showed normal left ventricular systolic function with ejection fraction of 59% by Simpson's biplane method. The RV was severely

Figure 2

Brain magnetic resonance imaging day one post-dive; Axial slices demonstrating multifocal cortical diffusion restriction (white areas) in keeping with multiple embolic infarcts



dilated (mid ventricle diameter 4.18 cm, normal < 3.5 cm) with flattening of the interventricular septum predominantly in diastole, consistent with increased RV filling pressures with normal systolic function (Figure 3). Agitated saline contrast revealed a large right-to-left interatrial shunt at rest. The following day, transoesophageal echocardiogram (TOE) with bubble contrast injection confirmed a dilated RV with preserved systolic function, a dilated right atrium (RA) with bowing of the interatrial septum indicating high RA pressure, and a PFO with moderate size right-to-left shunt at rest.

Cardiology were consulted and cardiac MRI (Figure 4) was performed on day five post-dive. The RV was moderately dilated with mildly impaired systolic function. There were no valvular lesions nor evidence of RV infarction. The RA was moderately dilated. The aetiology of the dilated right heart was thought to be increased pulmonary circulation resistance secondary to a high bubble load within the pulmonary capillary bed from DCS. Arrhythmogenic right ventricular cardiomyopathy was thought to be unlikely.

Repeat TTE on day 14 post-dive showed a reduction in RV size compared to previous (mid-ventricle diameter 3.95 cm) with preserved systolic function. The patient was discharged from hospital on day 14 post-dive, with her remaining HBOT performed as an outpatient. She received occupational therapy and physiotherapy. After completing a total of 22 sessions of HBOT, she still had residual deficits including reduced voluntary control of her left arm, gait disturbance to her left leg, and changes to higher level executive function.

Table 2

Hyperbaric oxygen treatment table and chamber type used; 14:90:08 – 243 kilopascals / 2.4 atmospheres absolute for 90 minutes with 8 minute decompression; 14:90:24 – 243 kilopascals / 2.4 atmospheres absolute for 90 minutes with 24 minute decompression; Mono – Monoplace; Multi – Multiplace; USN TT5 – United States Navy Treatment Table 5; USN TT6 – United States Navy Treatment Table 6

Days post-incident dive	Treatment table	Chamber
0	USN TT6	Mono
1	USN TT5 x 2	Multi
2	USN TT5 x 2	Mono
3	USN TT5	Mono
4	14:90:08	Mono
5	14:90:08	Mono
6	USN TT5	Multi
7	14:90:08	Mono
8	14:90:08	Mono
9	14:90:08	Mono
10	14:90:08	Mono
11	14:90:24	Multi
12	14:90:24	Multi
13	14:90:08	Mono
14	14:90:08	Mono
15	14:90:08	Mono
16	14:90:08	Mono
17	14:90:08	Mono
18	14:90:08	Mono
19	14:90:08	Mono

A TTE was repeated three months post-dive which showed interval reduction in RV size, with mild RV dilatation (mid ventricle diameter 3.5 cm) and normal RA size. Cardiac MRI was repeated five months post-dive which showed ongoing mild RV dilatation with an ejection fraction of 48%. She was reviewed at the hyperbaric unit six months post-dive and reported feeling well overall, however she reported persistent paraesthesia to both legs with ongoing balance issues and a best sharpened Romberg test of 25 seconds on her third attempt.

A PFO closure was performed seven months post-dive using a Gore Cardioform Septal Occluder® where she was found to have a large PFO, opening to six mm. She was treated with antiplatelet agents (aspirin and clopidogrel) for six months.

Figure 3
Transthoracic echocardiogram apical four chamber view day three post-diving showing end-diastolic right ventricular (RV) dilatation; medial - lateral diameter given in centimeters at base (normal < 4.1 cm) and mid ventricle (normal < 3.5 cm); bpm – beats per minute

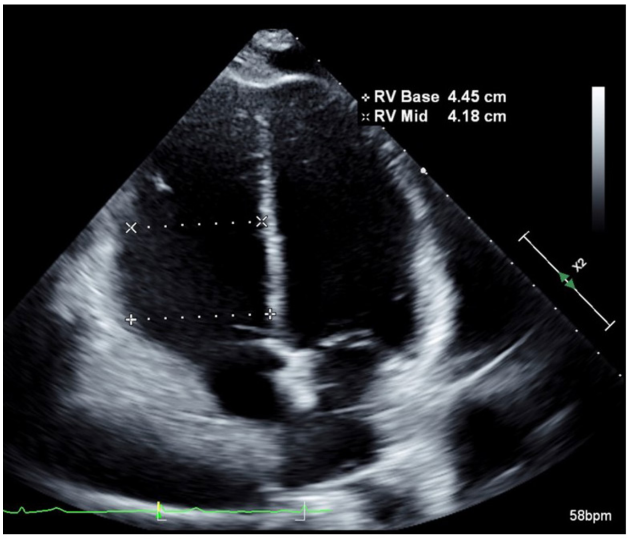


Figure 4
Cardiac magnetic resonance imaging day five post-dive; upper panel – short axis view; lower panel – four chamber view; demonstrates right ventricular dilatation in diastole. RV – right ventricle; LV – left ventricle

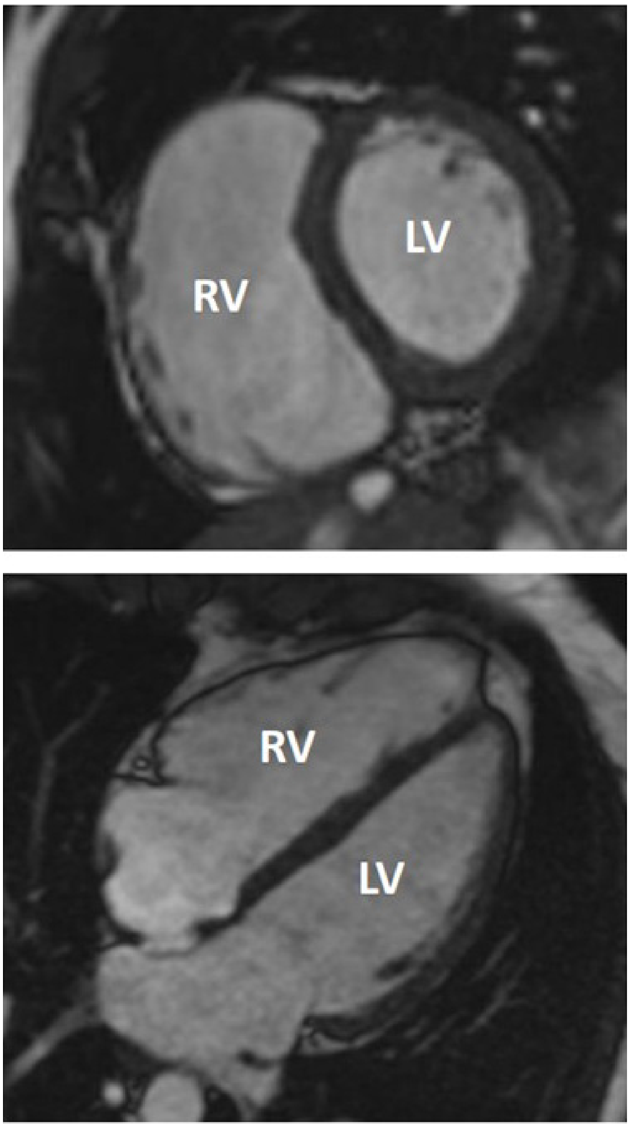


Figure 5
Transoesophageal echo 6 months post-PFO closure showing Gore Cardioform Septal Occluder® *in situ*

A TOE with bubble contrast performed six months post-PFO closure showed a well seated device without residual right-to-left interatrial shunt (Figure 5).

Discussion

Cardiopulmonary DCS typically presents early after surfacing from provocative dives, with a spectrum of symptoms including chest pain, dyspnoea and cough progressing to shock and death in severe cases.[3,4] Historically, severe cardiopulmonary DCS was associated with unsafe pressure-time profiles, particularly in caisson workers. For example, Ghawabi and colleagues reported a DCS rate of 0.97% after caisson workers were exposed to air pressures equivalent to 28 msw for up to six hours and 25 msw for up to eight hours.[5] The authors reported that 48 of 55 (87%) workers had at least one episode of DCS during the project, and 37 of the 55 (67%) of workers experienced cardiopulmonary DCS ('the chokes'). The high incidence rates are consistent with unsafe profiles and, because nearly every worker had DCS at least once, there is no need to postulate the role of physical predisposition to DCS, such as right-to-left shunts. Wilmshurst and colleagues compared the prevalence of atrial shunts in 97 divers who had DCS with 109 divers who had not had DCS. Twelve divers had cardiorespiratory DCS and seven of those had an atrial shunt, which was a significantly greater prevalence than in normal divers, which was 26 of 109 (24%).[6]

In the patient we describe, cardiorespiratory symptoms were not prominent, despite the severe degree of right heart dilatation, but she was initially tachycardic and tachypnoeic. The lowest oxyhaemoglobin saturation recorded acutely post-dive was 98%, although she was on supplemental oxygen for the duration of her initial management.

Animal models have demonstrated that when the pulmonary circulation is overwhelmed by increasing numbers of venous gas emboli, the pulmonary artery pressure can increase such that right heart failure and haemodynamic instability can ensue.[7,8] In this patient, the postulated mechanism of RV dilatation, with bubbles causing physical obstruction of the pulmonary vasculature and hence increasing pulmonary artery pressure, is analogous to that found when pulmonary thromboembolism (PE) causes increased pulmonary vascular resistance and pulmonary artery pressure.[9] The clinical effect of PE in patients with a PFO is well described. Submassive or massive pulmonary emboli can promote right-to-left shunting of deoxygenated blood across a PFO due to elevated RA and RV pressures, causing worsened hypoxaemia.[10] In patients with haemodynamically significant PE, those patients with a PFO were found to have a higher incidence of peripheral or visceral arterial occlusions and of cerebral infarction.[1] Of 139 patients with major PE (echocardiographic evidence of RV pressure overload or presence of pulmonary artery hypertension), the incidence of ischaemic stroke was increased in those with a PFO (13% vs 2.2%) as well as peripheral arterial embolism (15% vs 0%).[11] In our patient, elevated right heart pressure could similarly have increased the shunting of venous gas emboli across the PFO, causing the profound embolic manifestations seen on brain MRI.

Coronary artery gas embolism is another potential mechanism for bubble mediated right heart dysfunction in this case. In the supine position, in which the patient was initially managed, gas emboli can preferentially enter the right coronary artery as the right coronary sinus is the most superior and anterior in this position.[12] Coronary air embolism could potentially stun the myocardial territory supplied i.e., the RV. This is seen rarely after iatrogenic air embolism during cardiac catheterisation, but can cause complications including haemodynamic instability, myocardial infarction, ventricular arrhythmias and death.[13] This is another possible cause of right heart dilatation, but is unlikely in this case given the absence of ECG or troponin abnormality.

Consideration was given to the alternative hypothesis that the patient might have had pre-existing pulmonary hypertension with subsequent right heart dilatation, however this was deemed unlikely. The PFO was considered too small to cause significant right heart dilatation through a left-to-right shunt. Furthermore, if this were the case, a gradual reduction in RV diameter over time would not have been anticipated.

Another hypothesis was of chronic thromboembolic pulmonary hypertension resulting from asymptomatic pulmonary emboli, with the use of oestrogen containing oral contraceptive being a risk factor for thromboembolism. However, this was also considered improbable, as the patient was asymptomatic and had good pre-morbid exercise tolerance, although imaging for pulmonary embolism was not performed. The patient was treated with antiplatelet agents but was not anticoagulated, therefore we would not expect any chronic thromboembolism to resolve, with subsequent reduction in pulmonary hypertension in the absence of anticoagulation.

If an acute submassive pulmonary embolism had occurred around the time of the dive causing right heart dilatation, this would have caused symptoms such as chest pain and breathlessness, which the patient did not report. Instead, the patient displayed other signs of DCS, including nausea, vomiting and paraeshesias. These symptoms, coupled with a provocative dive profile with omission of decompression obligation and improvement with recompression therapy, make DCS a more plausible explanation.

Typically, RV dilatation due to acute pulmonary thromboembolism can take a significant time to resolve with right ventricular dysfunction being persistently present a year later in around 34% of cases.[14] In this case, the RV dilatation decreased from severe (mid-ventricle diameter 4.18 cm) on day three to the upper limit of normal (mid-ventricle diameter 3.5 cm) within three months. This further reduces the likelihood that thromboembolic disease was the underlying cause.

Conclusions

We report a case of DCS-related right heart dilatation, likely caused by bubble-mediated increase in pulmonary artery pressure. This is analogous to PE increasing pulmonary vascular resistance and right heart pressures. The increased right atrial pressure can increase right-to-left shunting across a PFO and facilitate paradoxical embolism of venous bubbles. This is the first report to the authors knowledge of transient RV dilatation from DCS associated with a PFO.

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Conflicts of interest and funding: nil

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Letters to the Editor

PFO and DCS of hyperbaric personnel

I have read with great interest the recent report from Wilmshurst and Edge on recurrent cutaneous decompression sickness (DCS) in a hyperbaric chamber attendant with a large persistent foramen ovale.[1] The authors claim within the discussion, "*the patient described in this report[1] and the patient in the paper by Colvin and colleagues[2] are the only cases in which DCS occurred in individuals that had dry occupational hyperbaric exposure with oxygen decompression*". I want to draw readers' attention to the recent report from our hyperbaric centre describing several cases of DCS of the hyperbaric attendants after oxygen decompression.[3] During 25 years of activity in the National Centre for Hyperbaric Medicine in Gdynia, Poland, during 41,507 hyperbaric sessions, DCS occurred six times in five medical personnel (one person twice). In three cases, skin symptoms of DCS occurred minutes to a maximum of two hours after oxygen safety decompression for no-decompression exposures. In one case, skin symptoms of DCS occurred 15 minutes after no-decompression exposure without extra oxygen breathing. The staff involved did not decide to undergo PFO screening in those four cases; they continued to work in a hyperbaric environment with increased conservatism, and there was no repetition of DCS regardless of age (59, 53, 40 and 28 years, respectively). The other two DCS cases involved one hyperbaric doctor who had spinal DCS for the first time after no-decompression exposure without safety oxygen decompression when 51-years-old; this was described in 2021.[4] While risk factors were clearly identified including age, overweight, dehydration and tiredness, a follow-up transoesophageal echocardiogram (TEE) with contrast administration and strain manoeuvre did not reveal the presence of PFO. Interestingly, the same man had a second occurrence of combined spinal and skin DCS five years later, also after no-decompression exposure, regardless of oxygen decompression, for safety reasons.

There is little doubt nowadays that PFO is a risk factor for DCS, especially in the neurological form.[5] But, on the other hand, I cannot agree with the statement that "*individuals, who have a large atrial right-to-left shunt, either a PFO or an atrial septal defect, make up the majority of people who have DCS as a result of working in modern hyperbaric facility*". Still, DCS is rare in hyperbaric personnel (0.014% in our centre, which is one case per 7,000 sessions). In my opinion, more attention should be placed on reducing occupational hazards (repetitive sessions, uncontrolled exercises, extreme temperature exposures) and modifying physiological risk factors (dehydration, poor physical status and non-optimal body constitution) than focusing on PFO as the main reason for DCS of hyperbaric personnel. The old concept of "*assume that you have PFO and avoid bubbles at all costs*" seems efficient for the medical environment. I cannot recall the primary reference for this citation, but I support Wilmshurst's and Edge's conclusion that "*the guidance produced by SPUMS and UKDMC for assessment of divers who might have a PFO is also applicable to other hyperbaric workers such as inside chamber attendants and hyperbaric tunnel workers*",[6] especially before considering PFO closure.

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doi: 10.28920/dhm55.1.65. PMID: 40090029.

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Accepted: 13 January 2025

Professor Jacek Kot, MD, PhD
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Keywords

Decompression sickness; Hyperbaric oxygen treatment; Persistent (patent) foramen ovale (PFO); Risk factors; Safety

Reply – PFO and DCS of hyperbaric personnel

We are grateful to Professor Kot for his interest in our recent case report and review of cases of decompression sickness (DCS) occurring after dry hyperbaric exposures.[1] We are also grateful to him for drawing our attention to the recently published case series by him and his colleagues that reported five hyperbaric chamber staff that had six episodes of DCS.[2] It was submitted for publication after ours.

The first episode of DCS in the individual who had two episodes was reported previously.[3] We included discussion of the earlier case report in our initial version of the paper, but we were asked to remove it to shorten our report.

In his letter, Professor Kot wrote he could not agree with our statement "*individuals, who have a large atrial right-to-left shunt, either a PFO or an atrial septal defect, make up the majority of people who have DCS as a result of working in modern hyperbaric facility*".[1] He did not quote the first part of our sentence, which explained our reservations as follows "*It is difficult to draw conclusions from a small number of case reports, but these limited data suggest that….*"[1]

Professor Kot's rejection of the possibility that right-to-left shunts are implicated in the majority of DCS episodes in modern hyperbaric workers is not based on his own observations. In his case series, only one of the five staff that had DCS had a test for to see whether he had a shunt.[2] The test was transoesophageal echocardiography, which is unreliable for the detection of shunts. That is why the SPUMS / UKDMC position statement on atrial shunts recommends performance of transthoracic echocardiography with bubble contrast.[4]

Professor Kot believes that risk factors for DCS in hyperbaric chamber staff are age, being over-weight, dehydration and tiredness.[2] There is no evidence for these as aetiological factors in DCS and the data in the five cases reported by Kot et al. provides no support.[2] In Professor Kot's five patients ages ranged from 28 to 59 years and BMI from 17.8 to 36.[2] Kot et al. provide no data on tiredness and dehydration, which are difficult to quantify. They provided no control data on staff that had never experienced DCS.

Two episodes of DCS reported in the series by Kot et al. occurred after the hyperbaric chamber staff deviated from the department's standard decompression protocol by failing to breathe oxygen during decompression.[2] Both episodes were neurological with latencies of five and 15 minutes. Three of the four episodes of DCS that occurred after oxygen decompression were cutaneous with latencies of 1–2 hours, and one was combined neurological and cutaneous DCS.[2] The clinical manifestations and latencies of DCS after pressure exposures that are considered low risk were typical of shunt mediated DCS in divers.[5,6] The preponderance of cutaneous DCS after oxygen decompression is consistent with the small number of reports in modern occupational hyperbaric exposure in dry conditions in individuals with atrial shunts.[1] Unfortunately the patients reported by Kot et al. did not have transthoracic echocardiography with bubble contrast.

We are compelled to disagree with Professor Kot. We prefer to base our opinion on the limited data available rather than on supposition.

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doi: 10.28920/dhm55.1.66. PMID: 40090030.

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Keywords

Decompression sickness; Echocardiography; Hyperbaric oxygen; Occupational health; Persistent (patent) foramen ovale (PFO)

Erratum

In December, we published an article titled "*Dive Medicine Capability at Rothera Research Station (British Antarctic Survey), Adelaide Island, Antarctica*" by Wood FNR, Bowen K, Hartley R, et al.

The corresponding author would like to include an additional author, as their contribution was significant but was inadvertently omitted in the initial online publication. While this correction has been made in several versions circulated by the journal, not all have been updated. As a result, we are issuing an erratum.

The title and abstract are as follows:

Dive medicine capability at Rothera Research Station (British Antarctic Survey), Adelaide Island, Antarctica

Felix N R Wood[1,2], Katie Bowen[1], Rosemary Hartley[1], Jonathon Stevenson[4], Matt Warner[1], Doug Watts[1,3]

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Keywords
Cold; Diving; Diving emergencies; Drysuit; Recompression; Remote locations

Abstract

(Wood FNR, Bowen K, Hartley R, Stevenson J, Warner M, Watts D. Dive medicine capability at Rothera Research Station (British Antarctic Survey), Adelaide Island, Antarctica. Diving and Hyperbaric Medicine. 2024 20 December;54(4):320–327. doi: 10.28920/dhm54.4.320-327. PMID: 39675740.)

Rothera is a British Antarctic Survey research station located on Adelaide Island adjacent to the Antarctic Peninsula. Diving is vital to support a long-standing marine science programme but poses challenges due to the extreme and remote environment in which it is undertaken. We summarise the diving undertaken and describe the medical measures in place to mitigate the risk to divers. These include pre-deployment training in the management of emergency presentations and assessing fitness to dive, an on-site hyperbaric chamber and communication links to contact experts in the United Kingdom for remote advice. The organisation also has experience of evacuating patients, should this be required. These measures, as well as the significant infrastructure and logistical efforts to support them, enable high standards of medical care to be maintained to divers undertaking research on this most remote continent.

doi: 10.28920/dhm55.1.67. PMID: 40090031.

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/

SPUMS President

Neil Banham

I have just returned from the 3rd International Conference on Diving and Hyperbaric Medicine in Muscat, Oman, held from 3–6 February. The conference had 280 delegates from 18 countries, with many from the Gulf being represented. The presentations were diverse and of high quality, with the conference venue having amazing audiovisual facilities. I was able to meet and spend time with EUBS President Jean-Eric Blatteau and UHMS Immediate Past President Peter Witucki, as well as our Editor - Simon Mitchell and Frauke Tillmans, the Research Director at DAN. There was also an opportunity to network with other colleagues and to learn about diving and hyperbaric medicine from a Middle Eastern perspective. We visited the Oman National Hyperbaric Medicine Centre and the newly built Medical City Hospital for Military and Security Services in Muscat, both ultramodern and very impressive facilities. My thanks to the organising team for this fantastic opportunity and for a great conference.

The recently established Mike Bennett Scholarship, created to honour our great friend and colleague Professor Mike Bennett AM, received three applications, all of high quality. The inaugural Scholarship was awarded to Dr Caleb Lin for his Cochrane review on the use of hyperbaric oxygen in sudden sensorineural hearing loss. Caleb will be funded to present his work at the EUBS Annual Scientific Meeting (ASM) in Helsinki in September. This Scholarship will again be offered for 2026, with a closing date of 31 December 2025. Further details re the Scholarship are to be found in the Notices section of this issue, as well as on the SPUMS website. South Pacific Underwater Medicine Society - SPUMS - Mike Bennett Scholarship

The 2025 SPUMS ASM being held in Bali, Indonesia is fast approaching. As of mid-February, there were almost 100 registrants.

Dates: 18–23 May 2025
Theme: '*Oxygen: Too little, too much or just right*'
Venue: Ramayana Candidasa, Bali, Indonesia
Link to register: South Pacific Underwater Medicine Society - SPUMS-ASM

Thanks again to Xavier Vrijdag and Hanna van Waart, our Bali ASM Convenors and to Diveplanit our travel provider.

Our 2026 ASM will be in Palau and will be convened by Ian Gawthrope and Doug Falconer. Palau is an amazing destination with some of the best diving in the world. I have fond memories of diving Blue Corner several times when I went to Palau for a previous SPUMS conference. Tentative dates are the week commencing Sunday 10 May 2026. There will be a new moon bump head parrotfish spawning event on the 13th/14th May – an enormous spectacle. It will be an early morning departure, and the site itself is a wide sandy basin that our large group could dive comfortably together.

Qantas are currently flying to Palau, departing Brisbane on Saturday mornings and returning Sunday morning. Further details will be available on the SPUMS website soon.

The Paediatric Diving Position Statement, which was workshopped at our 51st ASM in Cairns, has been published in the December issue of *Diving and Hyperbaric Medicine,* as has the SPUMS and United Kingdom Diving Medical Committee (UKDMC) Joint Position Statement (JPS) on return for diving following an episode of Immersion Pulmonary Oedema (IPO). The updated SPUMS and UKDMC JPS on persistent (patent) foramen ovale (PFO) and diving originally published in 2015, will be published in the March issue. This JPS will also include an Appendix with photographs highlighting important quality control issues for bubble contrast echocardiography.

An honour roll of our current and former Life Members can now be found on the SPUMS website here: South Pacific Underwater Medicine Society – SPUMS-Executive Committee.

The ANZHMG Introductory Course in Diving and Hyperbaric Medicine was recently held from17–28 February 2025, again in Fremantle. The course was again a great success with many SPUMS members as faculty. Thanks to the course Convenor Ian Gawthrope and to all those who helped make it happen. The Unsworth-Bennett prize for the highest achiever in the course was awarded to Aaron Victor. The 2025 course was fully subscribed, with a wait list, so I strongly suggest that you register your interest if you are considering attending the course in 2026, dates will again

be from mid to late February 2026 for two weeks.
https://spums.au/index.php/education/spums-approved-courses-for-doctors.

Scholarships for trainees to attend this course are available thanks to the generosity of the Australasian Diving Safety Foundation (ADSF). Please contact John Lippmann at johnl@adsf.org.au for more information. ADSF has also kindly sponsored SPUMS membership for a year for Course participants.

I am pleased to be able to announce the commencement of data entry into the Australasian Decompression Illness (DCI) Registry from 1 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, data will be available for research purposes. This data set will be a useful resource for those seeking to complete their SPUMS Diploma thesis.

A reminder that just prior to the 2025 ASM, nominations for the position of SPUMS President-elect will be sought, with the position being decided at the Bali AGM. The incoming President-elect will have a year to 'learn the ropes' prior to the completion of my second 3-year term as President at the 2026 AGM. I encourage you to consider yourself for this.

Dr Neil Banham
SPUMS President

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 brief synopsis (1–2 pages) of the project and be submitted to president@spums.org.au.

Closing date: 31 December 2025

Dr Neil Banham MBBS, FACEM, DipDHM, ANZCA DipAdvDHM
SPUMS President

SPUMS Facebook page
Find us at:
SPUMS on Facebook

Royal Australian Navy Medical Officers' Underwater Medicine Course

Dates: 13–24 October 2025

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 remains at AUD$1,355 (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)2-9647-5572*
***Fax:** +61 (0)2-9647-511*
***Email:** rajeev.karekar@defence.gov.au*

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 site 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

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 2026, dates will again be from mid to late February 2026 for two weeks.

Dates: 2026 TBC
Venue: Hougoumont Hotel, Fremantle, Western Australia
Cost: AUD$3,200.00 (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.

The

SPUMS
South Pacific Underwater Medicine Society

website is at
https://spums.org.au/

Members are encouraged to login and check it out!
Keep your personal details up-to-date.

The latest issues of *Diving and Hyperbaric Medicine* are via your society website login.

SPUMS Diploma in Diving and Hyperbaric Medicine

Requirements for candidates (May 2014)

In order for the Diploma of Diving and Hyperbaric Medicine to be awarded by the Society, the candidate must comply with the following conditions: They must:
1. Be medically qualified, and remain a current financial member of the Society at least until they have completed all requirements of the Diploma;
2. Supply evidence of satisfactory completion of an examined two-week full-time course in diving and hyperbaric medicine at an approved facility. The list of such approved facilities may be found on the SPUMS website;
3. Have completed the equivalent (as determined by the Education Officer) of at least six months' full-time clinical training in an approved Hyperbaric Medicine Unit;
4. Submit a written proposal for research in a relevant area of underwater or hyperbaric medicine, in a standard format, for approval before commencing the research project;
5. 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 report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–4 above.

In the absence of other documentation, 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 needs to broadly comply with the 'Instructions for authors' available on the SPUMS website https://spums.org.au/ or at https://www.dhmjournal.com/.

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 (EO) 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 peer review process.

Additional information – prospective approval of projects is required

The candidate must contact the EO in writing (or email) to advise of their intended candidacy and to discuss the proposed topic of their research. A written research proposal must be submitted before commencement of the research project.

All research reports must clearly test a hypothesis. Original basic and clinical research are acceptable. Case series reports may be acceptable if thoroughly documented, subject to quantitative analysis and if the subject is extensively researched in detail. Reports of a single case are insufficient. Review articles may be acceptable if the world 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.

It is expected that all research will be conducted in accordance with the joint NHMRC/AVCC statement and guidelines on research practice, available at: https://www.nhmrc.gov.au/about-us/publications/australian-code-responsible-conduct-research-2018, or the equivalent requirement of the country in which the research is conducted. All research involving humans, including case series, 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 proposal is approved prior to commencing research.

Projects will be deemed to have lapsed if:
- The project is inactive for a period of three years; or
- 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 explain to the EO by email why 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 by email to the EO for consideration by the SPUMS Executive. If a project has lapsed, and the candidate wishes to continue with their DipDHM, then they must submit a new application as per these guidelines.

The Academic Board reserves the right to modify any of these requirements from time to time. As of October 2020, the SPUMS Academic Board consists of:

Associate Professor David Cooper, Education Officer, Hobart
Professor Simon Mitchell, Auckland

All enquiries and applications should be addressed to:

Associate Professor David Cooper
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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/

EUBS President's report

Jean-Eric Blatteau

Dear Colleagues

As the President of EUBS, I am pleased to report on the successful hosting of the 3rd International Congress of Underwater and Hyperbaric Medicine, which took place in Muscat, Oman, from 3–6 February 2025. This remarkable event brought together experts from all over the world, including the presidents of EUBS, SPUMS, UHMS, the Editor-in-Chief of *Diving and Hyperbaric Medicine* journal and the Scientific Director of DAN US. This congress highlighted the growing role of hyperbaric medicine in Oman's healthcare system, with the presence of high-level authorities. It was impeccably organised, with excellent scientific presentations and outstanding hospitality. The Kempinski Hotel provided a magnificent setting, and the gala dinner, complete with traditional music and ceremonies, was truly memorable. With its rich culture, breathtaking scenery and world-class dive sites, from my point of view Oman is ideally placed, both geographically and logistically, to host an international TRICON congress in the future.

It will my great pleasure to meet you all again at the EUBS 2025 Congress in Helsinki in early September. Finland has long forged its identity through resilience and innovation, from the epic Kalevala to the music of Jean Sibelius, whose works have symbolised national unity. Personally, I am a great fan of his symphonic works. Today, this Finnish spirit continues to thrive in European leadership in technology, sustainable energy and design, always with a deep respect for nature. The country is also a center of digital innovation, gaming and creative industries, supported by an education system that fosters creativity and forward-thinking solutions.

Finland holds a special place in the history of diving, being home to one of the first and very strange, almost surreal, forerunners of the diving suit (18th century, Raahe Museum). This makes it an ideal place to meet and explore the latest advances in diving and hyperbaric medicine.

At a time of rapid technological advancement, its hoped we will discuss the growing role of artificial intelligence in our field. AI could prove invaluable in physiological modeling, decompression algorithms, risk prediction and automated data analysis, as well as in scientific writing and translation. These innovations offer exciting opportunities to strengthen research, improve clinical decision-making, and push the boundaries of our specialty.

I look forward to welcoming you all to Helsinki for an inspiring and forward-thinking congress.

Jean-Eric Blatteau
President
European Underwater and Baromedical Society (EUBS)

Figure
To illustrate the use of AI, I propose this Dall-E creation based on the announcement of our congress

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.

EUBS Notices and News

Annual Scientific Meeting 2025

After the great success of its 48th edition in Brest, France, the EUBS Annual Scientific Meeting will move to Helsinki (Finland) for our 49th meeting which will take place from 2–6 September 2025.

Finland has been recognised as the world's happiest country by the UN World Happiness Report for an impressive seven consecutive years. As a member of the European Union, Finland is welcoming and English-friendly, making communication easy despite the complexity of the Finnish language.

Finland is renowned for its beautiful scenery and clean environment. It is the most forested country in Europe and is often called the "*land of a thousand lakes*" though "*tens of thousands*" would be more accurate. Summers in Finland are marked by endless daylight, along with numerous events and festivals across the country.

Helsinki, the capital of Finland, is the northernmost capital in the European Union. It has over 681,000 inhabitants and is nearly 480 years old. The central Helsinki area is compact, making it easy to explore on foot. The city's coastal location offers numerous islands and coastlines to visit, along with plenty of greenery and parks, including a large central park that gradually transitions into forested areas as you move farther from the city center.

Reaching Finland is convenient, with direct flights available from major European cities, as well as destinations in Asia and North America. Travelers from Central Europe can also reach Finland by ferry (or train + ferry). Ferries from Estonia, Germany, Poland, or Stockholm provide a picturesque and relaxing journey.

EUBS is delighted to welcome you to participate in this meeting and help contribute to its success. If you have been monitoring the conference website http://www.eubs2025.com you will have noticed that the 'Registration' and 'Abstract Submission' are now open.

Important deadlines are:
24 April 2025 – end of Early Bird Registration period;
24 April 2025 – Abstract Submission deadline.

Get ready to write your abstract, register, and don't forget to bring your partner and kids along. We'll reconnect sooner than you expect.

If you would like to apply for a student Travel Grant for the meeting, please read the rules and procedures here: https://www.eubs.org/?page_id=914.

EUBS Executive Committee

This year, we have to elect a new Member-at-Large for ExCom, and also a new Vice-President. While both roles are important to our Society, the Vice-President is a particularly important function, as she/he/they are also the President-Elect. Nominations for both positions can be sent by simple 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 people nominated and discuss the roles with them further. Then, in early June, a shortlist of candidates will be put up 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 2025.

If you do not wish to present yourself, why not nominate someone else? Suggestions are welcome at the same email address above.

EUBS Affiliate Society agreements

For 2025, the agreement has been renewed with the following scientific societies 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 (https://sukelluslaakarit.yhdistysavain.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 delve 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's 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 on 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 email to oxynet@eubs.org. If you can collect information for more than one center in your area or country, please do.

Golden Trident Award

On 21 February 2025, during a ceremony held at the EUDI Dive Show in Bologna, Italy, two members of EUBS ExCom have received the "*Tridente d'Oro*" (Golden Trident), awarded by the International Academy for Underwater Sciences and Techniques (AIST). The AIST is based in Rome at the CMAS – World Confederation of Underwater Activities by which it is recognised and of which it is a member.

The Golden Trident Award was created in 1960 and considered the 'Nobel Prize of underwater activities'. It is in fact the highest award of excellence at a global level for particularly meritorious activities carried out in scientific, technical, technological and hyperbaric underwater activities; popular and artistic; sports and exploratory.

Since the first edition in 1960, over 200 famous people have been awarded the Golden Trident, such as Jacques-Yves Cousteau (1961), Jacques Piccard, Enzo Maiorca (1964), Jacques Mayol (1971). Scientists, researchers, pioneers, journalists and professors who represent excellence in their field at an international level, such as Olivier Isler (2011), Jarrod Jablonski (2015), Sylvia Earle (2017), Michael Menduno (2021) have been elected.

Doctors committing their expertise to decompression theory have also been honored, a recognition of their instrumental role in increasing underwater activity globally. The first physicians to be awarded the prize were Swiss Hannes Keller and French Jacques Piccard (1961), followed by Italian Roberto Galeazzi (1962). Albert Bühlmann was recognised as an Academician in 1991. Previous EUBS members who have received the Award are Pasquale Longobardi (2009), Alessandro Marroni (2014) and Costantino Balestra (2022).

Now, Jacek Kot (Poland; EUBS Past President) and Peter Germonpré (Belgium, EUBS Honorary Secretary) have joined this prestigious list.

Courses and meetings

Scott Haldane Foundation

As an institute dedicated to education in diving medicine, the Scott Haldane Foundation has organized more than 320 courses all over the world, over the past 33 years. SHF is targeting on an international audience with courses worldwide.

Below the schedule of upcoming SHF-courses in 2025.

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).

2025

9–10 May	Level 1 course Diving Medicine part 1 Zeist The Netherlands
16–17 May	Level 1 course Diving Medicine part 2 Amersfoort The Netherlands
17 May	Refresher course Diving Medical in practise Amersfoort The Netherlands
13–14 June	31st in-depth course Diving Medicine "*Hear, smell, feel*" (level 2d) The Netherlands
8–15 November	In-depth course What a Diving doctor MUST know (level 2d) Bali, Indonesia
15–22 November	In-depth course What a Diving doctor MUST know (level 2d) Bali, Indonesia
On request	Internship HBOt (level 2d) NL/Belgium

The course calendar will be supplemented regularly. For the latest information see: www.scotthaldane.org.

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. This should be available in the next month, so keep an eye out.

Diving and Hyperbaric Medicine: Instructions for authors

(Short version – updated June 2024)

Diving and Hyperbaric Medicine (DHM) is the combined journal of the South Pacific Underwater Medicine Society (SPUMS) and the European Underwater and Baromedical Society (EUBS). It seeks to publish papers of high quality on all aspects of diving and hyperbaric medicine of interest to diving medical professionals, physicians of all specialties, scientists, members of the diving and hyperbaric industries, and divers. Manuscripts must be offered exclusively to *Diving and Hyperbaric Medicine* unless clearly authenticated copyright exemption accompanies the manuscript. All manuscripts will be subject to peer review. Accepted contributions will also be subject to editing.

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***Journal information*:** info@dhmjournal.com

Contributions should be submitted electronically by following the link:
http://www.manuscriptmanager.net/dhm

There is on-screen help on the platform to assist authors as they assemble their submission. In order to submit, the corresponding author needs to create an 'account' with a username and password (keep a record of these for subsequent use). The process of uploading the files related to the submission is simple and well described in the on-screen help provided.

Types of articles: DHM welcomes contributions of the following types:

Original articles, Technical reports and Case series: up to 3,000 words is preferred, and no more than 30 references (excluded from word count). Longer articles may be considered at the editor's discretion. These articles should be subdivided into the following sections: an **Abstract** (subdivided into Introduction, Methods, Results and Conclusions) of no more than 250 words (excluded from word count), **Introduction, Methods, Results, Discussion, Conclusions, References, Acknowledgements**, **Funding** sources and any **Conflicts of interest**. **Legends/captions** for illustrations, figures and tables should be placed at the end of the text file.

Review articles: up to 5,000 words is preferred and a maximum of 50 references (excluded from the word count); include an informative **Abstract** of no more than 300 words (excluded from the total word count); structure of the article and abstract is at the author(s)' discretion.

Case reports, Short communications and **Work in progress reports:** maximum 1,500 words, and 20 references (excluded from the word count); include an informative **Abstract** (structure at author's discretion) of no more than 200 words (excluded from the word count).

Educational articles, Commentaries and **Consensus reports** for occasional sections may vary in format and length but should generally be a maximum of 2,000 words and 15 references (excluded from word count); include an informative **Abstract** of no more than 200 words (excluded from word count).

Letters to the Editor: maximum 600 words, plus one figure or table and five references.

The journal occasionally runs **'World as it is'** articles; a category into which articles of general interest, perhaps to divers rather than (or in addition to) physicians or scientists, may fall. This is particularly so if the article reports an investigation that is semi-scientific; that is, based on methodology that would not necessarily justify publication as an original study. Such articles should follow the length and reference count recommendations for an original article. The structure of such articles is flexible. The submission of an abstract is encouraged.

Supplements to a particular issue are occasionally published for purposes deemed appropriate by the editor. These may accommodate articles / treatises that are too long for the main journal or collections of articles on thematic areas. There is no open portal for submission of such material and any plans or suggestions for supplements should be discussed with the Editor before writing.

Formatting of manuscripts: All submissions must comply with the following requirements. **Manuscripts not complying with these instructions will be suspended** and returned to the author for correction before consideration. Guidance on structure for the different types of articles is given in the full version of these instructions.

Documents on DHM website https://www.dhmjournal.com/index.php/author-instructions

The following pdf files are available on the DHM website to assist authors in preparing their submission:

Instructions for authors (full version 2024 – this document)
DHM Keywords 2023
DHM Mandatory submission form 2024
Trial design analysis and presentation
Conflict of interest statement
English as a second language
Guideline to authorship in DHM 2015
Samples of formatted references for authors of journal articles (last reviewed 2024)
Recommendations for the conduct, reporting, editing, and publication of scholarly work in medical journals 2024
Helsinki Declaration revised 2013
Is ethics approval needed?

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