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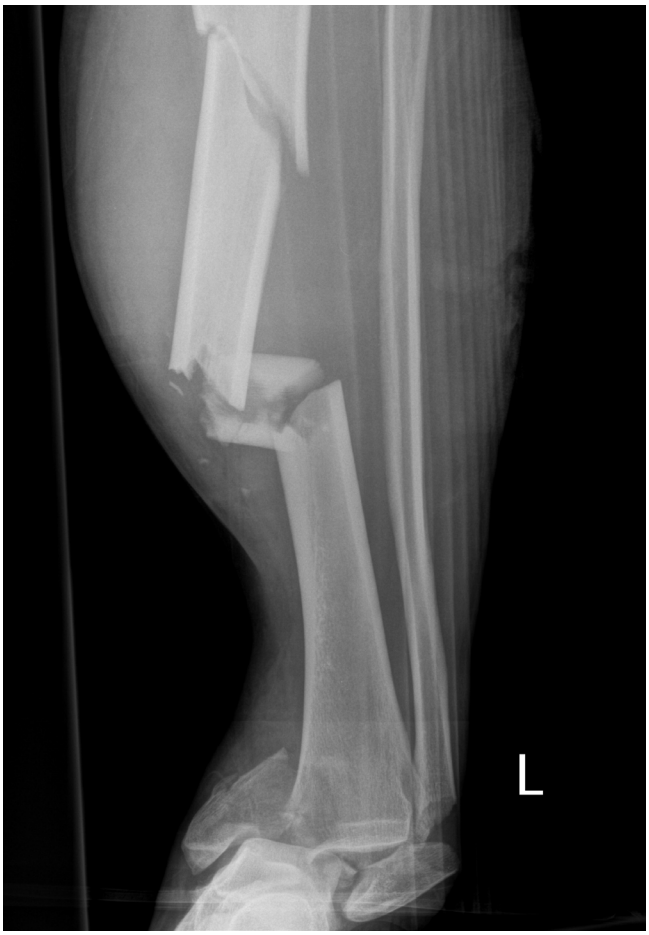

HBOT for lower limb trauma: the HOLLT RCT

Pressure effects on dentin bond strength

Lung function after a single heliox dive

HBOT as primary treatment for sudden hearing loss

Pulmonary imaging before HBOT

HBOT improves skin elasticity after irradiation

Dysbarism in a breath-hold diver

Takotsubo cardiomyopathy after IPO

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PURPOSES OF THE SOCIETIES

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

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DIVING AND HYPERBARIC MEDICINE

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The Editor's offering

The highlight of the September 2022 issue is the publication of the Hyperbaric Oxygen for Lower Limb Trauma (HOLLT) randomised controlled study. This investigation was inspired by, and built on, the small randomised study of hyperbaric oxygen treatment (HBOT) in crush injuries published by Bouachour and colleagues in 1996. The HOLLT study randomised patients with open tibial injury to standard trauma care or standard care plus 12 sessions of HBOT starting within 48 hours of injury. The study reports a strong trend to improvement in the pre-defined composite end-point (post-operative infection and/or necrosis), and significant reductions in the incidence of tissue necrosis and the occurrence of both infection and necrosis. Other secondary outcomes such as wound healing, absence of delayed union, and physical function were also significantly improved in the HBOT group.

The HOLLT study is an exciting and important development for our field in being a very well-conducted pragmatic trial showing improved outcomes in a surgical indication known to have a high incidence of complications with serious implications for patients. The study hypothesis has strong mechanistic rationale and biological plausibility, and builds on previously published data that were also supportive. The multicentre and multinational nature of the participating hospitals (located in Australia, Asia, North America and Europe) provides a strong basis for claiming that the results are generalisable. Implementation of HBOT care in serious trauma requires an expert team, strong collaborations with surgical colleagues, and colocation of hyperbaric and surgical services in a major trauma centre. Nevertheless, the HOLLT study demonstrates that these elements of a care map can gel together, resulting in improved outcomes for patients.

I am grateful to the HOLLT authors for choosing to publish this study in their 'own' journal.

Another highlight of the September issue is the review article by Connor Brenna and colleagues which addresses the role of pulmonary imaging prior to HBOT with a general aim of identifying patients who might be at risk of pulmonary barotrauma. There is long standing controversy around this topic, and the article provides a comprehensive review of relevant evidence and thoughtful interpretation of its implications. Although diving has a different risk profile (in general, participants with less risk undertaking an activity with more risk), much of the discussion Brenna's article has some relevance to diving. Thus, those with an interest more weighted toward diving than hyperbaric medicine will still find this article interesting.

Also in this issue there is a retrospective study by Andrijana Včeva and colleagues which appears to be the first to consider HBOT as the primary intervention in idiopathic sudden sensorineural hearing loss. Other relevant studies have used HBOT as an adjunct to standard care strategies such as steroid administration. Use of HBOT was associated with improvements that were probably greater than expected through the recognised spontaneous improvement that occurs in some patients. The observational design of the study limits certainty on this matter, but it is nevertheless an interesting and novel report. There is a promising pilot study suggesting a positive effect of HBOT on skin elasticity in irradiated breast tissue. This is exciting because it highlights another non-invasive objective outcome measure for such studies. Elsewhere there are studies of the effect of pressure changes on bond strength in different dental resin composites, the effect of a single deep heliox dive on lung function, and case reports pertaining to dysbarism in a breath hold diver and takotsubo cardiomyopathy in a scuba diver.

At the time of writing I have just returned from the EUBS meeting in Prague. This was a fabulous opportunity to reconnect with European colleagues for the first time in three years. The meeting was extremely well organised and attended, with a stimulating program of presentations and posters. It was also a privilege to visit this beautiful city where the people were warm and friendly. After all the frustrations of having the meeting postponed twice the organising team are to be congratulated for their resilience. I am looking forward to next year's meeting in Portugal, and SPUMS will also hold its first fully in-person meeting for three years in 2023.

Finally, in what seems to be becoming an all too regular occurrence in 2022, this editorial must acknowledge the passing of yet another icon of our field, Professor Peter Bennett, on 11 August 2022. It is difficult to decide what Peter was most famous for, but his seminal textbook Bennett and Elliott's Physiology and Medicine of Diving is without doubt the most influential work ever published in diving medicine, and it links him with two other legends of the field we also lost in 2022; co-editor of their eponymous book Professor David Elliott, and Professor Alf Brubakk who edited the 5th and most recent edition. DHM will carry an obituary for Professor Bennett as our final article of the year in the December issue.

Professor Simon Mitchell
Editor, Diving and Hyperbaric Medicine Journal

Front cover photo:
Complex compound tibial fracture. Photo courtesy of Dr Ian Millar.

Original articles

Hyperbaric Oxygen for Lower Limb Trauma (HOLLT): an international multi-centre randomised clinical trial

Ian L Millar[1,2], Folke G Lind[3], Karl-Åke Jansson[4], Michal Hájek[5,6], David R Smart[7,8], Tiago D Fernandes[9], Rosemary A McGinnes[2], Owen D Williamson[2], Russell K Miller[10], Catherine A Martin[2], Belinda J Gabbe[11,12], Paul S Myles[13], Peter A Cameron[11], for the HOLLT investigator group

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Keywords
Fractures; Hyperbaric oxygen treatment; Injuries; Musculo-skeletal; Orthopaedics; Outcome; Wounds

Abstract
(Millar IL, Lind FG, Jansson K-A, Hájek M, Smart DR, Fernandes TD, McGinnes RA, Williamson OD, Miller RK, Martin CA, Gabbe BJ, Myles PS, Cameron PA. Hyperbaric Oxygen for Lower Limb Trauma (HOLLT): an international multi-centre randomised clinical trial. Diving and Hyperbaric Medicine. 2022 30 September;52(3):164–174. doi: 10.28920/dhm52.3.164-174. PMID: 36100927.)

Introduction: Hyperbaric oxygen treatment (HBOT) is sometimes used in the management of open fractures and severe soft tissue crush injury, aiming to reduce complications and improve outcomes.

Methods: Patients with open tibial fractures were randomly assigned within 48 hours of injury to receive standard trauma care or standard care plus 12 sessions of HBOT. The primary outcome was the incidence of necrosis or infection or both occurring within 14 days of injury.

Results: One-hundred and twenty patients were enrolled. Intention to treat primary outcome occurred in 25/58 HBOT assigned patients and 34/59 controls (43% vs 58%, odds ratio (OR) 0.55, 95% confidence interval (CI) 0.25 to 1.18, $P = 0.12$). Tissue necrosis occurred in 29% of HBOT patients and 53% of controls (OR 0.35, 95% CI 0.16 to 0.78, $P = 0.01$). There were fewer late complications in patients receiving HBOT (6/53 vs 18/52, OR 0.22, 95% CI 0.08 to 0.64, $P = 0.007$) including delayed fracture union (5/53 vs 13/52, OR 0.31, 95% CI 0.10 to 0.95, $P = 0.04$). Quality of life measures at one and two years were superior in HBOT patients. The mean score difference in short form 36 was 2.90, 95% CI 1.03 to 4.77, $P = 0.002$, in the short musculoskeletal function assessment (SMFA) was 2.54, 95% CI 0.62 to 4.46, $P = 0.01$; and in SMFA daily activities was 19.51, 95% CI 0.06 to 21.08, $P = 0.05$.

Conclusions: In severe lower limb trauma, early HBOT reduces tissue necrosis and the likelihood of long-term complications, and improves functional outcomes. Future research should focus on optimal dosage and whether HBOT has benefits for other injury types.

Introduction

Hyperbaric oxygen treatment (HBOT) has long been advocated for acute traumatic injury but is little used in practice.[1–4] Animal models, case series and two small randomised trials suggest potential benefit but the evidence to date has been inadequate to support wider use of this treatment in the setting of severe trauma.[5–11]

Complex open fractures with severe soft tissue injury are associated with complication rates ranging from 10% to 100%.[12,13] Late complications such as deep infection and delayed union often require multiple additional interventions, adding to the burden of hospitalisation and disability that follows orthopaedic injury.[14–16]

Hyperbaric oxygen has therapeutic effects that should be of value in such injuries. These include anti-infective actions that are additive or synergistic with antibiotics, reductions in oedema and ischaemic necrosis, mitigation of reperfusion injury, and the potential to accelerate healing of bone, nerve, tendon, muscle, and skin.[8,17–26]

We conducted an international multicentre clinical trial of early HBOT in patients suffering an open tibial fracture with severe associated soft tissue injury.

Our hypothesis was that adding HBOT to the care of complex open tibial fractures would reduce the rates of acute wound necrosis and/or infection and that this would be associated with improved late outcomes.

Methods

Human research ethics approval was given by The Alfred Health Human Ethics Committee (206/04) and the Monash University Human Research Ethics Committee (CF07/4208). Approval was also obtained from the institutional human research ethics committee at each participating site. The protocol was registered with ClinicalTrials.gov (NCT 00264511) and on the Australian New Zealand Clinical Trials Registry (12607000559415).

STUDY DESIGN

This was an open label, pragmatic randomised trial with blinded outcome arbitration.

The study was conducted according to our previously published protocol[27] at 10 hospitals located in Australia, Sweden, the Czech Republic, Portugal, Chile, Italy, Austria, India and the United States.

There was no involvement of patients or the public in the design processes, conduct, oversight, or analysis of this trial.

INCLUSION AND EXCLUSION CRITERIA

Adult trauma patients with an open tibial fracture were eligible if their injuries were judged by the treating surgeon to be sufficiently severe to carry a high risk of major complications. Gustilo 3 grading was used as a guideline noting that soft tissue injury severity is a qualitative judgement and host factors play a part in risk such that some Gustilo 2 fractures might be considered 'high risk'.[12] Patients were excluded only if other injuries or trauma care requirements precluded HBOT, or if major contraindications to HBOT were identified. The enrolment window was 48 hours from time of injury.

ENROLMENT AND RANDOMISATION

Consent for participation was sought from patients, or for non-competent patients from a third party as allowed by local law and human research ethics committee approvals. Randomisation was via internet access to computer-based assignment of the intervention group and a study identification number, stratified by site and with treatment assignment allocated one to one in randomly selected and non-viewable blocks of six or eight.

INTERVENTIONS

Trauma care and HBOT sessions were provided to participants in accordance with the practices of each site, without any trial-related standardisation.

Hyperbaric oxygen treatment sessions involved pressurisation to 243 kPa or 284 kPa (2.4 or 2.8 atmospheres absolute) with total oxygen breathing durations of 80 to 100 minutes. Both multiplace and monoplace chambers were utilised. The trial protocol called for HBOT-assigned patients to receive 12 treatment sessions over approximately nine days, commencing as soon as possible after enrolment and after the initial fracture and wound management surgery.

DATA COLLECTION AND BLINDING

Baseline health data and demographics, injury characteristics and data on initial surgical management were collected at or soon after enrolment. Early-outcome data were nominally collected at 14 days post injury with a range of 12–15 days considered acceptable. Follow up was conducted at three, six, nine, 12, 18, and 24 months to collect pre-defined longer-term events and outcomes.

Data were entered into a centralised database via a secure internet-based interface which tracked entries and modifications. The database incorporated data validation and user assistance features. Access to each patient's data was restricted to the site investigator or data collector entering their own patient's data, and the project manager. Surgeons

initially operating upon patients were blinded to the trial group allocation. Clinicians and data collectors were not subsequently blinded.

Final fracture grading and all outcome measures involving qualitative scoring were adjudicated independently by two experienced orthopaedic specialists blinded to patient identity, site and trial group allocation. Investigators other than the project manager were unable to access the randomisation allocation and hyperbaric treatment section of the database until after the data set was 'locked' and provided to the study biostatisticians following closure of follow-up data entries.

OUTCOME MEASURES

The outcome measures reported were defined *a priori* and determined from the collected patient data according to procedures and guidance notes that are further detailed in the hyperbaric oxygen in lower limb trauma (HOLLT) protocol[27] and the statistical analysis plan. All derived, scored and arbitrated outcomes were determined with blinding to patient identity, intervention group allocation and the enrolling site. Where the two orthopaedic specialists arbitrating outcomes were not initially in agreement, they conferred to come to a decision. The primary outcome was the occurrence of infection or necrosis or both during the period from initial surgery to the 14-day assessment date. This was determined as follows. Enrolling centres were asked to record their determination of clinical episodes of 'infection' and 'necrosis' according to the study criteria. The definitive determination of primary outcome events was confirmed after blinded review of all available data including surgical debridements, other surgical findings and procedures, antibiotics prescribed, microbiology, wound data and photos where available. The US Centre for Disease Control wound infection guidelines were used in assessing infection events. The trial outcome of necrosis excluded minimal wound edge necrosis and debridements to 'clean up wound edges'. When patients were discharged early, data from the three-month review were also reviewed.

The components of the primary outcome were also assessed separately in accordance with our study hypothesis that HBOT would reduce the rates of acute wound necrosis and/or infection. Other pre-specified early secondary outcomes included identification of those acute complications that were clinically severe according to *a priori* guidelines. Characteristics of clinical care provided were assessed, including whether HBOT commenced within 24 hours or not and whether the number of HBOT sessions achieved met the arbitrarily chosen six that was defined as a 'therapeutic course'. Multivariate analysis was undertaken to assess whether there might be any inter-group difference after adjustment for any risk factor differences between groups based on injury severity.

Late outcome data included measures of wound healing, infections, bone grafts and non-union assessed at three-month intervals up to 12 months after injury. Radiological image files and records of hospital re-admissions and surgical procedures were also recorded. These data were reviewed and arbitrated by the blinded adjudicators as meeting or not meeting criteria for being recorded as a 'problem wound', a 'deep infection', 'osteomyelitis', or 'delayed union' using pre-determined guidelines. 'Problem wounds' were identified by the blinded assessors considering the same guidance factors used to determine 'clinically severe' acute infections and necrosis, as well as any prolonged hospitalisation or re-admission, requirement for additional surgical procedures and whether an open wound was associated with late wound related deep infections and necrosis. 'Osteomyelitis' was recorded if the treating centre had made that diagnosis and this was confirmed by checking for antibiotic use and surgical procedures. Determinations of 'delayed union' were based upon clinician diagnosis of non-union at nine or 12 months or a bone graft having been performed or scheduled for non-union or pseudo-arthrosis.

The reported measure 'incidence of significant late complications' is a composite of the above measures (occurrence of either a problem wound or a deep infection or osteomyelitis or delayed union or any combinations).

Questionnaire-based functional and quality of life assessments were administered at 12 and 24 months using the language specific short form 36 (SF36v2) and the lower limb components of the short musculoskeletal function assessment (SMFA).[28]

SAMPLE SIZE AND STATISTICAL ANALYSIS

An original sample size of 250 participants was selected to provide 80% power to detect a reduction in the incidence of the composite outcome of acute infection and/or necrosis from 30% to 15% at $P = 0.05$. The analysis of outcome data was undertaken in accordance with a pre-decided statistical analysis plan (see supplementary material).

The primary analysis was on an unadjusted intention-to-treat basis. Secondary outcomes analysis included using mixed effects logistic regression to adjust for any potential differences in risk of complications between treatment allocation groups, with injury severity grading as a fixed effect and recruiting centre as a random effect. Centres that recruited fewer than 10 patients were combined as a single 'other centre' to avoid instability in the model estimation procedure. The injury severity factors adjusted for were Gustilo grade, severe contamination and muscle loss.

Time to surgical wound closure and time to definitive fracture fixation were compared using a competing risk survival analysis with amputation as a competing risk.

For the SF36v2, SMFA and pain scores, mixed effects linear regression models, accounting for time since injury, were used.

Stata Statistical Software: Release 13 (StataCorp LP, College Station TX, USA) was used to analyse the data. A two-sided *P*-value < 0.05 was considered statistically significant with no adjustment made to *P*-values for the assessment of multiple secondary outcomes since they were pre-specified.

CHANGES TO TRIAL DESIGN

The trial was originally conceived as enrolling patients within 24 hours of injury. This time window was increased to 48 hours in response to difficulties in achieving early enrolments.

A futility analysis was performed by the data safety and monitoring committee after only 44 patients were enrolled in the first 3.5 years of the study. Without un-blinding, this identified a higher-than-expected incidence of recorded acute complications, leading to the prediction that a revised enrolment target of 120 subjects had reasonable prospects to demonstrate significant study outcomes.

STUDY SITE CHARACTERISTICS

Most sites were academic hospitals associated with Level 1 trauma centres. All hyperbaric centres were physically and organisationally integrated into a hospital.

Results

A total of 120 patients were enrolled over the period 13 February 2007 to 18 August 2014.

PATIENT CHARACTERISTICS

The group allocation ratio was exactly one to one. One patient allocated to the HBOT group had bilateral eligible fractures and these were evaluated as one injury, with the worst outcomes used for analysis.

There were no significant differences between the groups in patient or injury characteristics (Table 1).

SURGICAL MANAGEMENT

The characteristics of initial surgery performed did not differ between groups (Table 2).

There was no difference in time to surgical wound closure (hazard ratio 1.42, 95% confidence interval [CI] 0.84 to 2.39; $P = 0.19$) or time to definitive internal fixation (hazard ratio 1.31, 95% CI 0.83 to 2.07; $P = 0.25$).

For more information on surgical management and timing, see *sections S5, S8, S9 and S12 in the online supplementary material .

LOSSES AND EXCLUSIONS

Two patients in the HBOT group withdrew from the study. One withdrew prior to any treatment and one after an initial HBOT session. Both declined follow-up. One patient in the control group had insufficient data recorded for meaningful analysis. Acute outcomes are therefore reported for 117 (98%) patients. A CONSORT diagram appears on page 41 of the supplementary material.

HYPERBARIC OXYGEN TREATMENT

In total, 619 HBOT sessions were provided to 65 enrolled patients during the conduct of the HOLLT trial. The median time to commencing HBOT was 21.6 h (interquartile range 18.7 to 28.6), with 37 patients (65%) receiving their first session within 24 h of enrolment. There was no significant difference in clinically severe complications for those commencing treatment on the first versus the second post injury day (see supplementary Table S7).

Of 60 patients allocated to HBOT, 51 (85%) received the six or more HBOT sessions that were *a priori* considered a therapeutic course. Seven (12%) were intolerant, with three failing to complete their first pressurisation and four receiving only one treatment. One patient underwent amputation after five sessions for complications of a severe Gustilo 3C fracture and another with a Gustilo 2 fracture refused further treatments after receiving four sessions (see supplementary Table S22).

PRIMARY OUTCOME (INTENTION TO TREAT)

We found no statistically significant difference between groups in the incidence of the composite primary outcome of one or more acute phase complications (infection and/or necrosis), with 25 events (43%) in the HBOT group and 34 events (58%) in the control group (odds ratio [OR] 0.55, 95% CI 0.25 to 1.18; $P = 0.12$).

PRIMARY OUTCOME COMPONENTS

Necrosis was reduced in the HBOT group (29% vs 53%; OR 0.35, 95% CI 0.16 to 0.78; $P = 0.01$).

Footnote: *Supplementary material is available on the DHM Journal website: https://www.dhmjournal.com/images/Appendices/52_3/Millar_HOLLT_Supplementary_material_2022-523_2.pdf

Table 1
Characteristics of patients enrolled and randomised; data are *n* (%) or median (interquartile range); BMI – body mass index; HBOT – hyperbaric oxygen treatment

Parameter	HBOT (*n* = 60)	Control (*n* = 60)
Age (years)	40 (31.0–55.5)	40 (27.0–53.0)
Male	50 (83%)	47 (78%)
BMI kg·m^{-2}	26.5 (23.7–29.4)	25.2 (23.7–29.6)
Current Smoker	18 (30%)	15 (26%)
Diabetes	2 (3%)	2 (3%)
Injury severity score	13.5 (9–18)	10 (9–18)
Fracture location(s)		
Plateau	5 (8%)	6 (10%)
Proximal shaft	13 (22%)	7 (12%)
Mid shaft	21 (35%)	21 (35%)
Distal shaft	30 (50%)	31 (52%)
Pilon / Ankle joint	7 (12%)	9 (15%)
Multi-site	16 (27%)	14 (23%)
Fracture type		
Transverse	16 (27%)	12 (20%)
Spiral	7 (12%)	5 (8%)
Segmental	7 (12%)	5 (8%)
Comminuted	39 (65%)	43 (72%)
Wound characteristics		
Signif. contamination	14 (23%)	7 (11%)
Skin loss	26 (43%)	23 (38%)
Muscle loss	15 (25%)	9 (15%)
Bone loss	13 (22%)	10 (17%)
Arbitrated Gustilo grading		
Grade 1	1 (2%)	2 (3%)
Grade 2	13 (22%)	11 (18%)
Grade 3A	27 (45%)	28 (47%)
Grade 3B	16 (27%)	15 (25%)
Grade 3C	3 (5%)	3 (5%)

There was no statistically significant difference in the acute infection rate (22% vs 32%; unadjusted OR 0.61, 95% CI 0.26 to 1.43; $P = 0.26$).

Fewer patients in the HBOT group experienced the problem of having both infection AND necrosis (9% vs 27%; unadjusted OR 0.23, 95% CI 0.08 to 0.70; $P = 0.01$).

SECONDARY OUTCOMES

The primary outcome measures were analysed with multivariate adjustment for the baseline injury severity factors (Gustilo grade, contamination and hospital) in accordance with the statistical analysis plan. The statistical relationship between HBOT allocation and the incidence of acute infection and/or necrosis strengthened but remained non-significant (adjusted OR 0.43, 95% CI 0.17 to 1.09; $P = 0.08$), and the same occurred with respect to infection (adjusted OR 0.46, 95% CI 0.17 to 1.28; $P = 0.14$). The association between HBOT allocation and reduced necrosis was stronger (adjusted OR 0.28, 95% CI 0.11 to 0.72; $P = 0.008$), as was the association between HBOT allocation and the combination of infection and necrosis (adjusted OR 0.16, 95% CI 0.04 to 0.61; $P = 0.007$).

There were no differences in any of the other planned acute secondary outcomes (Table 3). There were fewer severe infections and severe necrosis events in the HBOT group but this was not statistically significant. Further detail is provided in supplementary material (S11).

At 12 months, nine of 117 (7.7%) patients had been lost to follow-up. The four patients who underwent early amputation were excluded from the following analysis of late limb injury complications.

Over the 14 day to 12 month period, patients receiving HBOT were less likely to suffer a defined late complication (6/52 vs 18/52; 12% vs 35%; OR 0.24, 95% CI 0.08 to 0.68; $P = 0.007$).

Table 2

Characteristics of acute care including initial (blinded) surgery; data are n (%) or median (interquartile range); *multiple methods used in some cases; ICU – intensive care unit; IM – intramedullary; HBOT – hyperbaric oxygen treatment

Parameter	HBOT (*n* = 60)	Control (*n* = 60)
Time from injury to surgery (hours)	5.4 (3.6–8.3)	5.1 (3.2–7.3)
Fasciotomy performed	6 (10%)	5 (8%)
Debridement performed	47 (78%)	43 (72%)
Major skin excision	5 (8%)	3 (5%)
Significant deep debridement	10 (17%)	9 (15%)
Length of stay (days)	15 (10–22)	15 (10–24)
ICU admission	10 (17.5%)	19 (32.2%)
Fracture management*		
Intramedullary nail	18 (30%)	19 (32%)
Internal fixation (other than IM nail)	13 (22%)	14 (23%)
External fixation	38 (63%)	37 (62%)
Splint	7 (12%)	7 (12%)

Table 3

Acute outcomes (up to 14-day assessment); no adjustments made for multiple measures of pre-specified secondary outcomes; *predefined primary outcome measure 'infection AND/OR necrosis'; **fasciotomy performed at surgery subsequent to initial surgery

Outcome components	HBOT (*n* = 58)	Control (*n* = 59)	OR [95% CI] *P*-value
Primary outcomes			
≥ 1 wound complication*	25 (43%)	34 (58%)	0.55 [0.25 to 1.18] 0·12
Necrosis	17 (29%)	31 (53%)	0.35 [0.16 to 0.78] 0·01
Infection	13 (22%)	19 (32%)	0.61 [0.26 to 1.43] 0·26
Infection AND necrosis	5 (9%)	16 (27%)	0.23 [0.08 to 0.70] 0·01
Secondary outcomes			
≥ 1 wound complication – multivariate baseline risk adjusted			0.4 [0.17 to 1.09] 0.08
Necrosis – multivariate baseline risk adjusted			0.28 [0.11 to 0.72] 0.008
Infection – multivariate baseline risk adjusted			0.46 [0.17 to 1.28] 0.14
Clinically severe necrosis	12 (21%)	17 (29%)	0.61 [0.25 to 1.48] 0.28
Clinically severe infection	9 (16%)	14 (24%)	0.58 [0.30 to 1.50] 0.26
Fasciotomy required**	2	3	
Amputation	1	3	
Subsequent surgery – patients	39 (67%)	33 (56%)	
Subsequent surgery – procedures (mean number per patient)	96 (2.5)	114 (3.3)	

Fewer patients receiving HBOT were observed to have an open wound at each of the three-monthly reviews. At six months, only one HBOT patient had an open wound, compared with 10 in the control group. There were no wounds in HBOT patients that were arbitrated as 'problem wounds' by blinded assessors whilst there were seven such problem wounds identified in the control group. The odds of wounds being healed at review over the 12 months were higher for HBOT patients compared to controls (mixed effects logistic regression OR 1.65, 95% CI 1.07 to 2.53; $P = 0.02$).

Delayed union was lower in the HBOT group; 10% vs 25% (OR 0.31, 95% CI 0.10 to 0.95; $P = 0.04$) (Table 4).

HEALTH-RELATED QUALITY OF LIFE OUTCOMES

Complete SF36v2 and SMFA lower limb subscale data were available for 74 (62%) patients at 12 months (35/60 HBOT, 39/60 Control) and for 60 (50%) at 24 months (29/60 HBOT, 31/60 Control). Assessments were not available from patients who declined participation and where enrolling centre resources did not enable administration of the

Table 4

Twelve month arbitrated outcomes (day 14 through to 12 months); no adjustment for multiple measures of pre-specified secondary outcomes; *delayed union AND/OR deep infection AND/OR problem wound; **not able to be analysed in a manner consistent with the *a priori* plan to determine odds ratios due to zero number in HBOT group (Fishers exact test statistic 0.006); ***non-united at nine or 12 months and/or bone graft performed for non-union or pseudarthrosis (early amputation cases not included); HBOT – hyperbaric oxygen treatment; N/A – not applicable; OR – odds ratio

Complication	HBOT	Control	OR [95% CI] *P*-value
≥ one serious complication*	6/52 (12%)	18/52 (35%)	0.24 [0.08 to 0.68] 0.007
Problem wound	0/53	7/52 (13%)	OR analysis N/A**
Deep infection	4/53 (8%)	8/52 (15%)	0.43 [0.12 to 1.56] 0.20
Delayed union***	5/52 (10%)	13/51 (25%)	0.31 [0.10 to 0.95] 0.04
Closed wounds at review			
14 days	37/58 (64%)	34/59 (56%)	
3 months	44/52 (87%)	39/52 (77%)	
6 months	50/51 (98%)	38/48 (79%)	
9 months	48/49 (98%)	38/44 (86%)	
12 months	43/44 (98%)	38/41 (93%)	
Mixed effects logistic regression comparison over 12 months: OR 1.65, 95% CI 1.07 to 2.53; *P* = 0.02			

Table 5

Patient reported quality of life measures at 12 and 24 months; CI – confidence interval; HBOT – hyperbaric oxygen treatment; SF36 – language specific short form 36; SMFA – short musculoskeletal function assessment

Scale	Group	Mean score (SD)		Mean difference, [95% CI] mixed effects regression using time from injury	*P*-value
		12 months	24 months		
SF36 physical function (higher is better)	HBOT	38.5 (9.7)	40.3 (11.2)	+2.90, [1.03 to 4.77]	0.002
	Control	34.2 (12.7)	40.3 (13.3)		
SMFA function index (lower is better)	HBOT	21.8 (13.6)	17.3 (14.1)	-2.54, [-4.46 to -0.62]	0.01
	Control	29.3 (20.1)	22.2 (18.4)		
SMFA daily activities (lower is better)	HBOT	26.8 (20.1)	20.4 (21.9)	-19.51, [-21.08 to 0.06]	0.05
	Control	38.2 (27.4)	26.0 (24.2)		

questionnaires. There was no differential loss to follow up between trial allocation groups at 12 months (X^2_1 = 0.56, *P* = 0.45) or 24 months (X^2_1 = 0.71, *P* = 0.71).

Hyperbaric oxygen patients reported better mean scores of physical functioning, less impairment of daily activities and lower mean pain scores at follow-up. One control group patient opted for elective amputation at 24 months (Table 5 and supplementary Table S20).

CROSS OVERS AND AS PER TREATMENT RECEIVED ANALYSIS

Six patients allocated to the control group received one or more HBOT sessions. Five of the six commenced HBOT late on day two or on day three post injury. All experienced necrosis and three developed infection. None received sufficient HBOT sessions to meet the 'therapeutic course' criteria and all were considered by their primary surgeon to need HBOT in view of incipient or actual complications of severe injury. All of these patients were included when 'as per treatment received' data analysis was undertaken, despite being a group with high likelihood of complications and late or insufficient sessions of HBOT. One patient started HBOT on day eight when assessed as being at high risk of postoperative wound breakdown due to age and diabetes. He did not experience complications and was not included in the 'as per treatment received' analysis due to the late commencement. In this 'as per treatment received' analysis, there were no statistically significant differences identified between treatment allocation groups.

ADVERSE EVENTS

There were no major complications of HBOT although treatment was prematurely discontinued for minor ear

barotrauma in two cases and for coincident nausea, vomiting, pain, agitation or anxiety in a further nine instances (15% of HBOT cases). See supplementary material for further detail.

One serious adverse event was notified: a patient allocated to the HBOT group experienced a free-flap failure due to irreversible venous thrombosis. The relevant hospital's clinical review committee concluded that this complication was unrelated to the study protocol or conduct. The patient did not receive further HBOT sessions following flap failure but underwent a second tissue transfer procedure which was successful.

Discussion

Our group has successfully completed the first multi-centre randomised clinical trial of HBOT in acute musculoskeletal trauma, confirming that it is possible to safely deliver HBOT during the acute care phase. The allocated groups were well matched and our 12-month outcome analysis is based upon a 92% follow up rate of wound healing, infection and orthopaedic procedure data.

The demographic, gender and injury patterns of the HOLLT patients were similar to those reported from advanced economy nations, with motor transport related injury and falls from heights predominant. Our study had many of the characteristics of what are considered 'pragmatic trials', with few exclusion criteria and normal clinical practises followed. Although most enrolling centres did not record the number of potentially eligible patients not approached for enrolment, there were reportedly very few, if any, identified patients who were excluded for reasons of unsuitability for HBOT. We therefore expect our findings should be generalisable to other centres.[29]

It is notable that HBOT patients had lower numbers of complications of every recorded type, in every sub-category. Importantly, the severity of acute phase complications appears reduced in the HBOT group, with a lower incidence of soft tissue necrosis and an associated reduction in the likelihood of wounds developing the concerning problem of co-incident infection and necrosis.

Severe open fractures of the tibia are well known for high rates of long-term complications.[12–15] Our study suggests HBOT can significantly reduce the risk of such complications. Over 12 months post-injury, there was a reduced incidence of complications overall and a reduction in the specific problems of delayed union and persistence of open wounds. Based upon 12- and 24-month health-related quality of life and function measures, HBOT patients had superior functional outcomes. These effects are all biologically plausible and consistent with the effects of hyperbaric oxygen in animal models and previous studies in crush injury and in wounds and soft tissue infections in other settings.

Our results are consistent with our *a priori* hypothesis that adding HBOT to conventional modern care of complex open tibial fractures would reduce acute wound complications and that this would be associated with improved late outcomes. It is likely that our positive results are generalisable to other severe musculoskeletal injuries at other anatomical locations, consistent with claims by others.[8,9,30–33]

Our positive results arise predominantly from the data for patients with Gustilo 3A and 3B fractures. Although all enrolled patients were judged by clinicians to have severity factors indicating a high risk of complications, our study supports the predictive power of Gustilo grading, with low rates of complications following injuries arbitrated as Gustilo 2. All three patients who received HBOT for Gustilo 3C fractures avoided amputation. The case for using HBOT seems stronger in more severe injuries, with local or systemic risk factors probably more relevant considerations in lower severity injuries.

Although we believe the morbidity and complications of HBOT were acceptable in this study setting, it should be noted that it can be challenging to provide HBOT to acute post-injury and post-operative patients.

These findings may have significant implications worldwide, demanding further research and evaluation of the feasibility of delivering HBOT to a higher proportion of acute trauma patients.

LIMITATIONS

Our selection of a composite of acute complication measures as primary outcome was based upon the assumption this would be a more sensitive measure than the more clinically important 12-month complication rate. We were also concerned about the practicality of achieving acceptable follow up over 12 months. When slow enrolment necessitated revising the original enrolment target from 250 to 120 subjects, this likely made the study underpowered for our chosen primary outcome. The two acute soft tissue complications of injury upon which our primary outcome was based have a complex interaction – infection or necrosis can occur in isolation, or infection can develop and lead to necrosis, or necrosis can occur which becomes infected. In hindsight, we would not recommend this composite outcome for future studies.

Although the lack of blinding of patients and their carers risks bias towards HBOT, we believe that this was unavoidable as sham hyperbaric treatments for control patients would have been potentially negative for the quality of their care and thus also a potential bias against the control allocation to 'standard care'. It is hoped that the use of objective measures and blinded arbitrators has minimised any significant bias in the study outcomes.

Conclusions

This multi-centre randomised trial of HBOT for severe open tibial fractures did not detect a statistically significant reduction in its pre-specified primary outcome measure of the overall number of acute complications of infection and/or necrosis, likely because it was underpowered following a reduction in its enrolment target from 250 to 120 due to slow recruitment. Nevertheless, the study hypothesis was validated by the findings that HBOT was associated with a reduction in acute tissue necrosis and infection, and subsequently, a reduction in problems with wound healing and bone union.

The ideal number and timing of HBOT sessions remains unknown, and it is possible that the optimal number may vary with injury severity. The 12 HBOT session target used in this study may be excessive for most cases. Studies to determine optimum dose and timing are indicated. It will be important to evaluate the costs of this moderately expensive and logistically complex treatment against clinical outcomes and health economics over a longer term.

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An International Steering Group helped establish this study, advising on key design features and seeking potential collaborators: Folke Lind (Stockholm, Sweden), Lin Weaver (Salt Lake City, USA), Daniel Mathieu (Lille, France), Michael Bennett (Sydney, Australia), Armin Kemmer (Murnau, Germany) and Thomas Kossmann (Melbourne, Australia).

Andrew Forbes, Chris Reid and Michael Bennett formed the Data Safety and Monitoring Committee. Rory Wolfe provided valuable oversight and advice regarding statistical methods.

Bebe Brown facilitated recruitment, site data input, and follow-up of all subjects enrolled at Royal Hobart Hospital

Conflicts of interest and funding

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All other study related costs and all clinical care and hyperbaric oxygen therapy costs were provided from within the budgets of each participating institution.

The funding sources had no role in the study design, conduct, analysis, writing or submission for publication. There were no commercial entities or interests involved in the trial. There are no identified conflicts of interest for any of the authors regarding the conduct and reporting of this study.

Data access

The Principal Investigator, Ian Millar, and the Project Manager, Rosemary McGinnes, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. The Principal Investigator only gained access to the site raw data entries and group allocation after data entry

closed and data were extracted from the Web Entry Data System for transmission to the study statisticians for analysis. Most statistical analyses were performed by Catherine Martin, with patient reported outcome data analysed by Belinda Gabbe.

Transparency statement

As Principal Investigator, first author and guarantor, Ian Millar affirms that the manuscript is honest, accurate and a transparent account of the study being reported, with no important aspects omitted and discrepancies from original plans reported and explained within the manuscript.

Data sharing

A file of de-identified patient data can be made available to researchers upon reasonable request, subject to a research plan being communicated to the HOLLT investigators with assurance of the identity and credentials of the requesting researcher(s). This file includes de-identified data extracted from the HOLLT study Web Entry Data System and the results of arbitrated outcomes for each of the 120 study participants.

Monash University holds an archive of all study information, raw data and image files. This is de-identified healthcare data which is re-identifiable via the international collaborators and cannot be released due to privacy requirements and trial agreements between Monash University and the study collaborators. It was, however, envisaged that future researchers might wish to conduct further analyses based upon these data, by entering into a confidentiality agreement with the HOLLT investigators and obtaining Human Research Ethics approval from The Alfred and Monash Ethics Committee and the HOLLT collaborator group.

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Influence of atmospheric pressure changes on dentin bond strength of conventional, bulk-fill and single-shade resin composites

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Aviation medicine; Composite resin; Prosthodontics; Diving medicine; Hyperbaric medicine; Scanning electron microscopy; Teeth

Abstract
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Introduction: The purpose of this study was to investigate the dentin bond strength of composite resins in response to environmental pressure changes.
Methods: Ninety extracted human molar teeth were used. A mould (3 mm x 4 mm) was adapted on dentin, resin composites (conventional [n = 30] and single-shade composites [Ohmnicroma] [n = 30]) were filled in two increments of 2 mm. The bulk-fill composites (n = 30) were filled with one 4 mm increment. The specimens were stored for 30 days in artificial saliva. The specimens were exposed to hyperbaric pressure (283.6 kPa; 2.8 atmospheres absolute [atm abs]) or hypobaric pressure (34.4 kPa; 0.34 atm abs) once daily for 30 days and the control group was stored at atmospheric pressure for 30 days. The bond strength was tested with a universal testing machine and the failures were examined with a stereomicroscope and scanning electron microscope. Statistical analyses were performed using analysis of variance with post hoc tests, and the Weibull analysis.
Results: Regardless of environmental pressure changes, the bulk-fill composites showed the highest bond strength. There was no significant difference in bond strength between the hypobaric and atmospheric pressure (control) groups after 30 days in all resins. The hyperbaric group showed lower bond strength for bulk-fill composites than the control group.
Conclusions: Dentists experienced in diving and aviation medicine should definitely take part in the initial and periodic medical examinations of divers and aircrew to give appropriate treatment. Bulk-fill composite resins can be preferred in divers and aircrew due to high bond strength values.

Introduction

Composite resins have undergone many developments in terms of their mechanical and aesthetic properties since the 1950s. These improvements have made them the preferred material in many treatments such as for dental caries and the repair of crown fractures.[1]

Most of the composite resins used today can be placed on the tooth with a thickness of up to 2 mm for an ideal restoration. When composite resins are applied with a layering technique, the restoration times are prolonged, and there is a risk of the possibility of incorporating voids or contamination between composite layers.[2] These disadvantages may result in bond failures. Recently, bulk-fill composites have been introduced to reduce the application time and eliminate the problems associated with incremental placement techniques. Bulk-fill composite resins can be placed up to 4 mm thick by curing once.[3] Current reports indicate that the bulk-fill resin has improved mechanical properties,[4,5] less polymerization stress and less microleakage.[6,7]

Omnichroma, which was first introduced in 2019, is the first composite resin-based material that could match any tooth with any shade, on any patient. This one-shade property of Omnichroma is unique. Thus, dentists do not need to be concerned that they may create multiple shades. This offers a fast, simple system with desirable and functionally esthetic restorations.[8]

Although atmospheric pressure is relatively constant within weather variations in daily life, in some situations like high-altitude flights, mountain climbing, diving and working under hyperbaric pressure, signficant environmental pressure

changes occur.[9,10] The most important pressure change effect in the oral cavity is barodontalgia. The term barodontalgia was first used in the 1940s to describe pain in the orofacial region associated with environmental barometric changes.[11] This mechanism is explained by Boyle's Law. The volume and pressure of an ideal gas at a constant temperature vary inversely. When a person descends under the sea, pressure increases and the volume of gas spaces in the body (e.g., sinuses) or within artificial substances like resins and restorations, will decrease. The reverse is true for ascents to altitude where ambient pressures are lower. These pressure changes may cause microleakages and dislodgement of dental restorations and crowns.[12,13] It was reported that environmental pressure changes can affect the retention of crowns depending on the cementation technique and the dental material.[13,14] Also, it was reported that one of the underlying causes of barodontalgia is leaking restorations (4–50%).[15]

Few studies have examined the effect of pressure changes on dental restorations. Most studies examining environmental pressure changes in dentistry pertain to cementation type, material and techniques. Within the development of new techniques, bulk-fill composites and Ohmnicroma are preferred due to their aesthetic and mechanical properties. As crown dislodgements or restoration fractures may cause painful and distressing problems in diving or flying, it is important to select the appropriate dental restoration. To the best of our knowledge, this is the first research that has assessed the effect of environmental pressure changes on the bonding strength of composite resins to dentin. There is also scant research on the mechanical properties of single-shade composites and bulk-fill composites. Therefore, the aim of this study was to investigate the bonding strength of different composite resins to dentin in artificial saliva after exposure to hypobaric and hyperbaric pressure changes. The null hypothesis was that the bond strengths of composite resins to dentin do not differ in specimens that are exposed to different environmental pressures.

Methods

The Eskisehir Osmangazi University Ethical Committee approved the study protocol (Approval No: 182155).

SPECIMEN PREPARATION

Ninety sound caries-free human molars, newly extracted due to periodontal diseases or orthodontic treatment, were selected. Adherent tissue was removed, and the teeth were cleaned and placed in 0.5% Chloramine-T solution and stored at 4°C until used. The roots were separated from the crowns at the cementoenamel junction. The teeth were bisected mesiodistally at the middle to buccal and palatal parts using a low speed saw, (Isomet Buehler, USA), and embedded in methacrylate resin (Birlesik Group Dental, Turkey) in plastic moulds (inner diameter 25 mm, height 20 mm) with their buccal and palatal surfaces facing up. The enamel surfaces were removed with 250 grit silicon carbide grinding paper and then roughened with 600 grit silicon carbide grinding paper. The teeth were then stored in distilled water and divided into 3 groups of 30 teeth per group. The specifications of materials are listed in Table 1.

Gluma, self-etch priming agent (Kulzer GmbH, Germany) was applied to the dentin surface and light-cured for 20 s in according to the manufacturer's instructions (Labolight LV III, GC, Japan). A cylindrical silicone mould was prepared in a diameter of 3 mm and 4 mm in height.

Group 1: The mould was adapted on dentin and filled with composite resin (Estelite Posterior Packable Composite, Tokuyama Dental, Japan) in two consecutive increments of 2 mm, followed by polymerizing each increment for 20 s.

Table 1

Experimental materials used in this study; 4-META – 4-methacryloxyethyl trimellitate anhydride; BisGMA – bisphenol A-glycidyl methacrylate; MDP – methacryloxydecyl dihydrogen phosphate; SiO_2 – silica; TEGDMA – triethylene glycol dimethacrylate; UDMA – urethane dimethacrylate; ZrO_2 – zirconia

Material (Manufacturer)	Composition	Lot	City Country
Reveal HD Bulk Fill (Bisco)	UDMA, Bis-GMA, Ytterbium fluoride	1800005251	Schaumburg, USA
Estelite Posterior Packable Composite (Tokuyama Dental)	UDMA, Bis-GMA, TEGDMA, ZrO_2-SiO_2	W110	Tokyo, Japan
Ohmnicroma (Tokuyama Dental)	UDMA / TEGDMA (Filler loading 79 wt% [68 vol%]), Uniform sized supra-nano spherical filler 260 nm SiO_2-ZrO_2, round shaped composite filler including 260 nm spherical SiO_2-ZrO_2	0062	Tokyo, Japan
Gluma Bond Universal (Heraeus Kulzer GmbH)	MDP phosphate monomer, 4-META, dimethacrylate resins, acetone, fillers, initiators, silane	K010923	Hanau, Germany

Group 2: The mould was adapted on dentin and filled with one 4 mm increment with bulk-fill composite resin (REVEAL HD Bulk, Bisco, USA), and light-cured for 20 s.

Group 3: The mould was adapted on dentin and filled with single-shade resin composite (Ohmnichroma, Tokuyama, Japan) in two consecutive increments of 2 mm, followed by polymerizing each increment for 20 s.

The samples were then stored for 24 h at room temperature in artificial saliva. The artificial saliva contained 16.5 mol·m^3 NaCl, 4.1 mol·m^3 KH_2PO_4, 24.8 mol·m^3 $KHCO_3$, 4.0 mol·m^3 Na_2HPO_4, and 0.25 mol·m^3 $CaCl_2$. The pH was adjusted to 7.[16,17]

PRESSURE CHAMBER TESTS

To test the effect of pressure cycling, each group was divided into three subgroups of 10 (Figure 1).

Group A was exposed to hyperbaric pressure. The hyperbaric chamber was a custom-made device (Hipertech Electronic and Machine Industry Company, Istanbul, Turkey) that enabled electronic control of pressure changes. The pressure cycle regimen consisted of 30 pressure cycles from 101.3 to 283.6 kPa (1.0 to 2.8 atmospheres absolute [atm abs]), a pressure exposure equivalent to 18 metres of seawater (msw) at a rate of 50.5 kPa·min^{-1}, reaching the maximum pressure in approximately 5 min. After 30 minutes at 283.6 kPa, the decompression phase began, again at a rate of 50.5 kPa·min^{-1} taking approximately 5 min. This process was repeated for 30 days, one cycle each day.

Group B was exposed to hypobaric pressure. The hypobaric chamber was a custom-made device (ETC; Southampton PA, USA) that enabled electronic control of pressure changes. The hypobaric chamber was decompressed to 34.4 kPa (0.34 atm abs, equivalent to 27,000 feet or 8,200 m altitude) over 5 min. After 30 min at 34.4 kPa, the chamber was recompressed to the normal atmospheric pressure over a period of 5 min. This process was repeated for 30 days, one cycle each day.

Group C was stored at atmospheric pressure in artificial saliva for 30 days.

SHEAR BOND STRENGTH MEASUREMENT

The shear bond strength was measured with the Universal Testing Machine (Lloyd-LRX, Lloyd Instruments, Fareham, UK) at a crosshead speed of 1 mm·min^{-1}. Specimens were put in the jig of the testing machine with the dentin surface parallel to the loading direction with a 500 N load cell in the testing machine (Figure 2). The bond strength values

Figure 1
Experimental design of the study

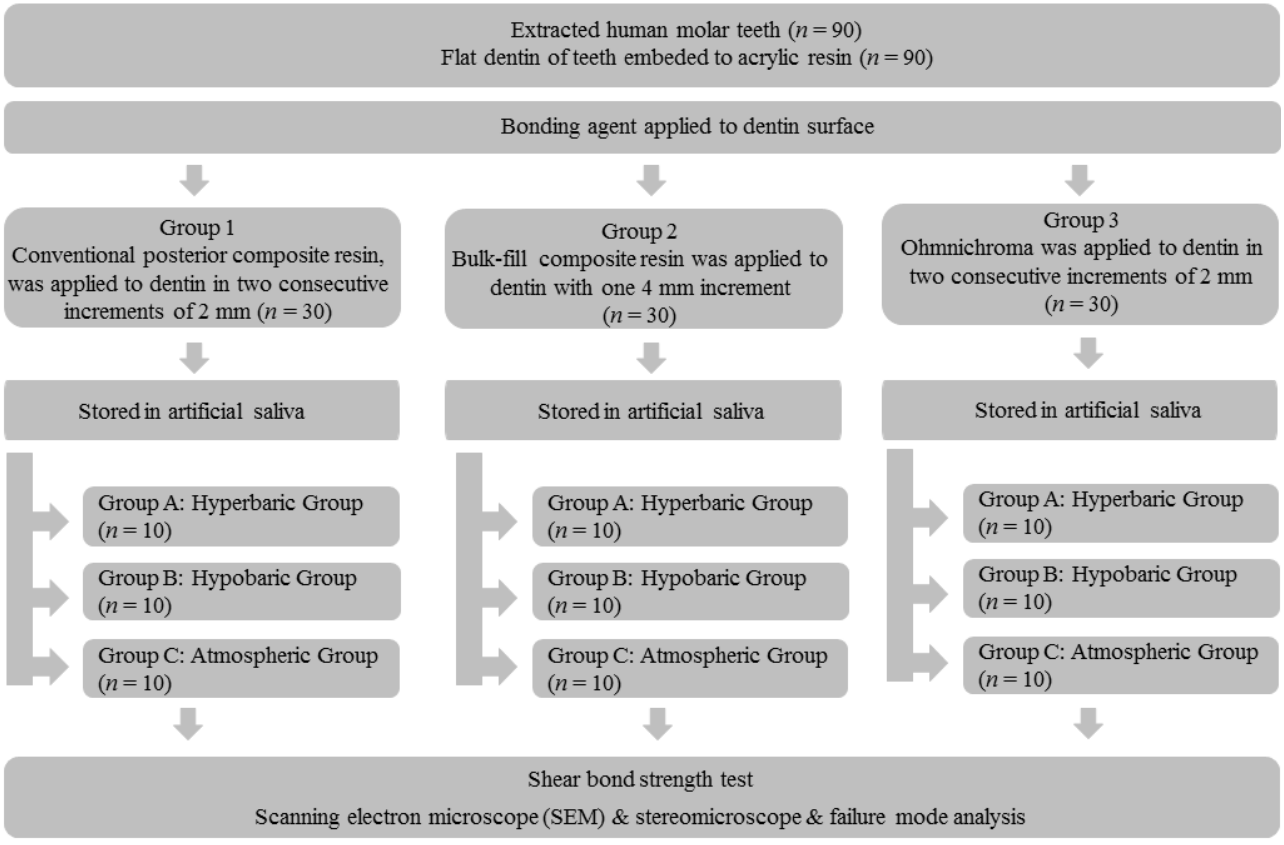


Figure 2
Composite resin bonded to dentin was mounted in the jig of the testing machine with the dentin surface parallel to the loading direction

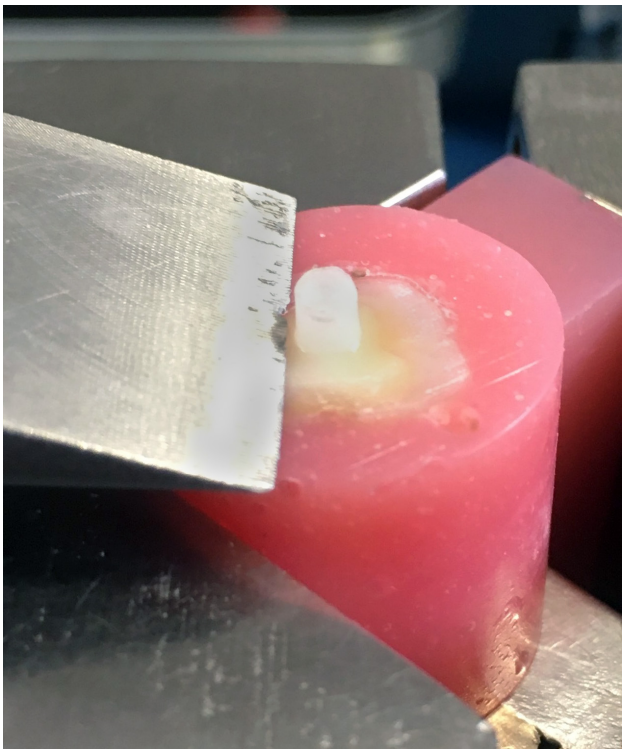
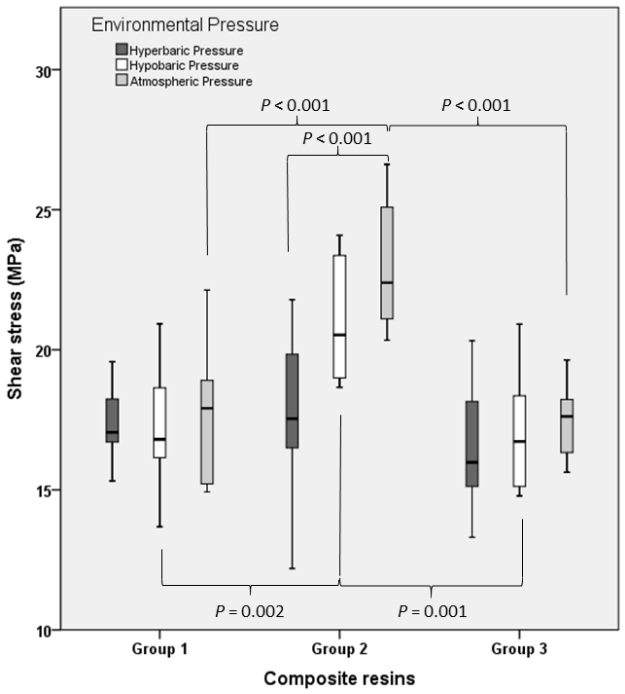


Figure 3
Boxplot graph of shear bond stress values. The box plots represent the median and the interquartile range; the whiskers represent the minimum and maximum values. Group 1 – Conventional; Group 2 – Bulk-fill; Group 3 – Ohmnicroma



were calculated by dividing the force at which bond failure occurred by the bonding area.

FAILURE MODE ANALYSIS

The debonded surface of the samples was observed under scanning electron microscopy (Hitachi Regulus 8230 FE-SEM, Japan) at x30, x350 and x1,000 magnification, and under a stereomicroscope (Nikon SMZ-745T, Nikon, Tokyo, Japan) at x30 magnification to assess the mode of failure. Type of failure was classified as:

- Type 1, Adhesive (less than 20% resin observed at dentin surface).
- Type 2, Cohesive (more than 80% resin observed at the dentin surface).
- Type 3, Mixed (20% to 80% resin observed at the dentin surface).

STATISTICAL ANALYSIS

IBM SPSS 24.0 for Windows (Armonk, New York, USA) was used for statistical analysis. The Shapiro-Wilk test was performed to establish that data were normally distributed. Differences between groups were tested using ANOVA followed by the *post hoc* Tukey test. Data were expressed as mean (SD). A *P*-value < 0.05 was considered statistically significant. Strength variations within each group were examined by calculating the Weibull modulus. A spreadsheet was used to rank the shear strength data in ascending order and appoint a rank over the range 1 to 10; a line graph was then fitted through the points using the median rank regression method. The Weibull modulus was calculated by slope analysis.

Results

SHEAR BOND STRENGTH

Shear bond strength outcomes are given in Table 2, and the boxplot graph is showed with statistical differences in Figure 3. The highest mean shear bond strength values were observed for Bulk-fill composite resins in atmospheric pressure, compared to Ohmnicroma and conventional posterior composite resins ($P < 0.001$). Also, a significant difference was observed between the bulk-fill composite resin groups exposed to hyperbaric and atmospheric pressures ($P < 0.001$). However, there were no significant differences between hypobaric and atmospheric pressure groups regardless of the type of resin.

WEIBULL MODULUS

The shear bond strength data of composite resins bonded to dentin and exposed to different environmental pressures were further analysed using the Weibull distribution function

Table 2
Shear bond strength values, results of Weibull analysis and number of failure types; Ad – Adhesive; Co – Cohesive; WCS – Weibull characteristic strength

Group	Composite resins	Environmental condition	Bond Strength (MPa)		Weibull modulus	WCS (MPa)	Failure analysis (*n*)		
			Mean (SD)	Range			Ad	Co	Mixed
1A	Posterior	Hyperbaric	17.3 (1.3)	15.3–19.6	14.7	17.9	9	–	1
1B	Posterior	Hypobaric	17.1 (2.1)	13.7–20.9	8.8	18.0	9	–	1
1C	Posterior	Atmospheric	17.9 (2.4)	14.9–22.1	7.9	19.0	8	–	2
2A	Bulk-fill	Hyperbaric	17.9 (2.8)	12.2–21.8	6.5	19.2	10	–	–
2B	Bulk-fill	Hypobaric	21.0 (2.1)	18.7–24.1	10.3	22.0	10	–	–
2C	Bulk-fill	Atmospheric	23.0 (2.3)	20.3–26.6	10.4	24.1	9	–	1
3A	Ohmnicroma	Hyperbaric	16.5 (2.1)	13.3–20.3	8.6	17.4	10	–	–
3B	Ohmnicroma	Hypobaric	17.0 (2.0)	14.8–20.9	9.1	17.9	9	–	1
3C	Ohmnicroma	Atmospheric	17.4 (1.3)	15.6–19.6	14.8	18.0	9	–	1

to predict the failure probability of bonding. The Weibull analysis for composite resin bonded to dentin under different environmental pressures is shown in Table 2. The Weibull modulus was the highest for Group 3C and the lowest for group 2A. Weibull characteristic strength for control (atmospheric pressure) groups was significantly higher in all resins (Group 1C, 18.98 MPa; Group 2C, 24.97 MPa; Group 3C, 18.00 MPa). The probability of failure versus shear stress for different environmental pressure changes is shown in Figure 4.

FAILURE ANALYSIS

The failure analysis for each group is listed in Table 2. All specimens exhibited mostly adhesive failure, regardless of environmental pressure changes. Fisher's exact test found no significant differences in the type of failure mode for both composite resin types and environmental pressure changes. Representative images of adhesive and mixed failures of samples are shown in Figure 5.

Discussion

The null hypothesis that the shear bond strengths of composite resins to dentin exposed to different environmental pressures do not differ in specimens was rejected as the bond strength of bulk-fill composite resins exposed to hyperbaric pressure were significantly lower than that of the bulk-fill composite resins at atmospheric pressure. Regardless of the environmental pressure changes, the bulk-fill composite resin showed the highest shear bond strength value and Weibull modulus and Ohmnicroma showed the lowest bond strength and Weibull modulus.

As dentin depth, tubule configuration and permeability have been shown to affect the bond strength, dentin was grounded to nearly the same depth in the present study.[18,19] Light curing conditions were standardised because inadequate polymerization might induce discoloration, microleakage, and reduce the bonding strength of restorations.[20] One type of self-etch adhesive system was used for standardisation and to eliminate the complications of multistep adhesive systems.

The bonding strength of composite resin depends on many factors such as the mechanical properties, composition, viscosity, the amount of shrinkage, translucency, and the method of application. In this study regardless of environmental pressure changes, the bulk-fill composite resin showed the highest bond strength. One study[21] evaluated the influence of curing light intensities on the translucency and surface gloss of bulk-fill composite resins. Reveal bulk-fill resin showed the highest translucency value with a high curing intensity. Higher translucency to curing light can provide full polymerization of the resin. The increased depth of cure, low polymerization stress from shrinkage, mechanical properties of bulk-fill composites may affect the results. However, in our study, the bond strength of the Ohmnicroma composite with the incremental technique was found to be low despite its high translucency. It was previously reported that use of the incremental technique showed lower polymerization shrinkage stress and microleakage compared to the bull-fill technique.[22] The differences in results may be due to the composition of composite resins with respect to components such as photoinitiators, polymerization inhibitors, and organic monomers. For instance, the bulk-fill composite used in this study does not contain the TEGDMA monomer, conversely the Ohmnichroma contains TEGDMA. It has been reported that the use of TEGDMA may reduce the mechanical properties and increase the water absorption of resin composites.[23] Higher tendency to water absorption, which leads to swelling of the matrix and breaking of polymer chains, may weaken the mechanical properties of resins.[24,25] As the samples were stored in artificial saliva for 30 days, this may have affected the results of our study. As material types and methodology differ in this study, also

Figure 4
Weibull plot of failure probability against stress to failure (MPa) for each group; A – Group 1 (Conventional); B – Group 2 (Bulk-fill); C – Group 3 (Ohmnicroma)

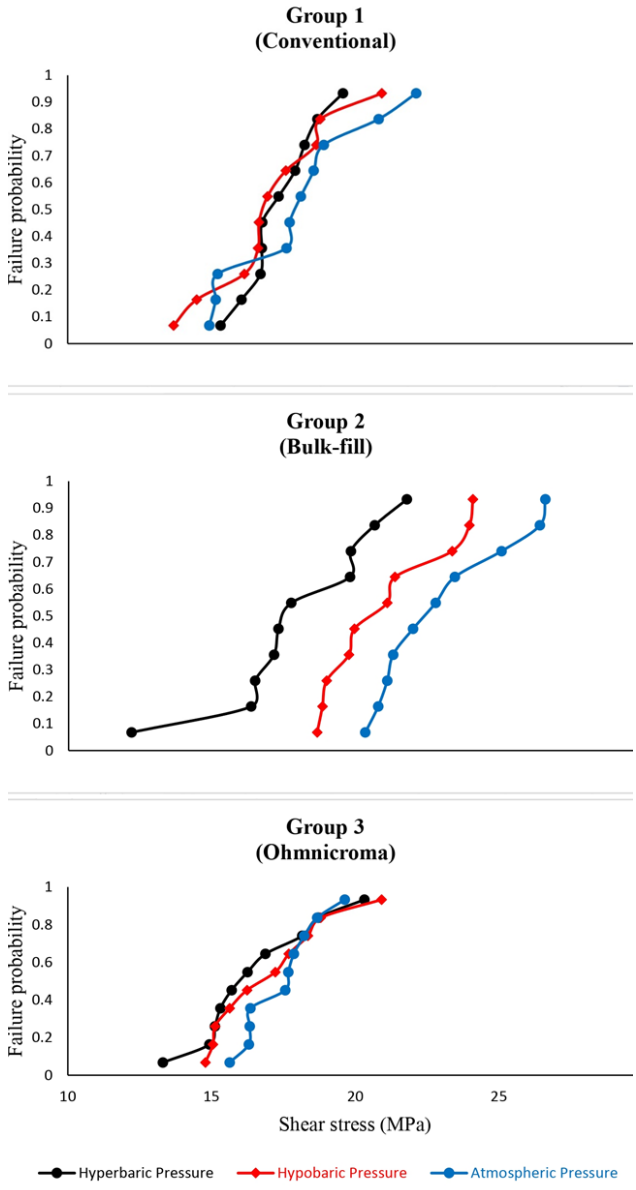
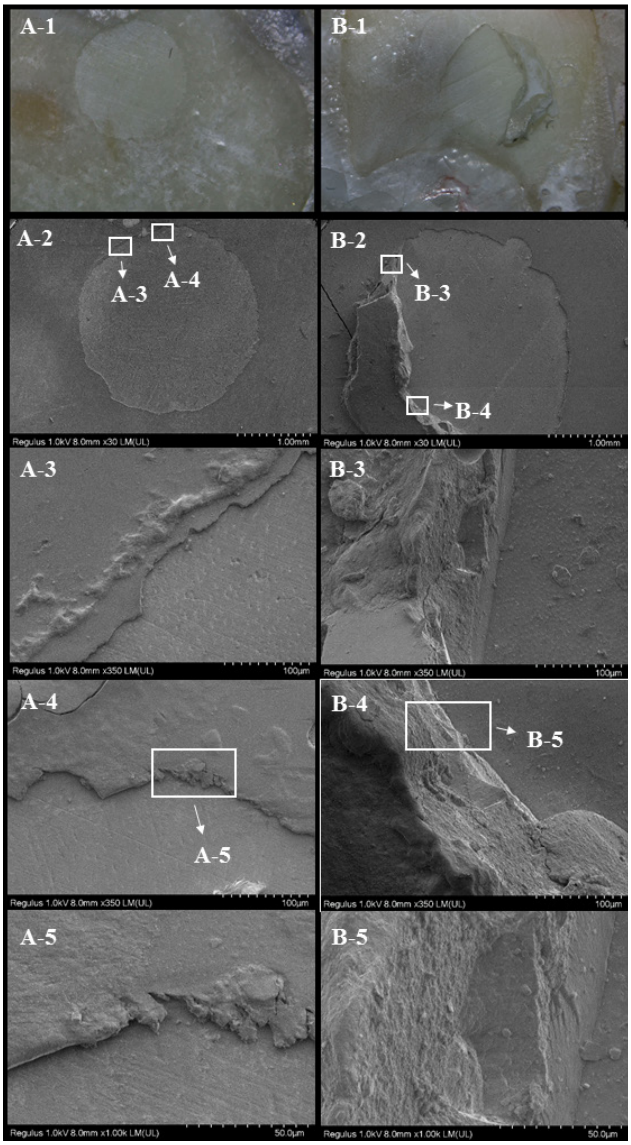


Figure 5
Representative stereomicroscope and scanning electron microscope (SEM) images of adhesive (A1–A5) and mixed (B1–B5) types of failure after debonding; A1 and B1 are stereomicroscopy images (magnification x30). All other images are SEM; A2, B2 x30; A3, B3, A4, B4 x350; A5, B5 x1,000



the structural defects of composite resins, dentinal tubule orientation, or misalignment during testing may affect the results of our findings.

Based on Boyle's law predictions, any air void in a material expands or contracts in response to pressure change. In dental restorations this may weaken the structure.[26] In diving or flying, stress may occur in air voids such as the pores in the resin layers, in bonding areas or inside the dentinal or root canals. When decompressing to sea level after diving or to an increased altitude during flight, any enclosed gas spaces experience compression or expansion forces. The cumulative stress of compression-expansion can produce fractures within the resin layer and/or along the interface surface. In this study, the bond strength decreased in both hypobaric and hyperbaric groups compared to atmospheric pressure groups. However, this reduction was only statistically significant in hyperbaric groups.

Another study[27] has compared the effect of different environmental pressures on the bond strength of fiber posts to root canals. They found a statistically significant decrease in the diver group, and concluded that rapid pressure changes in diving adversely affect the bond strength of dental restorations. Divers appear more likely to suffer barodontalgia than aircrew (9.8 versus 5.8%) due to dental therapy, deep dental caries, pulpitis and leaking restorations (4–50%).[15] Those results are in line with those reported here.

Additionally, the bulk-fill resin was the most affected by environmental pressure changes among the other composites and was significantly compromised by hyperbaric exposures. Viscosity properties and possible air voids occurring on the dentin-composite resin bonded interface may have caused microfractures during pressure changes. It was reported that flowable composite resin, vibration methods when applying composite or preheating composite could help limit the presence of air voids.[28] More studies are needed to select the appropriate resin in individuals exposed to environmental pressure changes.

In this study, diving and flight conditions were simulated in hypobaric and hyperbaric chambers for 30 days, 30 min a day. A 10-year study of the dental health of German naval personnel examined the long-term effects of barometric pressure changes. Over this 10-year period, it was observed that personnel working in hyperbaric environments suffered worse dental problems when compared to personnel working at ground level.[29] It is possible that prolonged exposure to environmental pressure changes can cause a negative prognosis in oral dental health. As greater effects may be expected during longer periods of cyclic pressure changes, the limited number of pressure cycles in the present study may be a limitation. More cycles over longer periods may produce greater changes.

Weibull distribution has shown to be an alternative method for evaluation of the fracture probability of materials.[25] In the present study, the Weibull modulus value was lower in all pressure-change groups compared to the control groups. This suggests that environmental pressure change decreases the reliability of the materials. These results are consistent with the shear bond stress results.

Analysis of the failure mode can help to explain bond strength results. In this research, bond-strength values were usually associated with adhesive failures. The specimens from all subgroups revealed bond failures occurring at the dentin surface. There were almost no remnants of composite resin observed on the dentin surface, suggesting that composite resin strength might be stronger than the resin-dentin bond strength.

So far only limited independent data on environmental pressure effects on dental restorations are available. The present study is the first that considers environmental pressure changes in the testing procedure. But physical and chemical changes in oral environmental conditions were not examined. Thus, confidently extrapolating the results to a clinical situation is not possible. More studies are needed with different environmental pressure cycles, longer durations, different dental materials and mechanical tests to fully understand the effect of ambient pressure changes on teeth and dental materials.

Conclusions

Within the limitations of this study, the following conclusions can be drawn.

First, the highest mean shear bond strengths were recorded for bulk-fill composite resins across all environmental pressure changes. Inversely, the bulk-fill resin was the resin most affected by the environmental pressure changes among the other composites. The hyperbaric group showed significantly lower bond strength values than the control group ($P < 0.001$). Second, Ohmnicroma composite resin showed the lowest bond strength. Third, barometric changes can affect the bond strength of composite resins to dentin. Dentists should be careful choosing the appropriate dental material in aircrew and divers, where fractures and cracks in dental restorations may cause painful and distressing problems. Finally, divers and aircrew should pay attention to their dental health as well as their general health. Dentists experienced in diving and aviation medicine should take part in the initial and periodic medical examinations of these people. In these examinations, dental caries should be evaluated, and a comprehensive examination including vitality tests of all teeth should be performed. For restorations that require treatment, planning should be done with appropriate treatment methods. Bulk-fill composite resins can be preferred in divers and aircrew due to high bond strength values.

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Lung function changes in divers after a single deep helium-oxygen dive

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Keywords
Diving, Heliox; Hyperoxia; Pulmonary function; Surface decompression

Abstract
(Bao X, Yang T, Fang Y, Sun Y, Wang N. Lung function changes in divers after a single deep helium-oxygen dive. Diving and Hyperbaric Medicine. 2022 30 September;52(3):183–190. doi: 10.28920/dhm52.3.183-190. PMID: 36100929.)
Introduction: This study measured pulmonary function in divers after a single helium-oxygen (heliox) dive to 80, 100, or 120 metres of sea water (msw).
Methods: A total of 26 divers participated, of whom 15, five, and six performed a 80, 100, or 120 msw dive, respectively. While immersed, the divers breathed heliox and air, then oxygen during surface decompression in a hyperbaric chamber. Pulmonary function was measured twice before diving, 30 min after diving, and 24 h after diving.
Results: At 30 min after the 80 msw dive the forced expiratory volume in 1 s (FEV_1)/forced vital capacity (FVC) ratio and the maximum expiratory flow at 25% of vital capacity (MEF_{25}) values decreased (89.2% to 87.1% and 2.57 $L{\cdot}s^{-1}$ to 2.35 $L{\cdot}s^{-1}$, $P = 0.04$, $P = 0.048$ respectively) but FEV_1/FVC returned to the baseline values by 24 h post-dive. Other pulmonary indicators exhibited downward trends at 30 min after the dive, but statistical significance was lacking. Interestingly, though several parameters decreased after the 100 msw dive, statistical significance was not reached. After the 120 msw dive, the FEV_1/FVC and MEF_{75} decreased (90.4% to 85.6% and 8.05 $L{\cdot}s^{-1}$ to 7.46 $L{\cdot}s^{-1}$, $P = 0.01$, $P = 0.007$). The relatively small numbers of subjects who dived to 100 and 120 msw depths may explain the inconsistent results. The subjects diving to 100 and 120 msw were more trained / skilled, but this would not explain the inconsistencies in results between these depths.
Conclusions: We conclude that single deep heliox dives cause a temporary decrease in FEV_1/FEV and MEF_{25} or $MEF_{75,}$ but these changes can recover at 24 h after the dive.

Introduction

Diving is a high-risk operation associated with elevated ambient pressure, altered gaseous characteristics and changes in cardiovascular stress after immersion in water; all impact the lungs.[1] Long-term deep diving (by commercial divers) triggers small airway disease and decreased lung function,[2,3] but such effects have not been found in military or recreational divers.[4–6] If an individual is clinically susceptible, a single dive can change pulmonary function.[7,8] Hyperoxia, venous gas microembolus formation, changes in breathing characteristics, respiratory heating, and water loss are possible adverse effects after a single wet scuba dive.[8,9]

Helium is less soluble and more diffusible than nitrogen. A mixture of helium and oxygen (heliox) serves as the breathing medium during deep dives to avoid the narcotic effects of nitrogen under pressure.[10] Heliox is of lower density than nitrogen and oxygen mixtures (air or nitrox) and facilitates deep diving. The respiratory resistance increases and the dynamic lung volumes decrease as the pressure increases with greater gas density. Breathing of a low-density heliox mixture partially normalises dynamic lung volumes. Heliox breathing reduces airway flow resistance and thus the work of breathing.[11,12] However, high-level respiratory heat loss during heliox diving (due to the physical properties of helium) and the long decompression time under water may negatively affect the human respiratory system. Heat loss from the body surface is greater in a hyperbaric heliox environment than in air.[13] Cold may lead to marked respiratory changes, such as hyperventilation and hypocapnia through neurogenic mechanisms.[14]

A few studies have explored pulmonary effects associated with heliox diving. One reported that a dive to 55 to 80 metres of seawater (msw) breathing trimix (a mixture of helium, nitrogen and oxygen) was associated with accumulation of extravascular lung water and reduced left ventricular contractility.[15] A decrease in the transfer factor for carbon monoxide (TL_{CO}) was observed after eight saturation dives to pressures of 3.1–4.6 MPa.[16] The forced expiratory volume in 1 s (FEV_1)/forced vital capacity (FVC) ratio was reduced after several open-sea, closed-circuit rebreather dives to 90 and 120 msw performed within 4 days; the divers breathed trimix.[17] However, the effect of a single deep heliox dive (to more than 80 msw) on human pulmonary function is unknown. We thus evaluated changes in lung function parameters after single heliox dives to 80, 100, and 120 msw.

Methods

The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Ethical Committee of the Naval Medical Center (protocol code 202008). All subjects provided written informed consent.

SUBJECTS

Twenty-six healthy male divers were recruited. Of these divers, 15, five, and six performed 80, 100, and 120 msw heliox dives, respectively. Their baseline characteristics are summarised in Table 1. Health status and previous diving experience were self-reported. All divers met "*The Medical Examination Standards for Professional Divers*" (China National Standard, GB 20827-2007, 2007.08.01). Failure to meet the divers' physical examination standards, or a history of upper respiratory tract infection or Eustachian tube dysfunction in the past week were the exclusion criteria. All study subjects were asked not to smoke, exercise vigorously, and drink coffee before diving.

DIVE PROTOCOL

To reduce in-water and total decompression times we employed surface decompression with oxygen ($SURDO_2$). This fulfills all or part of the decompression requirements using a recompression chamber rather than holding the diver in the water. The reduced time in water aims to prevent dangerous reduction in body temperature. Inside the recompression chamber divers are maintained at a constant pressure and are unaffected by the sea-surface conditions. Dive profiles are shown in Figure 1. Prior to the surface decompression, dives took place in open water conditions with a water temperature of 23–24°C. The decompression profiles were prescribed by a Naval Medical Institution algorithm programmed into a dive computer. During descent at 15–20 $m \cdot min^{-1}$ the diver (wearing a wetsuit) was gradually transitioned from air-breathing to heliox-breathing ($He:O_2$ 82:18 v/v) using surface supply open-circuit breathing apparatus (KMB 28B diving mask, Kirby-Morgan, Santa Maria CA, USA). They remained at depth for 15 min, and returned to the first decompression stop at 6 $m \cdot min^{-1}$. After converting the breathing gas from heliox to air at the first stop, each diver ascended incrementally (Figure 1) to 12 msw where they changed to breathing 100% oxygen. After 30 min at the 12-msw stop, the diver returned to the surface and within 6 min of leaving 12 msw was recompressed to 15 msw depth equivalent in the hyperbaric chamber (breathing 100% oxygen). The time between surfacing and recompression was 5 min. The $SURDO_2$ procedure is shown in Figure 1.

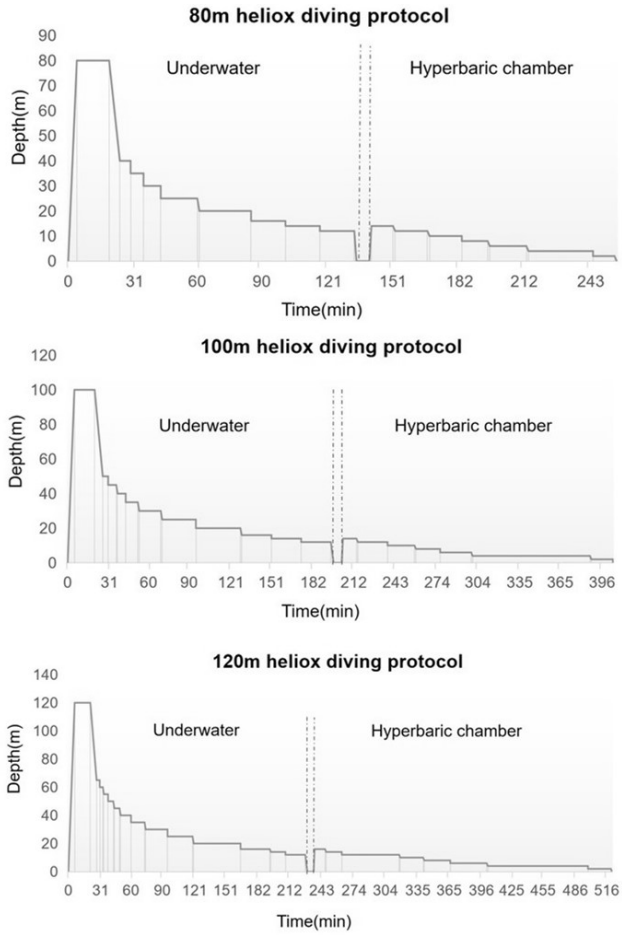
PULMONARY FUNCTION TESTS

For all divers, baseline pulmonary function was measured during the week before diving, at 30 min after completing the $SURDO_2$, and at 24 h after the dive was complete. Pulmonary function tests were recorded using an electronic spirometer (COSMED Inc., Rome, Italy). To reduce variability in the measurement of lung function, all measurements were performed by one person. During the measurement,

Table 1
Characteristics and baseline lung function of divers engaged in heliox diving to different depths; msw – metres of seawater

Parameter	80 msw depth *n* = 15			100 msw depth *n* = 5			120 msw depth *n* = 6		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Age (years)	24.1	4.6	18–32	29.3	2.8	26–33	27.5	2.7	24–31
Body mass (kg)	71.3	9.6	60–88	72.8	6.0	69–85	66.8	4.2	60–72
Height (cm)	174.3	4.1	170–183	173.3	3.2	168–178	172.0	1.7	170–175
Experience (years)	5.2	2.9	2–12	10.8	3.1	7–15	13.0	2.2	10–16
Lung function	**Mean**		**SD**	**Mean**		**SD**	**Mean**		**SD**
FVC (Z-score)	-0.50		0.91	-0.30		0.68	-0.06		0.78
FEV_1 (Z-score)	-0.31		0.74	0.11		0.58	0.22		0.42
FEV_1/FVC (Z-score)	0.49		1.50	0.58		0.84	0.62		0.98
$FEF_{25–75\%}$ (Z-score)	-0.30		1.02	0.05		0.59	-0.18		0.42
$MEF_{25\%}$ (Z-score)	0.06		1.02	0.36		0.51	0.31		0.42
FEV_1/VCmax% (Z-score)	0.49		1.50	0.58		0.84	0.62		0.98

Figure 1
Decompression procedures after 80, 100 and 120 msw heliox dives



each diver repeated three blows with full force under the guidance of the surveyor. When collecting the baseline value and the data 24 h after the dive, the collection time was fixed in the morning. The data averages obtained during three reproducible flow-volume loops (Standardization of Spirometry 2019 Update[18,19]) were calculated and compared with the baseline averages (again, of three reproducible values) obtained in the morning.

STATISTICAL ANALYSIS

All statistical analyses were performed using GraphPad Prism software. Paired-sample *t*-tests (two-tailed) and unpaired *t*-tests with Welch's correction were performed (based on the distribution normality, as checked by the Shapiro-Wilk test). Normally distributed data are presented as the mean (standard deviation, SD). A *P*-value < 0.05 was considered to indicate statistical significance.

Results

80 MSW DIVE

Compared with the baseline values, the forced expiratory volume in one second/forced vital capacity ratio (FEV_1/FVC) decreased significantly, from 89.2% (SD 8.4) to 87.1% (7.7), at 30 min after diving (P = 0.04), but returned to baseline at 24 h after diving (Figure 2, P = 0.16). The maximum expiratory flow at 25% of the vital capacity (MEF_{25}) also decreased at 30 min after diving from 2.57 (0.82) L·s^{-1} to 2.35 (0.67) L·s^{-1}, P = 0.048. It tended to return to baseline at 24 h after diving, but a significant difference from baseline remained, 2.48 (0.73) L·s^{-1} vs 2.57 (0.82) L·s^{-1}, P = 0.048. The FEV_1, forced expiratory flow at 25–75% of the forced vital capacity ($FEF_{25–75\%}$), and MEF at 50 and 75% of vital capacity ($MEF_{50\%}$ and $MEF_{75\%}$) slightly decreased immediately after diving (compared with the baseline values), but statistical significance was not attained (Figure 2). No other indicator changed significantly after diving.

100 MSW DIVE

Figure 3 shows that after a 100 msw heliox dive, compared with before the dive, all pulmonary function parameters trended downward but not significantly (P > 0.05). The FVC, FEV_1, and FEV_1/FVC returned to the baseline values 24 h after diving, whereas the peak expiratory flow (PEF), $FEF_{25–75\%}$, and $MEF_{25\%}$, $MEF_{50\%}$ and $MEF_{75\%}$ decreased further (Figure 3). However, the changes were not significant.

120 MSW DIVE

The results after 120 msw heliox dives were similar to those after 80 msw dives. As Figure 4 shows, compared with the pre-dive data, the FEV_1/FVC decreased markedly, from 90.4 (4.3)% to 85.6 (3.1)% at 30 min after diving (P = 0.01) but returned to the baseline value at 24 h after diving (P = 0.47). The $MEF_{75\%}$ changes followed a similar pattern. The $MEF_{75\%}$ decreased significantly at 30 min after diving compared with the pre-dive value, 7.46 (1.08) L·s^{-1} vs 8.05 (1.17) L·s^{-1}, P = 0.007, but returned to baseline at 24 h later, 7.52 (0.96) L·s^{-1}, P = 0.3. No other indicator was affected by diving.

EFFECTS OF DIVING DEPTH

We compared the lung function changes after 80, 100, and 120 msw heliox dives. Table 2 shows that the FVC, PEF, and $MEF_{75\%}$ at 30 min after diving decreased as the dive depth increased, but the differences were not significant (all P > 0.05). Table 2 also shows that lung function changes after diving were not affected by the dive depth.

Discussion

We found that a single deep heliox dive temporarily affected lung function, which returned to normal at 24 h after the dive. We found a tendency toward small airway dysfunction after a single 80 msw heliox dive. The FEV_1/FVC and $MEF_{25\%}$ were significantly reduced at 30 min after an 80 msw heliox dive; the FEV_1/FVC returned to normal at 24 h after the dive, but the $MEF_{25\%}$ remained significantly reduced. While in 120 msw heliox dive, the FEV_1/FVC and $MEF_{75\%}$

Figure 2

Changes in pulmonary function parameters at 30 min and 24 h after 80 msw heliox diving ($n = 15$) compared with the pre-dive ('pre-div') (baseline) data; data are expressed as the mean (SD); *$P < 0.05$; FVC – forced vital capacity; FEV_1 – forced expiratory volume in one second; PEF – peak expiratory flow; $FEF_{25–75}$ – forced expiratory flow over the middle half of the FVC; MEF_{25} – maximum expiratory flow at 25% of FVC; MEF_{50} – maximum expiratory flow at 50% of FVC; MEF_{75} – maximum expiratory flow at 75% of FVC

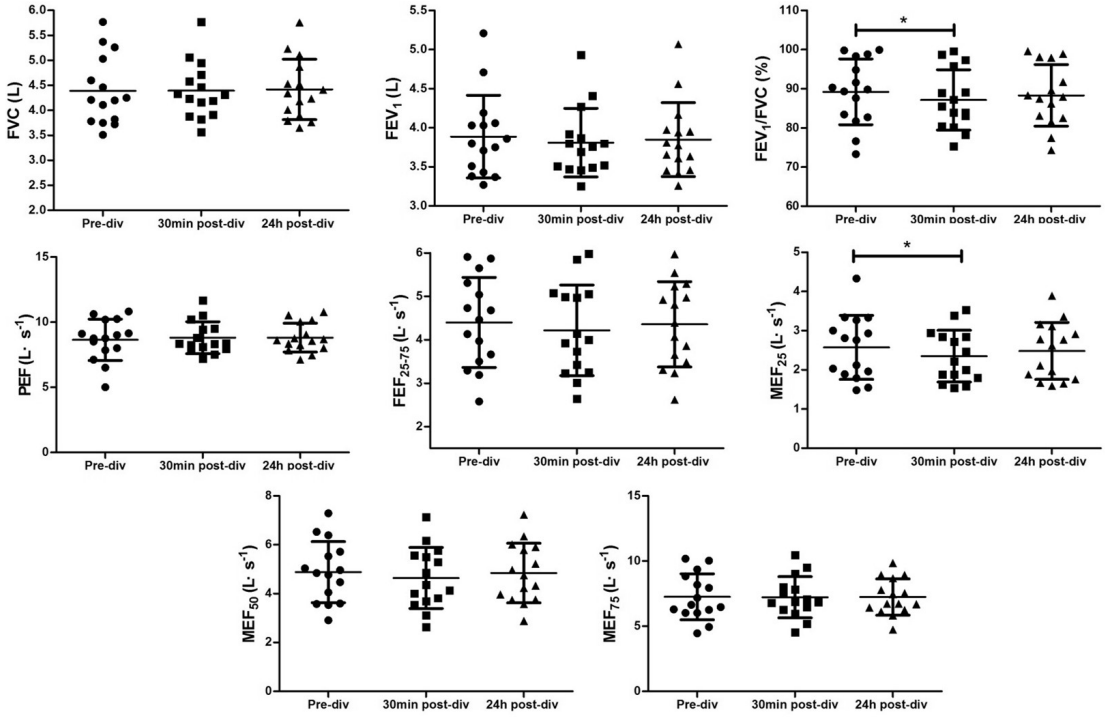


Figure 3

Changes in pulmonary function parameters at 30 min and 24 h after 100 msw heliox diving ($n = 5$) compared with the pre-dive ('pre-div') (baseline) data; data are expressed as the mean (SD); FVC – forced vital capacity; FEV_1 – forced expiratory volume in one second; PEF – peak expiratory flow; $FEF_{25–75}$ – forced expiratory flow over the middle half of the FVC; MEF_{25} – maximum expiratory flow at 25% of FVC; MEF_{50} – maximum expiratory flow at 50% of FVC; MEF_{75} – maximum expiratory flow at 75% of FVC

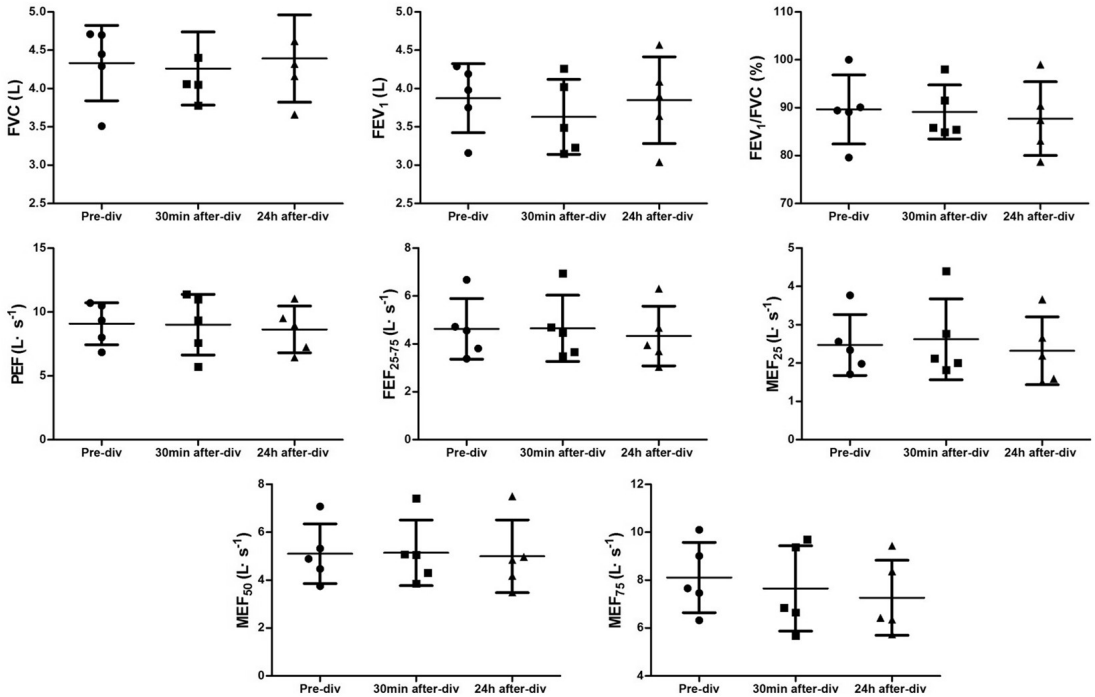
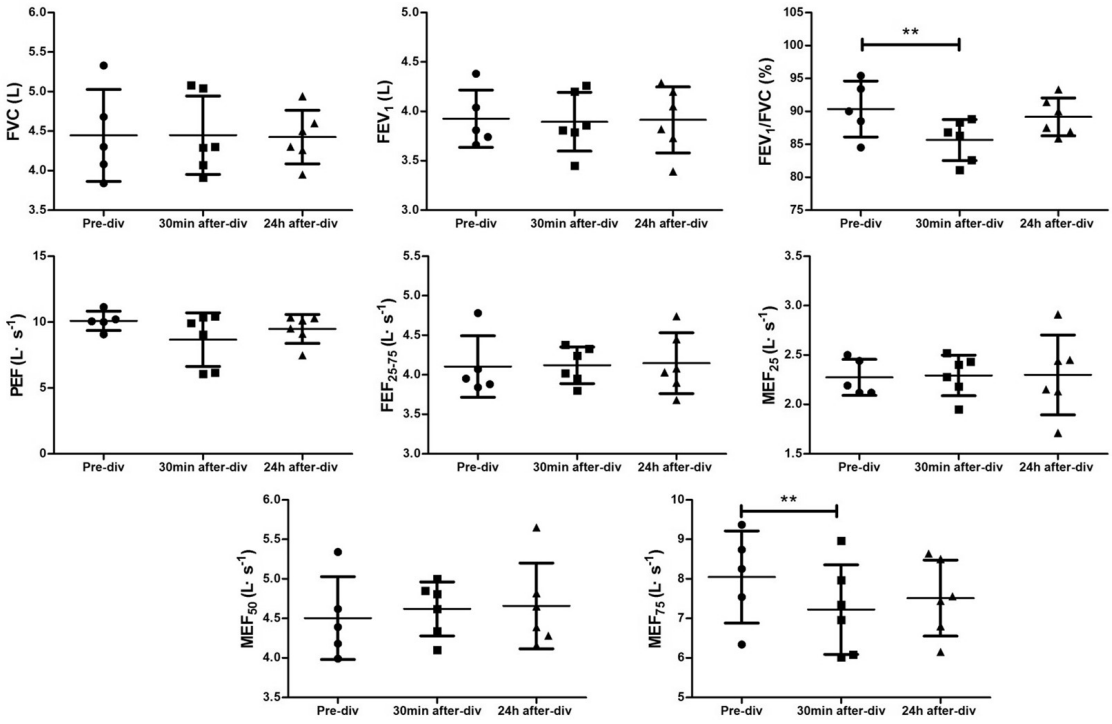


Figure 4

Changes in pulmonary function parameters at 30 min and 24 h after 120 msw heliox diving ($n = 6$) compared with the pre-dive ('pre-div') (baseline) data; data are expressed as the mean (SD); $^{**}P < 0.01$; FVC – forced vital capacity; FEV_1 – forced expiratory volume in one second; PEF – peak expiratory flow; $FEF_{25–75}$ – forced expiratory flow over the middle half of the FVC; MEF_{25} – maximum expiratory flow at 25% of FVC; MEF_{50} – maximum expiratory flow at 50% of FVC; MEF_{75} – maximum expiratory flow at 75% of FVC



decreased markedly at 30 min but returned to normal at 24 h after the dive.

After the 100 msw dives, the pulmonary parameters tended to decrease at 30 min after diving, but statistical significance was not attained. There are two possible reasons. The first reason is the large inter-individual variability in diver lung function and the small cohort of divers. There were 15 subjects for the 80 msw heliox dives, while there were only five subjects for the 100 msw dives and six for the 120 msw dives. Second, those diving to 100 and 120 msw had more diving experience and were more proficient compared with the shallower divers, which could possibly affect breathing patterns during diving. However, when the diving depth reached 120 msw, statistically significant differences were again apparent, possibly because the dive time becomes significantly longer as the dive depth increases.

A single deep saturation dive to a depth of 300 m or more reduces lung function.[20,21] A mean reduction in the TL_{CO} of 10–15% is the most consistent finding; some studies reported reductions in peak oxygen uptake (VO_2 peak values). Changes in lung function appear to be, at least partially, reversible at 6–8 weeks after diving. However, some studies found that repeated saturation and compressed air diving caused long-term effects.[1,22] Long-term diving reduces the FEV_1/FVC ratio.[23] This reduction may be due to a selective increment of FVC or decrement in FEV_1 in divers after long-term diving. However, in the present study investigating single dives, FVC values did not change significantly after the 80 msw dive, while FEV_1 showed a small downward trend 30 minutes after the dive (no statistical difference). Some authors have suggested that changes found in FVC or FEV_1 less than 5% are attributable to intra-individual variation and not suggestive of a pathological process.[24] In our study, the changes in FVC and FEV_1 after diving at 80 msw were around 5%, and the maximum change was 11%. Therefore, it is possible that a single heliox dive may not cause pathological changes, but it does not mean that these changes are meaningless. Of course, this part of the conclusion needs further investigation.

Oxygen toxicity may be one cause of changes in lung function, but it is not the only cause. We calculated the 'unit pulmonary toxic dose' (UPTD) values of for the dives in this study. In the $SURDO_2$ phase of the 80, 100 and 120 msw dives, the UPTD values were 208, 344 and 527, respectively. In an earlier study,[25] persons were exposed to continuous oxygen breathing at 152, 203 and 253 kPa (1.5, 2.0 and 2.5 atmospheres absolute [atm abs]) for average durations of 17.7, 9.0 and 5.7 h, respectively. Lung flow-volume and spirometric measurements were performed before, during, and after oxygen exposure. When subjects were exposed to 152 kPa (1.5 atm abs) oxygen for 3.8 hours, that is, when the UPTD value was 724, compared with the control group, FVC decreased by 1.1%, FEV_1 decreased

Table 2

Comparison of difference in lung function (△ values) at 30 min and 24 hours after diving versus baseline in heliox dives to different depths. Data are mean (SD) or median (range). FVC – forced vital capacity; FEV_1 – forced expiratory volume in one second; PEF – peak expiratory flow; $FEF_{25–75}$ – forced expiratory flow over the middle half of the FVC; MEF_{25} – maximum expiratory flow at 25% of FVC; MEF_{50} – maximum expiratory flow at 50% of FVC; MEF_{75} – maximum expiratory flow at 75% of FVC

Parameter	△80 msw depth Baseline vs 30 min	△100 msw depth Baseline vs 30 min	△120 msw depth Baseline vs 30 min	△80 msw depth Baseline vs 24 h	△100 msw depth Baseline vs 24 h	△120 msw depth Baseline vs 24 h
FVC (L)	0.01 (0.29)	-0.07 (0.40)	-0.12 (0.20)	0.03 (0.15)	0.06 (0.41)	-0.06 (0.24)
FEV_1 (L)	-0.08 (0.22)	-0.24 (0.52)	-0.09)0.12)	-0.04 (0.11)	-0.10 (-0.12–0.28)	-0.07 (0.12)
FEV_1/FVC (%)	-2.05 (3.5)	-0.52 (4.62)	-4.1 (1.98)	-0.30 (-8.60–1.40)	-1.92 (7.10)	-0.10 (-9.50–2.4)
PEF ($L{\cdot}s^{-1}$)	-0.40 (-1.33–6.65)	-0.07 (0.73)	-0.08 (-3.90–0.15)	-0.06 (-0.60–2.11)	0.16 (-1.56–0.39)	-0.22 (0.42)
$FEF_{25–75}$ ($L{\cdot}s^{-1}$)	-0.18 (0.61)	-0.02 (0.22)	-0.01 (0.29)	-0.02 (-0.64–0.24)	-0.30 (0.65)	-0.08 (0.45)
MEF_{25} ($L{\cdot}s^{-1}$)	-0.22 (0.40)	0.15 (0.44)	0.04 (0.21)	-0.09 (0.16)	-0.15 (0.59)	-0.10 (0.31)
MEF_{50} ($L{\cdot}s^{-1}$)	-0.24 (0.65)	0.04 (0.25)	0.16 (-0.49–0.23)	-0.04 (0.37)	-0.11 (0.61)	-0.04 (0.63)
MEF_{75} ($L{\cdot}s^{-1}$)	-0.33 (-2.20–6.00)	-0.46 (0.49)	-0.58 (0.26)	-0.17 (-1.10–3.00)	-0.85 (1.04)	-0.26 (0.49)

by 0.6%, and FEV_1/FVC did not change significantly. In the present study, the UPTD for the 80 msw dive was about 200, but the FEV_1 decreased by 2%, FVC increased by 0.1%, and the FEV_1/FVC decreased by 2.3%. The UPTD value of the 120 msw dive was about 600, but the FEV_1 decreased by 2.3%, the FVC decreased by 2.8%, and the FEV_1/FVC decreased by 4.5%. Based on this comparison, the changes in pulmonary function parameters after the present helium-oxygen dives were significantly greater than those caused by simple exposure to oxygen. Therefore, we believe that oxygen toxicity is not the only cause of changes in lung function. This conclusion is consistent with other research. One study[26] found that exposures to an inspired PO_2 of approximately 130 kPa caused changes in pulmonary function parameters whether the exposure was in a dry chamber or underwater. However, the incidence and individual severity of pulmonary oxygen toxicity was exacerbated in underwater oxygen exposure that included moderate aerobic exercise for half the time. Another study found that the TL_{CO} and forced mid-expiratory flow rate decreased markedly after deep saturation dives.[27]

A decrease in $MEF_{25–75\%}$ is common in subjects with obstructive and restrictive airway disorders, as well as those with diffuse small airway lesions. The pulmonary function changes of professional divers in their first three years of diving are mainly manifested as changes in small airways conductance.[2] Long-term diving increased the FVC and induced obstructive ventilation.[28] A cross-sectional study on 180 healthy male divers and 34 healthy male controls revealed that the divers had a lower mid-expiratory flow ($MEF_{25–50\%}$). The changes were inversely related to the number of years of diving, indicating that diving exerts long-term effects on respiratory function.[22]

A single dive can change the expiratory flow and volume and the lung diffusion capacity. The FVC, FEV_1, $MEF_{25–75\%}$, and spirometric data did not change after a simulated deep dive.[29] However, the FVC, FEV_1, and $MEF_{75\%}$ decreased significantly after a cold-water dive (4°C, 25 min, 10 m).[30] Thus, the results are affected by the diving environment and methods. In the study by Thorsen et al., 4–15 divers performed 17 different saturation dives to depths of 5–450 msw. The decrease in the TL_{CO} after diving was correlated with the cumulative hyperoxic exposure and the level of venous gas microembolism. The decrease in the forced mid-expiratory flow rate was correlated with the cumulative hyperoxic exposure.[31] Hyperoxia, hyperbaria, and venous gas microembolism may all contribute to changes in pulmonary function after a single saturation dive. In the present study, the decreased $MEF_{25–75\%}$ indicates that a single deep heliox dive compromises small airway function, but this is transient, recovering after 24 h. The possible causes of the decrease in $MEF_{25–75\%}$ are as follows. First, as mentioned above, oxygen toxicity is one possibility. One study reported that 90 min at 0.25 MPa once a day over 10 days led to a significant decrease in $MEF_{50\%}$ (-15%) and $MEF_{25\%}$ (-33%) of FVC.[32] However, these repetitive

exposures are difficult to compare with the single exposure reported here. The early effects of breathing oxygen with partial pressures between 50 and 300 kPa include a decrease in FEV_1, FVC and maximal expiratory flow rates.[25] Second, when divers inhale oxygen in the hyperbaric chamber, they tend to complain that the gas is dry, associated with a high exhalation resistance. However, further experiments are needed to explore the possible relevance of these factors.

This study has some limitations. The number of subjects is small, particularly in the 100 and 120 msw dive groups. In addition, as divers must be rapidly transferred to a hyperbaric oxygen chamber (to complete surface decompression after ascent), we did not measure lung function before $SURDO_2$. This would have allowed comparison of the changes in lung function before diving, after ascending to the surface and after $SURDO_2$ to determine whether oxygen toxicity or deep diving is the main cause of the changes in lung function. We also did not measure the levels of decompression-induced microbubbles after diving.

Conclusions

A single deep heliox dive can trigger transient changes in pulmonary function. Specifically, it causes a decrease in FEV_1/FVC and $MEF_{25\%}$ or $MEF_{75\%}$ after diving, but these changes recover at 24 h after the dive.

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Pretreatment hearing grades and hearing recovery outcomes after primary hyperbaric oxygen treatment in patients with idiopathic sudden sensorineural hearing loss

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Abstract
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Introduction: Previous studies suggest the effectiveness of hyperbaric oxygen treatment (HBOT) in idiopathic sudden sensorineural hearing loss (ISSNHL) but it is mostly used as an adjuvant and salvage treatment. This study evaluated the effect of primary HBOT according to pretreatment hearing grades and hearing recovery outcomes using modified Siegel's criteria in patients with ISSNHL.
Methods: Fifty-nine ISSNHL patients treated with only HBOT were included. A pure-tone audiogram was recorded before and after a course of HBOT (90 min at 203 kPa daily for 20 days). Using the modified Siegel's criteria, patients were divided into groups according to hearing threshold before and after treatment.
Results: Hearing thresholds were significantly lower after HBOT compared to pre-treatment values across all patients ($P < 0.001$) with a median value of recovery of 22.5 dB (interquartile range 12.5–33.7 dB). Significantly lower hearing threshold values were recorded at 500, 1,000, 2,000, and 4,000 Hz after treatment ($P < 0.001$). The greatest recovery was at 1,000 Hz, (change in median threshold = 32 dB) but without a significant difference compared to other frequencies ($P = 0.10$).
Conclusions: HBOT is a legitimate choice as the primary treatment for ISSNHL, especially if it is readily accessible, and if there are contraindications for corticosteroid therapy.

Introduction

Idiopathic sudden sensorineural hearing loss (ISSNHL) is a medical emergency, defined as hearing loss greater than 30 dB over at least three consecutive frequencies, and that develops within three days.[1,2] In addition to hearing loss, this condition can be accompanied by vertigo, tinnitus, and a feeling of ear congestion. The annual incidence is approximately five to 20 cases per 100,000.[3] Numerous potential causes of sudden hearing loss are listed in the literature, such as infectious, vascular, traumatic, toxic, neurological, metabolic, and neoplastic, but in 85% of cases, the cause cannot be determined and is thus 'idiopathic'.[4] Due to the variety of causes, the high percentage of idiopathic cases, and the occurrence of spontaneous recovery in up to 65% of cases, choice of treatment and evaluation of treatment efficacy in sudden sensorineural hearing loss is challenging.[3] Various treatments have been proposed and applied worldwide. According to the latest clinical practice guideline from 2019, corticosteroids are recommended as first-line therapy for ISSNHL and intratympanic application of corticosteroids may be used as rescue therapy.[5] There are many studies of the use of corticosteroids, but there is limited evidence of their efficacy and there may be adverse effects.[1] A Cochrane systematic review does not suggest definitive efficacy of oral corticosteroids,[6] and another recent review suggests no significant difference in hearing recovery between patients treated or not treated with corticosteroids.[7]

Idiopathic sudden sensorineural hearing loss can also be treated with hyperbaric oxygen treatment (HBOT). The use of HBOT in ISSNHL is based in part on the notion that compromised vascular supply and consequent cochlear ischaemia contribute to the development of sudden hearing loss. In addition, inflammatory and other mechanisms are also mentioned among the possible causes of ISSNHL;[6] these pathophysiological processes are also potentially modified by HBOT. Numerous studies suggest benefit

from HBOT,[8–12] but it is mostly promoted as an adjuvant or salvage treatment for ISSNHL. Several studies suggest that the greatest recovery is achieved in combination with corticosteroids.[10–12] Only a few studies mention the use of HBOT as primary therapy for ISSNHL,[5] and there has been demonstration of apparent efficacy in this setting.[12] It is relevant that the only treatment for ISSHL that has had a cautiously positive Cochrane review (in 2012)[13] is HBOT and this was used to justify the inclusion of ISSHL as a clinical indication for HBOT by Undersea and Hyperbaric Medical Society in 2014.

Despite the latter, corticosteroid therapy remains the most widely accepted primary treatment for ISSNHL, and the efficacy of HBOT in comparison to other forms of treatment requires further research. A related problem is the lack of a universal system for assessing the effectiveness of therapy, which would greatly help in comparing the results of numerous scientific papers on this topic. One of the most commonly used systems for presenting recovery is Siegel's criteria. Recently, modified Siegel's criteria for ISSNHL have been presented, which also include pretreatment hearing grades for better prognostic assessment.[14] This study aimed to evaluate the effect of HBOT according to modified Siegel's criteria in patients with ISSNHL.

Methods

The study was approved by the ethics committee of the Clinical Hospital Centre Osijek (Approval No. 158-51-04-15-06).

A total of 59 patients treated for ISSNHL with HBOT in the period from January 2015 to the end of December 2019 were included in this retrospective study. Patients were offered various treatments for ISSNHL, and the patients included in this study were those who refused corticosteroid therapy. The most common reasons for refusing other forms of treatment were fear of side effects and diagnosis of diabetes. We recorded demographic data, level of hearing loss before and after treatment, time from onset of symptoms to the onset of treatment, as well as the presence of tinnitus and vertigo. Only patients with sudden sensorineural hearing loss of idiopathic cause were included. Exclusion criteria were age under 18, diagnosis of Meniere's disease, brain tumor, acoustic trauma, bilateral hearing loss, barotrauma, chronic otitis media, history of ear surgery, failure to obtain a pure-tone audiogram after treatment, and receipt of another form of therapy primarily or adjuvantly.

A pure-tone audiogram was recorded in all patients during the first visit to the otorhinolaryngologist and after completion of the HBOT course. Hearing thresholds and hearing loss were calculated according to the average hearing threshold at the four frequencies (500, 1,000, 2,000, and 4,000 Hz). According to the modified Siegel's criteria,[14] patients were divided into groups before treatment according to the hearing threshold, and according to recovery after HBOT. Pretreatment hearing grades were grade one (hearing threshold < 25 dB), grade two (hearing threshold 26–45 dB), grade three (hearing threshold 46–70 dB), grade four (hearing threshold 71–90 dB) and grade five (hearing threshold > 90 dB). The following recovery groups after HBOT were determined according to modified Siegel's criteria: complete recovery (final hearing threshold < 25 dB), partial recovery (improvement > 15 dB and final hearing threshold 25–45 dB), slight recovery (improvement > 15 dB, final hearing threshold > 45 dB), no improvement (improvement < 15 dB, final hearing threshold 76–90 dB) and non-serviceable ear (final hearing threshold > 90 dB).

HBOT PROTOCOL

Hyperbaric oxygen treatment was administered in a multiplace hyperbaric chamber, in which patients inhaled pure medical (100%) oxygen on a mask, at a pressure of 203 kPa (2 atmospheres absolute) for 90 minutes. Each treatment consisted of three phases: compression of the chamber over 15 minutes, oxygen inhalation under pressure for one hour, and depressurisation of the chamber over 15 minutes. The procedure was performed once daily, for 20 days.

STATISTICAL ANALYSIS

Data were analysed using SPSS Statistics for Windows (IBM Corp. Armonk, NY, USA). Differences in categorical variables or proportions were tested by the Chi-square test. The normality of the distribution of continuous variables was tested by the Shapiro-Wilk test and non-parametric analyses were applied. Differences between two independent groups were tested by the Mann-Whitney U test, and for three or more groups by the Kruskal-Wallis test (Dunn correction). The correlation of continuous variables was estimated by the Spearman correlation coefficient ρ (rho). All *P*-values were two-sided. The significance level was set to alpha < 0.05.

Results

A total of 59 patients (31 males and 28 females, median age 56 years, interquartile range [IQR] 48–65 years) with ISSNHL were included in the study.

The median time from the onset of symptoms to treatment was three days (IQR 2–7 days). According to the modified Siegel's criteria and hearing thresholds before HBOT there were no grade one patients, three (5.1%) grade two patients, 14 (23.7%) grade three patients, 18 (30.5%) grade four patients and 24 (40.7%) grade five patients.

Following HBOT, hearing loss was significantly reduced with the median loss across all frequencies falling from 81.2 dB (IQR 70.0–95.0) to 58.1 dB (IQR 47.5–77.5) ($P < 0.001$). The difference in the median value of hearing loss before and after HBOT across all patients was 22.5 dB (IQR 12.5–33.75). Significantly lower

Table 1
Median hearing threshold before and after HBOT ($n = 59$) at four frequencies; $P < 0.001$ for all before / after comparisons; dB – decibel; Hz – Hertz; HBOT – hyperbaric oxygen treatment; IQR – interquartile range

Frequency (Hz)	Threshold (dB) Median (IQR)	
	Before HBOT	After HBOT
500	74 (55–95)	42.2 (25–60)
1,000	83 (70–100)	50.8 (20–70)
2,000	84 (65–100)	58.6 (45 80)
4,000	87 (70–100)	66 (55–80)

Table 2
Recovery in hearing thresholds (difference between before and after HBOT) at all frequencies ($n = 59$); dB – decibel; Hz – Hertz; IQR – interquartile range

Recovery (dB) before to after HBOT Median (IQR)	Frequency				*P*
	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz	
	25 (10–50)	30 (15–45)	20 (10–40)	20 (10– 5)	0.10

Table 3
Recovery category after HBOT stratified by pretreatment hearing grades; data are number of patients; HBOT – hyperbaric oxygen treatment

Grade before HBOT	Recovery category after HBOT				Total	*P*
	Complete recovery	Partial recovery	Slight recovery	No improvement		
Grade two	0	0	0	3	3	0.003
Grade three	3	3	3	5	14	
Grade four	2	0	5	11	18	
Grade five	0	1	17	6	24	
Total	5	4	25	25	59	

hearing thresholds were observed at 500, 1,000, 2,000 and 4,000 Hz after treatment, with the largest difference at 1,000 Hz (Table 1) but without a significant difference compared to other frequencies (Table 2).

Most of the patients after HBOT were in the slight recovery and no improvement groups. There were no patients in the non-serviceable ear group. Most patients in the no improvement group belonged to pretreatment grade four, and most of the patients in the group of complete recovery were in grade three before treatment (Table 3).

There were four patients who started HBOT greater than 14 days from the onset of symptoms. The median value of hearing recovery (difference in hearing thresholds before and after HBOT) was 17.5 dB (IQR 4.1–38.4), and the median hearing threshold after HBOT was 54.3 dB (IQR 51.8–68.1) for these 'delayed' patients. There was no significant difference in recovery (difference in hearing threshold before and after HBOT) between patients who started therapy within seven days, 7–14 days, or > 14 days from the onset of symptoms ($P = 0.39$). There was no association between treatment initiation time and recovery (Spearman's Rho = 0.08; $P = 0.52$).

Significantly more patients in Siegel's grades four (6/18) and five (8/24) had tinnitus and vertigo ($P = 0.04$). There was no significant difference in the presence or absence of tinnitus and vertigo with regard to the recovery group ($P = 0.9$), although tinnitus and vertigo were most common in patients in the slight (8/25) and no improvement groups (9/25).

Discussion

This retrospective study aimed to show the effect of HBOT as primary therapy in patients with ISSNHL classified according to modified Siegel's criteria. There was a signficant reduction in the median hearing loss across all frequencies

with the median threshold falling from 81.2 dB to 58.1 dB; a median difference of 22.5 dB. The study group seemed consistent with the known demographics of ISSNHL. There were slightly more men (52.5%) than women, According to the literature, the representation of ISSNHL by gender is equal, and the most exposed age group is between 50 and 60 years, which is consistent with our data.[1,15]

There is evidence that hearing loss in low and mid-frequencies has a better prognosis.[16,17] In the present study, the largest difference in median hearing threshold before and after HBOT, i.e., the largest recovery, was at 1,000 and 500 Hz, but without a significant difference compared to other frequencies (Table 2). A possible explanation for the greatest recovery at lower frequencies might be the difference in the vulnerability of hair cells. Hair cells in the basal part of the cochlea that detects high frequencies are more sensitive to damage than those found in the apex, so damage to the basal part has a worse prognosis.[7,17,18]

According to the modified Siegel's criteria, patients were divided into five pretreatment hearing loss grades and five post-HBOT grades based on the final hearing thresholds and improvement. Most patients were in grade five before HBOT (Table 3), meaning that most patients had a hearing threshold > 90 dB, and after HBOT most patients were in the slight and no improvement groups, which agrees with the data from the literature that says that greater hearing loss predicts less recovery.[19–22] More patients in grade three achieved complete recovery compared to other groups of patients, while in the no improvement group there were more patients from grade four (Table 3). The three patients in grade two pre-HBOT all fell into the no improvement group after HBOT. According to the Cochrane systematic review from 2012, patients with moderate and severe hearing loss have the greatest recovery after using HBO,[13] which is consistent with our results. Similarly, other studies demonstrated the best recovery in pretreatment grade three,[14] or in in patients with hearing loss > 61 dB.[23]

Among the negative prognostic factors for recovery a longer delay to initiation of treatment is considered important.[4,19,20,22] Hearing recovery outcomes are thought to be better if HBOT is started within two weeks from the onset of symptoms.[5,13] In the present study the median delay from the onset of symptoms to the start of treatment was three days (IQR 2–7). Delays were divided into three groups (< 7 days, 7–14 days, > 14 days), and no significant difference was found in recovery with respect to the time of the beginning of therapy. Given that it is recommended to start therapy within two weeks, the group of patients who started after 14 days from the onset of symptoms was of particular interest. These four patients had a median hearing threshold after HBOT of 54.3 dB and a median threshold recovery of 17.5 dB. These patients belonged to the slight improvement group after HBOT, therefore it is still possible to improve the hearing threshold with HBO as primary therapy even after 14 days.

Vertigo and tinnitus occur in 40% of patients with ISSNHL, and they are considered a negative predictive factor for recovery,[24] although there are dissenting opinions.[22] In the present study there was no clear difference in the presence or absence of symptoms of tinnitus and vertigo with regard to recovery after HBOT, but tinnitus and vertigo were still present in larger numbers in patients with slight and no improvement group.

In the available literature, HBOT is commonly used as adjuvant therapy, and according to guidelines, corticosteroids are recommended as primary therapy.[5] Corticosteroids are thought to achieve hearing improvement in ISSNHL by suppressing the immune system, improving microcirculation, reducing inflammation, and oedema.[25,26] The hyperoxygenation achieved with HBOT has a similar effect. Hyperoxygenation stimulates neovascularisation, vasoconstriction and reduces local oedema, and also alters the levels of proinflammatory mediators.[27–29] Due to a similar mechanism of action, and taking account of the present results, we suggest that HBOT can be used as the primary treatment for ISSNHL. HBOT has the advantage of minor side effects compared to corticosteroid therapy, albeit with greater cost and logistic difficulties. The logistic ease of providing HBOT in this study can be attributed to the good cooperation of our institution with the polyclinic that conducts HBOT locally, the treatments being covered by the patient's health insurance, and the regular attendance of patients for treatments.

LIMITATIONS

The principal limitation of this study is the lack of a comparator group primarily treated with corticosteroids that would allow comparison of outcomes with those obtained using HBOT. Similarly, the known potential for some ISSNHL cases to improve spontaneously in the absence of treatment limits our ability to confidently attribute all measured recovery to HBOT. The study is also small and retrospective in design. Prospective research with control groups should certainly be conducted and without such definitive studies inconsistent adoption of HBOT in ISSNHL is likely to continue.[30] Despite these limitations, the results of this study provide qualified support for the use of HBOT as primary therapy, and as well as an incentive for further research.

Conclusions

Hyperbaric oxygen therapy is an acceptable and promising choice as the primary treatment for ISSNHL, especially if it can be provided with logistical ease, and if there are contraindications or relative contraindications for corticosteroid therapy.

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Review article

The role of routine pulmonary imaging before hyperbaric oxygen treatment

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Abstract

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Respiratory injury during or following hyperbaric oxygen treatment (HBOT) is rare, but associated pressure changes can cause iatrogenic pulmonary barotrauma with potentially severe sequelae such as pneumothoraces. Pulmonary blebs, bullae, and other emphysematous airspace abnormalities increase the risk of respiratory complications and are prevalent in otherwise healthy adults. HBOT providers may elect to use chest X-ray routinely as a pre-treatment screening tool to identify these anomalies, particularly if a history of preceding pulmonary disease is identified, but this approach has a low sensitivity and frequently provides false negative results. Computed tomography scans offer greater sensitivity for airspace lesions, but given the high prevalence of incidental and insignificant pulmonary findings among healthy individuals, would lead to a high false positive rate because most lesions are unlikely to pose a hazard during HBOT. Post-mortem and imaging studies of airspace lesion prevalence show that a significant proportion of patients who undergo HBOT likely have pulmonary abnormalities such as blebs and bullae. Nevertheless, pulmonary barotrauma is rare, and occurs mainly in those with known underlying lung pathology. Consequently, routinely using chest X-ray or computed tomography scans as screening tools prior to HBOT for low-risk patients without a pertinent medical history or lack of clinical symptoms of cardiorespiratory disease is of low value. This review outlines published cases of patients experiencing pulmonary barotrauma while undergoing pressurised treatment/testing in a hyperbaric chamber and analyses the relationship between barotrauma and pulmonary findings on imaging prior to or following exposure. A checklist and clinical decision-making tool based on suggested low-risk and high-risk features are offered to guide the use of targeted baseline thoracic imaging prior to HBOT.

Introduction

Hyperbaric oxygen treatment (HBOT) is generally very safe, but adverse events may occur during treatment.[1] Changes in atmospheric pressure during HBOT may cause pulmonary barotrauma (PBt) during the decompression phase of the treatment.[2,3] Isolated case reports have documented several pressure-change-related respiratory complications with HBOT, including arterial gas embolism (AGE), tension pneumothorax (PTX), and pneumomediastinum.[4–6] While uncommon, these adverse events are associated with significant morbidity and mortality.

PULMONARY COMPLICATIONS DURING HYPERBARIC OXYGEN TREATMENT

Pulmonary barotrauma during HBOT is rare. Our combined five-year experience (2016–2021) of three North American HBOT referral centres in Toronto, Canada (University Health Network and Rouge Valley Medical Centre) and Lebanon, NH, USA (Dartmouth-Hitchcock Medical Center), comprising 62,040 treatments performed on 2,250 patients, includes only a single case of PBt. This equates to an incidence of 0.0016% per treatment, or 0.044% per patient.

To review the utility of pre-treatment screening for predicting or preventing PBt during HBOT, we searched for articles describing patients undergoing pressurised treatment/testing in a hyperbaric chamber who had significant findings on pulmonary imaging either before hyperbaric exposure (i.e., pre-existing blebs, bullae, cysts) or afterwards (i.e., barotrauma, gas emboli). The search included several major databases (MEDLINE-Ovid, Embase, Cochrane CENTRAL, and CINAHL) and is detailed in *Appendix 1. A total of 1800 articles were screened independently by two

authors (CB and SK) to identify relevant reports, which are described in Tables 1 and 2.

Our search identified 11 reports of respiratory complications after HBOT/hyperbaric exposure with relevant radiological findings as specified above. For those reports where the patients were receiving HBOT, one detailed 126 patients undergoing mechanical ventilation and concurrent HBOT (for a variety of indications), of whom six experienced patient-ventilator asynchrony while in the hyperbaric chamber.[7] An additional six single-case studies documented a heterogeneous group of patients aged 5–80 (one female and five males) for whom HBOT was complicated by tension PTX,[6,8] pulmonary oedema,[9] pneumomediastinum,[10] acute pulmonary embolism,[11] and AGE.[12] A final report described a survey of 98 HBOT centres, reporting a combined incidence of PBt of 0.00045%.[13] For those cases that involved hyperbaric air exposure (e.g., pressure tolerance testing), one case series described two otherwise healthy individuals who sustained AGE while undertaking routine pressure tolerance testing in a hyperbaric chamber,[14] while another report described a single case of AGE during decompression from a 'dry dive' in a patient with previously undiagnosed pulmonary sarcoidosis.[5] A final, single case reported the discovery of a bronchopulmonary sequestration determined to contraindicate diving but not HBOT.[15] Isolated case reports of underwater divers and passengers on commercial airline flights describe otherwise asymptomatic adults experiencing fatal complications, such as air emboli, when exposed to variable changes in ambient pressure.[14–19]

Approximately half of the case reports described patients with pre-existing pulmonary comorbidities such as acute respiratory distress syndrome (ARDS), chronic obstructive pulmonary disease (COPD), or pulmonary sarcoidosis, pointing to possible associations with the risk of PBt during HBOT. None of the identified studies reported a significant impact of pre-treatment pulmonary screening on the decision to proceed with HBOT. In fact, in some cases pulmonary pathology was identified prior to HBOT but did not deter treatment (presumably because the centres had previously treated patients with similar pulmonary pathologies, without incident).

CURRENT PRE-HYPERBARIC OXYGEN TREATMENT SCREENING PRACTICES FOR AIRSPACE ABNORMALITIES

The hyperbaric medicine community wants to identify features that predict respiratory injury during treatment, to prevent this adverse event for those at increased risk. Pulmonary bullae, blebs, or cysts – emphysematous pockets of air within the lung parenchyma,[20,21] may be among these features.[13] Less commonly, congenital respiratory anomalies such as bronchogenic cysts and/or bronchopulmonary sequestration can be identified on imaging studies and may be associated with elevated risk of barotrauma with rapid changes in atmospheric pressure.[15,22,16–19]

Airspace abnormalities are remarkably common in the general population (Table 3). Emphysematous changes and air trapping, once thought to represent high-risk features for pressure-related respiratory complications, are frequently present in individuals without lung disease.[23] Airspaces within the visceral pleural or the subpleural lung itself are classically delineated as blebs or bullae on the basis of diameter (smaller or larger than 1 cm, respectively).[24] The prevalence of pulmonary blebs among adults without known pulmonary disease has been reported in two cohort studies, one quoting 6.0% using diagnostic thoracoscopy[25] and the other reporting 24.6% using postmortem computed tomography (CT).[26] Similarly, pulmonary bullae have been reported in 2.3–5.3% of asymptomatic patients,[26,27] often coincident with blebs. Other emphysematous changes can be found in the lungs of 14.2–16.1% of adults.[27,28] A variety of reports have described incidental findings of pulmonary nodules in 0.4–12.8% of adults,[28–33] and one quoted as many as 48.4% in a population of cardiac patients imaged using CT angiography.[27] Other pulmonary pathologies identified in patients who have experienced barotrauma during HBOT or air dives include pulmonary fibrosis[4] and sarcoidosis,[5] which occur in 0.1%–0.8%[34,35] and 0.03–0.09%[36,37] of the general population, respectively. Airspace disease may be even more common among patients undergoing assessment for HBOT than in the general population. For example, the main applications for HBOT are in treating radiation injury for patients who received radiation treatment for head and neck cancers, and these patients are likely to have a smoking history and hence potentially also some degree of COPD.

Patients with these pulmonary aberrations are often clinically asymptomatic, although they have an increased baseline risk of developing a PTX when the volume of gas in these spaces increases, commensurate with a decrease in atmospheric pressure (e.g., when an airplane is ascending to altitude or a hyperbaric chamber is being depressurised).[38] Given the increased compliance of these intrathoracic air pockets, patients with these findings who are subjected to pressure changes during HBOT are thought to be at a heightened risk of barotrauma.[13]

Some HBOT centres require a routine chest X-ray (CXR) prior to initiation of treatment to identify patients with pulmonary bullae, blebs, or PTX.[39,40] Certain centres also pursue additional investigations, such as CT imaging or spirometry, to characterise the nature of pre-existing respiratory disease and assess the risk of injury, while others routinely use CT chest imaging before HBOT.[8] Other

Footnote: *Appendix 1 is available on DHM Journal's website:
https://www.dhmjournal.com/images/Appendices/52_3/Brenna_Pulmonary_Appendix1_2022-523.pdf

investigations which may be available to providers evaluating patients for the presence of absence of gas trapping include whole body plethysmography[41] and ventilation scans using xenon,[42] nitrogen, or helium,[43] although these tests may not be available in all centres and the evidence supporting their use in pre-HBOT screening is currently limited. Despite the common practice of obtaining CXR or CT imaging as a screening tool prior to HBOT, the basis for this approach remains unclear. Presently, specific guidance on the use of pulmonary imaging prior to HBOT is not provided by the Undersea and Hyperbaric Medicine Society, the Canadian Undersea and Hyperbaric Medical Association, or the European Committee for Hyperbaric Medicine.

SENSITIVITY AND SPECIFICITY OF PRE-TREATMENT PULMONARY IMAGING

Chest X-ray is the mainstay of pre-HBOT pulmonary screening tools, largely because of its relatively low cost and minimal radiation dose.[20,44] Its diagnostic sensitivity for minor airspace abnormalities (including bullous and bleb disease) is low,[44] and relevant pathology may go unrecognised despite screening. CXRs are valuable tools for the diagnosis of pathologies such as consolidation and pleural effusion,[44] but have poor interrater reliability and limited specificity for pathologies which do not vary greatly in density.[20] The sensitivity of a CXR for even moderately severe and severe emphysematous changes is only 41%,[45] and minor airspace abnormalities like bullae and blebs can easily be missed. For example, one study describes three cases of pulmonary air cysts missed on CXR, and subsequently found on chest CT scans, in divers who had experienced PBt.[46] CXR is similarly limited in its ability to detect PTX, with a pooled diagnostic sensitivity of only 52%.[47]

In fitness-to-dive assessments CXR had a false negative rate of 32% for the identification of relevant intrapulmonary pathology.[48] The routine use of CXR for the detection of blebs, bullae, cysts, and other airspace disease may not add more to the pre-dive assessment than the individual's medical history.[46,48] This is likely also true for pre-HBOT screening in patients without any risk factors. In patients for whom a significant concern for pulmonary pathology exists, CT imaging has superior diagnostic accuracy.[44]

High-resolution CT has been proposed as a substitute for CXR in pre-HBOT screening, particularly in subjects with clinical indications.[8,12,14,48] The radiation exposure associated with high-resolution CT varies dramatically based on imaging parameters but, if performed conservatively, is comparable to a CXR.[49] While CT is a superior diagnostic tool for airway abnormalities such as pulmonary cysts,[21] it frequently identifies findings of unknown medical significance.[23,48] One study conducted in the emergency department setting noted that 33.4% of the general population had some form of incidental findings on CT imaging, such as pulmonary nodules.[50] Another, conducting postmortem CT chest scans in a sample of the general population (ages 21–71, without lung disease) reported a 33.8% prevalence of small bullae and/or blebs.[26] Incidental, clinically insignificant CT findings may be more prevalent in older patients,[51] and complicate the potential role of CT imaging in 'clearing' patients for HBOT. Additionally, while CT provides information on the presence and size of any relevant pulmonary pathology, it cannot provide guidance on whether the structure can equalise pressure during compression or decompression. While size is an important consideration (larger bullae have higher wall stress and are more likely to rupture than small ones), the relevant consideration for HBOT is whether the structure communicates with the bronchial tree during pressure changes.

CLINICAL INTERPRETATION OF PULMONARY FINDINGS

Because of the shortcomings of imaging modalities available for pre-HBOT screening, how to estimate the risk associated with potential findings is unclear. Many of the studies outlined in Table 1 report respiratory complications of HBOT despite adherence to pre-HBOT imaging protocols and unremarkable imaging studies prior to treatment.[5,7–10,14] The difficulty associated with interpreting incidental imaging findings is highlighted by two case reports detailing patients whose pre-HBOT imaging identified bullous or bleb disease, but who nonetheless proceeded with HBOT and sustained respiratory complications.[6,12]

Without clear evidence to discriminate abnormalities representing an elevated risk for PBt from incidental morphology, the utility of pre-HBOT imaging is limited. In a survey of practice patterns among 98 HBOT centres, a majority of centres reported choosing to proceed with treatment for patients in whom pulmonary blebs or bullous lesions were radiologically identified.[13] Of those centres which did not, 54% screened patients with a history of lung disease using CXR, while a minority screened those with known pathology using CT, high-resolution CT, or spirometry.[13] Some of the surveyed centres reported taking additional precautions when treating patients with identifiable blebs or bullous lesions (such as slower compression/decompression rates, pressure limits, and bronchodilator administration).[13] The applicability of the survey to current practice can be challenged given its age, low response rate (36.8%), and methodological limitations. But among its 98 responding centres, imaging results seldom influenced treatment decisions in a meaningful way.[13] Nonetheless, PBt was still remarkably infrequent among the surveyed centres, with a reported incidence of 0.00045% or nine instances from approximately 2,000,000 HBOT sessions.[13]

Table 1

Previous reports of pulmonary complications during hyperbaric oxygen exposures; data are reported as raw numbers unless otherwise noted. *number of responding hyperbaric centres, not numbers of patients; ARDS – acute respiratory distress syndrome; AGE – arterial gas embolism; CO – carbon monoxide; COPD – chronic obstructive pulmonary disease; CT – computed tomography; CXR – chest radiography; DCS – decompression sickness; F – female; HBOT – hyperbaric oxygen treatment; M – male; N/A – not applicable; NR – not reported; PBt – pulmonary barotrauma; PCT – prospective cohort trial; PTX – pneumothorax; PVD – peripheral vascular disease; US – ultrasound

Citation, country, and study design	Population			HBOT exposure			Pulmonary imaging		
	n	Age, Sex	Patient comorbidities	Exposure indication	Sessions	Respiratory complications	Pulmonary imaging modality	Impact on exposure	Relevant commentary on pre-exposure imaging
Bessereau et al. (2017)[7] France PCT	126	Mean Age: 57 Sex: M = 78 F = 48	ARDS (23%), mechanical ventilation (100%)	DCS, CO poisoning, AGE, soft tissue infection, chronic wounds	Mean = 1	Patient-ventilator asynchrony (*n* = 6)	Imaging modality not specified	Did not inform treatment decision	CXR is limited in identifying small or anterior PTX with certainty. Chest US and tomodensitometry are both better, and physicians should perform more relevant, non-invasive tests.
Cakmak et al. (2015)[8] Turkey Case report	1	Age: 28 Sex: M	ARDS	Lower extremity wounds	7	Tension PTX (*n* = 1)	CXR and CT prior to HBOT – no bullae or blebs. After the 7th session, CT showed total right lung collapse with left mediastinal shift.	Did not inform treatment decision	Sensitivity of the CT scan in the detection of blebs and bullae is 88%. A bleb or bullae that was not detected on CT may be the reason for PTX in the reported patient.
Cho et al. (2018)[9] Japan Case report	1	Age: 31 Sex: M	N/A	CO poisoning	2	Pulmonary oedema (*n* = 1)	Pre-HBOT CXR unremarkable. Repeat CXR after 2nd HBOT session noted pulmonary oedema.	Did not inform treatment decision	NR
Jaeger et al. (2013)[10] USA Case report	1	Age: 5 Sex: M	NR	CO poisoning	1	Pneumo-mediastinum (*n* = 1)	Post-intubation CXR normal. CXR after HBOT found occult pneumo-mediastinum	Did not inform treatment decision	Routine pre- and post-HBOT CXR in intubated patients may prevent or minimise adverse outcomes related to pneumomediastinum
Obiagwu et al. (2015)[11] USA Case report	1	Age: 80 Sex: M	Ischaemic cardio-myopathy, diabetes, PVD	Diabetic foot ulcer	NR	Acute pulmonary embolism (*n* = 1)	No pre-HBOT screening. CXR after HBOT and intubation bilateral alveolar perivascular infiltrates.	N/A	NR

Table 1 continued.

Rivalland et al. (2010)[12] New Zealand Case report	1	Age: 72 Sex: M	COPD, oral squamous cell carcinoma	NR	1	Cerebral AGE (n = 1)	CXR prior to HBOT clearly showed bullous disease in the left upper lobe. Post-HBOT, CXR again demonstrated bullae in the left upper lobe.	Did not inform treatment decision	CXR is appropriate if abnormal respiratory history (e.g., tuberculosis, smoking, or pneumonia). CT is more sensitive for cystic change, but may find insignificant lesions in normal subjects and should probably be reserved for cases where CXR is equivocal and index of suspicion for significant lesions is high.
Toklu et al. (2008)[13] Turkey Survey	98*	NR	NR	NR	NR	PBt (n = 9) from approximately 2,000,000 exposures (0.00045%)	Only 33.7% of centres excluded patients with air cysts, and 54% of these screened patients with known lung disease using CXR. Others used CT or spirometry.	Most centres (66.3%) proceeded regardless of findings on imaging	This survey demonstrated that (1) a large proportion of HBOT centres treat patients with blebs/ bullae, (2) CXR is the most common thoracic screening tool, and (3) the prevalence of PBt is very low in HBOT.
Unsworth et al. (1973)[6] Australia Case report	1	Age: 55 Sex: F = 1	Squamous cell carcinoma, permanent tracheostomy	Wound healing	8	Tension PTX (n = 1)	Pre-HBOT CXRs showed COPD and right middle lobe (inflammatory or neoplastic) opacity. Post-HBOT CXR noted right-sided tension PTX.	Did not inform treatment decision	Some patients may be excluded from HBOT based on history or physical examination alone. CXR and pulmonary function studies using spirometry and nitrogen or helium washout patterns may add value.

Table 2

Previous reports of pulmonary complications during hyperbaric air exposures; data are reported as raw numbers unless otherwise noted. The exposure indication in all cases was routine pressure tolerance testing or a dry dive experience. AGE – arterial gas embolism; CT – computed tomography; CXR – chest radiography; HBOT – hyperbaric oxygen treatment; M – male; N/A – not applicable; PBt – pulmonary barotrauma

Citation, country, and study design	Population			Hyperbaric exposure		Pulmonary imaging		
	n	Age, Sex	Comorbidities	*n*	Respiratory complications	Pulmonary imaging modality	Impact on exposure	Relevant commentary on pre-exposure imaging
Buschmann et al. (2010)[14] South Africa Case series	2	Mean Age: 30 Sex: M = 2	N/A	1	AGE (*n* = 2)	Case 1: CXR on day 1 was normal. A CT chest on day 2 noted a 2.5 cm right basal subpleural bleb/bulla. Case 2: CT (chest) on day 8 was normal.	Did not inform treatment decision	CXR is commonly performed but based on weak evidence. CT more sensitive, but cost may not be justified with an overall low incidence of PBt/AGE and an unclear relationship between findings and pulmonary risk of barotrauma. Lung compliance rather than anatomical lesions (blebs/bullae), may guide risk.
Tan et al. (2020)[15] Singapore Case report	1	Age: 26 Sex: M	N/A	N/A	N/A	Lateral pre-exposure CXR revealed a left lower lobe pulmonary nodule. A chest CT then diagnosed a cavitary left lower lobe (intralobar) broncho-pulmonary sequestration.	Did not inform treatment decision	Bronchopulmonary sequestrations and other air-filled parenchymal lesions should contraindicate diving (but the patient was still considered eligible for HBOT). Although this case supports routine use of lateral CXR in pre-diving health screening, its marginal utility should be weighed against costs (financial, radiation exposure, and false positive rates).
Tetzlaff et al. (1999)[5] Germany Case report	1	Age: 46 Sex: M	Pulmonary sarcoidosis (discovered after hyperbaric exposure)	1	AGE (*n* = 1)	CXR was normal four years pre-exposure. Post-exposure CXR showed bilateral middle and upper lobe infiltrates. CT showed scarring in both lungs.	Did not inform treatment decision	Case illustrates a potential risk of PBt during hyperbaric exposure, even in asymptomatic subjects with normal imaging. Authors emphasise careful evaluation of spirometry and CXR in patients undergoing hyperbaric exposure.

Table 3

High-risk features in the general population; prevalence of high-risk features for pulmonary complications of hyperbaric oxygen treatment, including pulmonary blebs and bullae, other emphysematous changes, pulmonary fibrosis, and sarcoidosis. Data are reported as percentage of study population or number per 100,000 patients. CAD – coronary artery disease; CXR – chest radiography; CT – computed tomography; NR – not reported

High-risk feature	Study population	Screening method	Prevalence	Citation
Pulmonary blebs only	Dutch population without pulmonary disorders	Post-mortem CT imaging	24.6% (32/130)	de Bakker et al. (2020)[26]
	Young healthy adults	Thoracoscopy	6.0% (15/250)	Amjadi et al. (2007)[25]
Pulmonary blebs and bullae	Dutch population without pulmonary disorders	Post-mortem CT imaging	6.9% (9/130)	de Bakker et al. (2020)[26]
Pulmonary bullae only	Dutch population without pulmonary disorders	Post-mortem CT imaging	2.3% (3/130)	de Bakker et al. (2020)[26]
	Patients with CAD	CT angiography	5.8% (10/171)	Yorgun et al. (2010)[27]
Other emphysematous changes	Adult trauma patients	Spiral CT	14.2% (297/2092)	Barrett et al. (2009)[28]
	Patients with CAD	CT angiography	16.4% (28/171)	Yorgun et al. (2010)[27]
Incidental pulmonary nodules	Adult trauma patients	Spiral CT	10.9% (229/2092)	Barrett et al. (2009)[28]
	General population	CT angiography	12.8% (33/258)	Gil et al. (2007)[29]
	Cardiac patients	Electron-beam CT	4.8% (65/1356)	Horton et al. (2002)[30]
	Cardiac patients	Electron-beam CT	0.44% (8/1812)	Hunold et al. (2001)[31]
	Cardiac patients	Cardiac CT	2.4% (4/166)	Haller et al. (2006)[32]
	Cardiac patients	Cardiac CT	6.6% (33/503)	Onuma et al. (2006)[33]
	Cardiac patients	CT angiography	48.5% (83/171)	Yorgun et al. (2010)[27]
Pulmonary fibrosis	General Population (Quebec, Canada)	NR	0.08% (76/100,000)	Tarride et al. (2018)[34]
	General population, ages 16–84 (USA)	NR	0.0099% (9.85/100,000)	Raghu et al. (2016)[35]
Sarcoidosis	General adult population (USA)	NR	0.88% (29,372/3,340,000)	Baughman et al. (2016)[36]
	General population, ages 20–69 (USA)	CXR or histology	0.03% (259/830,891)	Rybicki et al. (1997)[37]

Considering the relatively high incidence of otherwise-benign pulmonary lesions in the general population and the low incidence of pulmonary complications following HBOT, we can conclude that many patients with pulmonary abnormalities are routinely undergoing HBOT without any observed complications. A patient with relevant pulmonary abnormalities is more likely to have unremarkable pre-treatment CXR imaging than they are to experience iatrogenic pulmonary complications during HBOT. Based on an incidence for PBt during HBOT of 0.00045%,[13] the number needed to treat (NNT) to prevent one case of barotrauma would be 2,222 if there was a perfectly sensitive and specific tool to identify patients certain to experience that complication. In reality, the NNT must be much higher to account for both the limitations in CXR sensitivity and the unknown likelihood that an identified abnormality will predispose to barotrauma. In current practice, if patients identified as having radiological risk factors for PBt are not actually excluded from HBOT, the NNT of CXR is infinity.

Table 4
Low-risk features of patient history and physical exam which may be reassuring of low-risk for pulmonary complications following hyperbaric oxygen treatment. ARDS – acute respiratory distress syndrome; COPD – chronic obstructive pulmonary disease; HBOT – hyperbaric oxygen treatment PTX – pneumothorax

Possible low-risk features
No history, symptoms, or physical exam findings of asthma, COPD, pulmonary fibrosis, sarcoidosis, PTX, or ARDS
Unremarkable thoracic imaging, if previously performed and available for review
Previous HBOT without incident
History of scuba diving or air travel without incident
Age < 40 years
Non-smoker

Based on the current evidence, we suggest that thousands of patients would have to undergo pulmonary imaging – with its own associated costs and risks – to prevent one from undergoing HBOT and developing PBt. The process would also exclude patients who would not have otherwise sustained barotrauma, and could also include some who would suffer it nonetheless. Given the challenges in applying imaging findings to the clinical determination of which patients are safe to endure hyperbaric conditions, we suggest that pre-HBOT imaging adds very little to a thorough history and physical exam in low-risk populations.

RISK STRATIFICATION BEYOND PRE-TREATMENT IMAGING

Pre-HBOT imaging can (sometimes) provide information on whether a patient has intrathoracic anatomical abnormalities, but it can offer little guidance on whether those abnormalities are likely to cause problems in the hyperbaric chamber. We instead draw on common features of patients reported as having experienced PBt during HBOT in the scientific literature[4–12,14,15] to suggest a checklist of possible clinical indicators of relatively low risk for pulmonary complications of HBOT (for whom imaging may have the least to offer). These features include: the absence of pre-existing obstructive lung diseases, restrictive lung diseases, PTX, or ARDS; a history of HBOT, scuba diving, or air travel without incident; age younger than 40 years; and non-smoking (Table 4). When prior thoracic imaging is available, especially if it is recently performed, it should be reviewed.

The risk factors for spontaneous pneumothoraces or emphysematous lung changes (e.g., younger age, male sex, low body mass index, pulmonary infection, and cigarette and/or marijuana smoking),[46,52–54] which are themselves predictors of PBt during HBOT, may also indirectly inform hyperbaric exposure risk. Based on the available evidence, and clinical experience, a practical clinical risk tool is provided in *Appendix 2 (in the form of a questionnaire) to support clinicians' and patients' decisions to pursue or forego chest imaging prior to HBOT.

ROUTINE PULMONARY SCREENING BEFORE OTHER VOCATIONAL OR RECREATIONAL HYPERBARIC EXPOSURES

While the present article focuses on pulmonary screening prior to HBOT, its findings are applicable to medical assessments preceding other hyperbaric exposures. Pulmonary barotrauma occurring in divers is well described,[55,56] and the risk can be extrapolated to others working in environments prone to rapid atmospheric compression and decompression, such as caisson or compressed air workers. The incidence of PBt in these groups has not been clearly defined, but reports of affected divers have identified several risk factors including airway obstruction, pre-existing respiratory disease or structural parenchymal abnormality (e.g., bullae or blebs), or a reduced mid-expiratory flow at 25% of vital capacity.[57–59]

Despite the risk of PBt associated with compression and decompression in these contexts, whether pulmonary imaging is required as part of the standard medical assessment of prospective commercial or recreational divers remains controversial. Recognising the low yield of a screening CXR, the guidelines of some national organisations (such as the UK Health and Safety Executive)[60] and many major sources of knowledge in the field suggest that CXR is not a requirement unless justified by heightened individual risk.[61,62] Others, in contrast, have suggested that there is a role for routine CXR screening for all prospective divers,[63] or at least for professional divers/diving instructors.[46,64] When pulmonary screening is warranted by local policy or a high index of suspicion for PBT-predisposing factors, high-resolution CT imaging has been advocated as a potential tool for the initial examination of divers,[46,65] although this is not currently practical in many settings.

The pre-HBOT risk stratification checklist presented in Table 4 overlaps with, and can be supplemented by, the known risk factors identified for PBt among divers such as pre-existing respiratory disease and blebs/bullae.[57,58] However, the precise risk profiles of HBOT and other hyperbaric exposures may differ. For example, compression/

Footnote: *Appendix 2 is available on DHM Journal's website:
https://www.dhmjournal.com/images/Appendices/52_3/Brenna_Pulmonary_Appendix2_2022-523.pdf

decompression injury during diving typically involves much faster pressure change and relates largely to nitrogen, which is inert and less soluble, while oxygen (in HBOT) is more soluble and metabolically consumed. These differences may help explain the relative rarity of AGE during HBOT, which we found reported in only two case studies.[4,12]

LIMITATIONS

The core limitation of this review is its susceptibility to publication bias. Cases where pulmonary complications were avoided via the identification of bullae or blebs on pre-HBOT imaging are almost certainly under-reported in the literature, although survey data suggest most centres do not consider CXR findings of bullae or blebs to be an absolute contraindication to HBOT, and routinely proceed with treatment – with a very low overall incidence of PBt.[13] This core limitation could be overcome in the future by using an international multicentre hyperbaric oxygen treatment registry[66] designed to collect and analyse outcomes and complications related to HBOT exposures.

Conclusions

This review highlights the limitations of routine pulmonary imaging as a screening tool prior to HBOT. Reports of PBt during HBOT often describe patients with known pre-existing pulmonary pathology (e.g., asthma, COPD, pulmonary fibrosis, sarcoidosis, PTX, or ARDS) or occult intrathoracic abnormalities (e.g., bullous lesions or blebs). Abnormalities which might be considered to increase the risk of pulmonary complication during HBOT are common, even among otherwise healthy individuals without any pulmonary disease. Importantly, normal pre-HBOT CXR does not preclude patients from developing barotrauma. The use of routine imaging prior to HBOT does not provide a reliable way to reduce the risk of iatrogenic injury in low-risk populations. In high-risk patients or when clinical findings are unclear (e.g., unable to rule out a PTX), high-resolution CT imaging may be a superior test for the identification of airway or parenchymal lung disease in carefully selected patients. The presence of an abnormality on CT scan, however, does not provide a dependable measure of whether the lesion might rupture or leak with changes in atmospheric pressure. Ultimately, the provider will need to use clinical judgement when determining how to proceed for patients deemed high-risk for respiratory complications of HBOT.

A thorough approach to patients' past medical histories and physical examinations are more relevant steps in assessing the risk for iatrogenic respiratory complications related to HBOT. Further research is needed to characterise how specific features of patients' demographic and past medical history may influence the risk of iatrogenic lung injury during HBOT. This review suggests that, for low-risk individuals, HBOT can proceed without pre-treatment chest imaging.

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Short communication

Effect of hyperbaric oxygen treatment on skin elasticity in irradiated patients

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Breast cancer; Fibrosis; Late radiation tissue injuries; Radiotherapy; Radionecrosis

Abstract
(Pandey K, Teguh DN, van Hulst RA. Effect of hyperbaric oxygen treatment on skin elasticity in irradiated patients. Diving and Hyperbaric Medicine. 2022 30 September;52(3):208–212. doi: 10.28920/dhm52.3.208-212. PMID: 36100932.)
Background: Hyperbaric oxygen treatment (HBOT) is often used in an attempt to reverse/treat late radiation-induced tissue fibrosis (LRITF). This study aimed to quantify the effects on skin elasticity.
Methods: Skin retraction time was used as a marker of skin elasticity in 13 irradiated breast cancer patients. The measurements were carried out on the affected side as well as the unaffected/healthy side at a mirrored location. Readings were taken at the start and end of HBOT (mean 43 sessions, 80 min at 243 kPa).
Results: Patient age ranged from 39–70 years. All patients underwent surgical lumpectomy and radiotherapy prior to undergoing HBOT. The mean time between radiotherapy and HBOT was 70 months. Seven of the 13 patients underwent chemotherapy. Mean irradiated skin retraction time improved from 417 (SD 158) pre-HBOT to 171 (24) msec post-HBOT ($P < 0.001$). Mean pre-HBOT retraction time in the non-irradiated skin was 143 (20) msec and did not change.
Conclusions: This promising pilot study that suggests that HBOT may improve skin elasticity in patients with LRITF.

Introduction

Breast cancer is the most common cancer in women in Europe. It represents around 25% of all types of cancers worldwide.[1] A woman with no current risk factors has a cumulative risk of 9% of getting breast cancer over a lifetime of 74 years.[1] Female breast cancer had a 5-year survival rate of 84% in 2020.[1]

Prognosis strongly depends on the stage of the cancer at the time of diagnosis. Currently, there are five known treatment options for breast cancer: surgery, radiotherapy, chemotherapy, hormone therapy and targeted therapy.[2]

Most breast cancer patients undergo multi modal therapy including radiation.[3] Repeated radiation triggers a chronic inflammatory response causing pain and discomfort. It adversely affects normal surrounding tissues, which can become hypoxic, hypocellular and hypovascular, often described as '3 H tissue'.[4] This radiation injury results in delayed and inadequate surgical wound healing.[4] In many patients, radiation and surgery is accompanied by chemotherapy. This combination though, increases the severity of late radiation induced tissue fibrosis (LRITF).[5]

Current therapies for LRITF include hyperbaric oxygen treatment (HBOT), anti-inflammatory treatment with corticosteroids or interferon gamma, vascular therapy with pentoxifylline and antioxidant treatment with dismutase, pain management with medication, physiotherapy and oedema therapy.[6]

Late radiation-induced effects, as discussed in this study, are defined as occurring at least three months after the use of radiation.[7] HBOT has long and short term effects on LRITF.[8] Short-term effects include oedema reduction, phagocytosis activation, and anti-inflammatory effects.[8] Long-term effects include neovascularization, osteoneogenesis, and stimulation of collagen formation by fibroblasts.[9] HBOT induces significant angiogenesis and mobilisation of stem cells from the bone marrow, leading to wound healing and recovery of radiation injury.[2] HBOT creates a steep oxygen gradient from the atmosphere to the patient's body making large amounts of dissolved oxygen available in tissues fueling angiogenesis and improving white cell and fibroblast function.[10,11]

Breast cancer patients receiving HBOT for LRITF have reported improvements in quality of life, functionality

and lower pain scores.[10] These outcomes are based on patient-reported outcome measures (PROMS), without any objective assessment. In the absence of objective outcome quantification, it is difficult to include HBOT as a standard form of treatment for LRITF management.

In this pilot study we aimed to objectively measure the effect of HBOT on LRITF by quantifying skin-elasticity using the DermaLab® suction cup (Cortex Technology, Hadsund, Denmark) which has been used for measuring skin-elasticity as well as radiation fibrosis in the past.[12,13]

Methods

The Medical Ethics Committee affiliated with the Amsterdam University Medical Center approved our methods of handling personal details and privacy and concluded that they were concordant with the guidelines of the Association of the Universities in the NL and declaration of Helsinki.

This was a prospective pilot study quantifying the effects of HBOT on LRITF. Breast cancer patients, from a variety of racial/ethnic groups, treated with surgery followed by radiation, and with complaints of LRITF were included. The study was conducted from May to December 2020. Informed consent was obtained before commencement of HBOT. Patients were chosen on a voluntary basis and were free to opt out at any point during the study.

HBOT consisted of 43 sessions on average: one session a day, five days a week for eight weeks. Each session lasted 115 minutes. The subjects breathed 100% oxygen at 243 kPa (2.4 atmospheres absolute [atm abs]) for a total of 80 minutes (four 20-minute periods with intervening five-minute breaks during which they breathed air).

The skin-elasticity of the area affected with LRITF was measured using the commercially available skin testing device DermaLab Suction Cup® (Cortex Technologies, Denmark) through skin retraction time, an inverse measure of skin-elasticity: the higher the skin retraction time, the lower the elasticity. A vacuum probe on the skin measured the stress necessary to achieve a given transformation.[12] Although the device provided multiple derived variables, this study considered the directly measured variable of skin retraction time.[14] The location with the most pain, discomfort and the subsequent highest retraction time was chosen as the measurement site.

The measurements were carried out at the start and end of HBOT on the irradiated breast (test) as well as a mirror location on the non-irradiated breast (control). Each measurement was carried out thrice and the mean was used for data tabulation.[15] The test and control locations were marked with a permanent marker.

A paired Student's *t*-test was carried out using Microsoft Excel (Version 14.4.1) to test the difference between pre- and post-HBO_2 skin retraction time. Data were reported as mean (standard deviation [SD]), and a *P*-value of < 0.05 was considered to be significant.

Results

The study group consisted of 13 women ranging from 39 to 70 years of age, with a mean age of 56 years (Table 1). Four underwent 40 HBOT sessions, five underwent more than 40 sessions, and four less than 40 sessions. The lowest number of sessions completed was 35. One patient was retreated (after earlier HBOT in 2019) due to a recurrence of LRITF-associated problems. The average number of sessions was 43.

At the start of treatment, the skin retraction time at the irradiated site was significantly higher than the control site. There was a significant reduction in skin retraction time for the irradiated site at the end of HBOT compared to that at the start. Skin retraction time for the control area did not change significantly over the course of HBOT. The results showed a significant improvement in radiation-site

Table 1
Demographic and clinical characteristics of the study population

Characteristics of Study population (*n* = 13)	
Age (years)	
Mean	56
Median (range)	54 (39–70)
Radiotherapy	
Yes	13
No	0
Time since radiotherapy (months)	
Mean	70
Median (range)	54 (8–247)
Maximum radiotherapy dose (Gy)	
Mean	55.2
Median (range)	55.9 (50–55.9)
Chemotherapy	
Yes	11
No	0
Unknown	2
Surgery (Lumpectomy)	
Yes	13
No	0
Unknown	0

Table 2
Pre- and post-HBOT skin retraction times (in milliseconds)

Patient	Radiated breast		Non-radiated breast		HBOT sessions (*n*)
	Pre-HBOT	Post-HBOT	Pre-HBOT	Post-HBOT	
1	481	161	121	114	36
2	326	149	120	121	50
3	514	201	180	180	49
4	346	167	146	148	36
5	314	151	144	144	38
6	762	176	123	124	40
7	386	146	145	146	47
8	263	158	147	145	40
9	222	174	161	167	40
10	262	162	143	143	60
11	292	147	174	173	40
12	687	226	122	115	35
13	446	199	131	135	50
Mean (SD)	417 (158)	171 (24)	143 (20)	143 (21)	43 (7)
Δ Retraction time	246.00		0.15		
***P*-value**	$P < 0.001$		$P = 0.8824$		

skin-elasticity (reduction in skin retraction time) of all post-radiation therapy breast cancer patients included in this pilot. The improvement in skin-elasticity was statistically significant ($P < 0.001$) (Table 2). There were no HBOT related complications in this study.

Discussion

This pilot study shows that HBOT may significantly improve skin-elasticity in breast-cancer patients with LRITF. All 13 patients in this study showed an increase in skin-elasticity. Radiation induces fibrosis of the skin and underlying tissue, causing loss of local function, pain and discomfort. The objective measurements suggesting improvement in skin-elasticity following HBOT reported here indicate its effectiveness in the management of LRITF.

Worldwide, radiation therapy is a part of the multimodal breast cancer treatment, reducing local recurrence and increasing disease-free survival.[16,17] It frequently results in thickening, fibrosis, and inflammation of the irradiated skin as a consequence of radiation-induced tissue toxicity.[18] This often results in severe fibrosis and pain. Fibrosis may also lead to altered breast appearance causing severe psycho-sexual consequences.

Irradiation as described above can result in substantial thickening of the skin and damage of deeper structures (such as muscle) as a result of fibrosis.[19] This widespread fibrosis can lead to pain, discomfort and a reduced quality of life.[20] Chronic effects of LRITF include fibrosis, skin atrophy and ulceration with impaired healing. HBOT in this group of patients can not only help with improvement in pain, fibrosis, and oedema, but also be used pre- and post-procedure for future breast related cosmetic surgery.[3,21]

There have been a multitude of therapeutic options described for the management of post-radiation fibrosis including physical massage, use of antioxidants, use of superficial lotions and gels, and fat grafting of the affected area. HBOT is an approved option for radiation-induced fibrosis and is widely used to aid wound healing, reduce fibrosis, reduce pain and discomfort related to LRITF.[3] HBOT promotes tissue regeneration and wound healing with the help of local and systemic effects.[18] It seems to do this through a series of changes in tissues such as hypoxia reversal, radical stress and lactate concentration.[22] These stimuli result in release of vascular endothelial growth factors, promoting new blood vessel formation. Additionally, oxygen delivery also aids in white cell and fibroblast recruitment, further aiding wound healing. As with many therapies, HBOT is not free of risks, but it is relatively safe with a very low complication rate.[23] Occasionally it can cause side effects such as barotrauma, central nervous system and pulmonary oxygen toxicity and hyperoxic myopia.[8,23] Middle ear barotrauma is one of the most common issues.[23]

LRITF is strongly related to the cumulative radiation dose.[18] The average radiation given to the patients in this study is consistent with the doses required to cause LRITF.[13] Previous studies have shown that LRITF of swallowing muscles was observed when a radiation dose of 46–70 Gy was given.[24] In this study however, there appeared to be no correlation between the amount of radiation received and baseline skin elasticity in the damaged breast. This could partly be due to the small variance in the radiation dosage used.

Quantification of retraction times could play an important role in assessing superficial-induced fibrosis. Few relevant data are available. One study showed the mean healthy skin retraction times in the upper arm to be 392 ms.[25] While this value is higher than the values we observed for healthy skin retraction times, it is important to note that this study only measured retraction times for the arm. Furthermore, previous studies also show that with an increase in age, a decrease in skin elasticity is observed.[26]

Being a pilot study, it had its own limitations in the form of a small population, a lack of controls and variable time between the end of radiotherapy and the start of HBOT. A key limitation related to the DermaLab method was the fact that it did not measure deep-situated tissues.[27] As the maximum suction that the DermaLab could apply was only 15.625 millipascal, retraction times for deeper situated tissues could not be measured.[27]

The small study population is a limitation. A larger definitive study could be designed using a power calculation based on the present data to ensure that the appropriate number of participants have been chosen. A control group consisting of similar patients who did not undergo HBOT would be added. Future projects investigating the quantitative as well as qualitative effects of HBOT would be optimal in order to shed more light on the efficacy of HBOT in this group of patients.

Conclusion

In conclusion, this promising pilot study has shown that HBOT may provide benefit in patients suffering from LRITF. Despite numerous medical advances in the past decade, measuring fibrosis and the rate of fibrosis remains a challenge. The DermaLab device has proven to be a reliable apparatus in terms of measuring LRITF. A prospective controlled trial using PROMS along with quantitative measurements through the use of DermaLab Suction Cup is currently in preparation at our center.

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Case reports

Recurrent dysbarism presenting with amnesia and hypoaesthesia in a professional breath-hold diver

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Breath-hold diving; Decompression sickness; Hyperbaric oxygen; Apnoea; Free diving

Abstract

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Dysbarism is a medical condition arising from change in ambient pressure which outpace the rate at which the body adapts to it. We report a case of recurrent dysbarism consistent with possible decompression illness presenting with amnesia, hypoaesthesia and other neurological manifestations in a professional breath-hold diver treated successfully with hyperbaric oxygen and fluid resuscitation.

Introduction

Dysbarism is a medical condition arising from changes in ambient pressure that outpace the rate at which the body adapts to it. This encompasses decompression sickness (DCS), nitrogen narcosis, high-pressure neurological syndrome, barotrauma, and arterial gas embolism (AGE).[1]

Two of these dysbaric conditions (DCS and AGE) involve bubble formation, and it may be difficult to distinguish between them clinically. For that reason they are sometimes referred to collectively as 'decompression illness' (DCI).[2] DCS is a multi-system condition that arises when dissolved gas molecules, primarily composed of nitrogen, emerge from solution and form bubbles within body tissues.[2] This occurs due to inadequate elimination of dissolved gas during ascent from a dive, and thus decompressing from high underwater pressure to atmospheric pressure.[3] AGE can occur when expanding gas causes pulmonary barotrauma, introducing bubbles into the arterial circulation.[2]

Professional breath-hold divers achieve great depths with fast descents and ascents with the practice of glossopharyngeal insufflation (often referred to as 'lung packing') and exsufflation; the latter being a strategy that facilitates equalising of paranasal sinuses and the middle ear. The deeper and longer breath-hold dives place them at an increased risk of DCS.[4]

We report a case of a professional breath-hold diver with recurrent dysbarism consistent with possible DCI. He presented with amnesia, hypoaesthesia and other neurological manifestations treated successfully with hyperbaric oxygen and fluid resuscitation.

Case report

The patient provided consent for publication of their case.

A 52-year-old male professional breath-hold diver carried out three recreational breath-hold dives accompanied by a diving buddy. The dives took place in calm seawater during winter season, with water temperature on the day of diving averaging 16°C. He completed the following dives without lung packing:

- Dive 1: maximum depth 33 metres of seawater (msw), total dive time (TDT) 1–2 min followed by a 5–6 min surface interval;
- Dive 2: maximum depth 42 msw, TDT 2 min 30 sec followed by an 8–9 min surface interval;
- Dive 3: maximum depth 60 msw, TDT 2 min 30 sec.

Within 10 minutes of surfacing from his last dive, he noted difficulty coordinating his right lower limb while swimming back to shore. He was offered assistance by his diving buddy which he refused. He completed a difficult water exit over uneven rocks independently and drove home unassisted. After 50 minutes, his right lower limb ataxia resolved spontaneously but was followed shortly by less severe ataxia in his left lower limb, described by the patient as "*difficulty with coordination*". This also lasted approximately 50 minutes and was associated with bilateral paraesthesia in the hands. These symptoms then resolved. He also noted non-vertiginous dizziness but denied any urinary incontinence or

urinary problems. Six hours later, he developed a right frontal headache which rapidly became bifrontal, radiating to the back of his head in a band-like distribution. He described it as a "*pressure*" sensation without throbbing and denied any preceding aura. It was associated with mild photophobia.

Approximately 24 hours later, the patient was well and he completed another three breath-hold dives uneventfully with 5-minute surface intervals:

- Dive 1: maximum depth 33 msw, TDT 1 min;
- Dive 2: maximum depth 40 msw, TDT 2 min;
- Dive 3: maximum depth 53 msw, TDT 2 min 30 sec.

Approximately 48 hours later, the patient mentioned that he had a headache and dizziness. He attributed the symptoms to caffeine intake and proceeded to dive as follows, again with 5-minute surface intervals:

- Dive 1: maximum depth 10–12msw, TDT 1 min;
- Dive 2: maximum depth 35 msw, TDT 2 min, after which the patient mentioned to his diving buddy that the headache had disappeared at the deepest point of the dive;
- Dive 3: maximum depth 45 msw, TDT of 2 min 30 sec.

Approximately 72 hours later, the patient presented to an accident and emergency department complaining of unresolved, severe, band-like headache and dizziness. He was noted to be alert and oriented to place and person but was unable to give a clear history and chronology of events. He did not recall that there was a third participating diver on two of the diving days, as well as being unsure whether he himself was diving on those days. A collateral history was therefore obtained from the diving buddy.

On examination the patient was comfortable breathing air with a Glasgow Coma Scale of 15. His vital signs were stable and a cardiorespiratory examination was within normal limits. Hamman's sign was negative and there was no subcutaneous emphysema. There was no neck stiffness, no rashes and he was afebrile.

Neurological examination did not elicit pyramidal drift or cerebellar signs. Tone, power, reflexes and gait were normal throughout. Serial sevens (subtraction) were assessed and he achieved 5/5. Hypoaesthesia was present over the lateral aspect of the foot. Visual acuity was 6/6 bilaterally and visual fields were normal. No nystagmus was found. Further cranial nerve assessment was normal apart from longstanding hearing loss on the left side present since childhood. An unenhanced CT brain was performed and no abnormalities were detected.

The case was managed jointly by a specialist in diving medicine and a consultant neurologist. Intravenous crystalloid infusion, paracetamol and aspirin were administered and the patient was transferred urgently to the hyperbaric unit where he was recompressed as per US Navy Treatment Table 6 for suspected DCI.

The patient's headache decreased in intensity during the 2nd oxygen period at 284 kPa (18 msw equivalent). At 192 kPa (9 msw equivalent), the patient was able to answer questions about the last three days correctly, with answers tallying with his diving buddy's version of events.

On completion of the US Navy Treatment Table 6, the patient mobilised with a normal gait. Sensation was found to be normal with resolution of the previous sign. He claimed to be feeling better and that his dizziness had resolved. He was transferred to a general acute hospital for an urgent magnetic resonance imaging (MRI) scan which detected no intracranial abnormalities. He remained neurologically intact and was discharged home. A follow-up transthoracic echocardiogram with agitated saline bubble contrast study showed normal cardiac function and no evidence of a right-to-left shunt, including no late passage of bubbles into the left atrium.

The patient was otherwise healthy and a non-smoker. Interestingly, he gave a history of apparent dysbarism secondary to breath-hold diving 11 years earlier experienced while training for a competition. On this occasion, he had dived to 40 msw for a TDT of 1 min 30 sec, followed by a 90 msw dive. Ten minutes after surfacing, he had experienced numbness in his left thigh and calf and was treated in a hyperbaric chamber for 2.5 hrs at 284 kPa with resolution of symptoms. These dives had been preceded by two dives to 95 msw and two dives to 40 msw in the prior 72 hours.

Discussion

We present a case of recurrent dysbarism in a professional breath-hold diver with no known risk factors. One specific form of dysbarism in breath-hold divers is DCI involving either AGE or DCS or both. Taravana syndrome is a form of DCS resulting from multiple deep breath-hold dives with short surface intervals. It was first reported in the Polynesian harvester divers of the Tuamotu archipelago, where '*Tara*' means '*to fall*', and '*vana*' means '*crazily*'.[5] The combination of significant depths and short surface intervals predisposed them to clinical manifestations of Taravana syndrome.[6] The symptoms include headache, dizziness, hemiparesis/hemiplegia and disturbance of consciousness.[7,8]

In the present case, the temporal relation of the onset of neurological manifestations to a pattern of deep dives with short surface intervals provides reasonable indication that this was a case of DCI. However, the duration of the dives and the relatively mild symptoms somewhat contrast with classical Taravana syndrome described in the literature. A diving pattern resulting in Taravana syndrome typically involves 20 to 60 dives per hour for anywhere between 2 to 6 hours daily, unlike the presented case where a maximum of three dives were completed per day. Moreover, symptoms such as hemiparesis, speech disturbance and visual deficits typical of Taravana were absent.[9]

Taravana patients typically demonstrate ischaemic lesions on MRI that are compatible with neurological findings, before and after recompression,[10,11] yet the present case had normal MRI findings after recompression. Despite MRI being considered a relatively sensitive test, the diffuse and patchy nature of spinal and cerebral damage following DCS poses difficulty in identifying lesions definitive of neurologic involvement.[12] The case has thus been described as recurrent dysbarism, perhaps a manifestation of DCI, following breath-hold diving rather than being characterised as 'Taravana syndrome'.

One of the main presenting signs was an altered memory of events which interestingly appears to have occurred after an initial dysbaric injury and persisted in the three following days of diving until the diver sought medical assistance. Unfortunately, a formal cognitive assessment was not performed. Hence, the symptoms and response to hyperbaric oxygen treatment were subjectively reported.

Venous bubbling has been noted using echocardiography after repetitive deep breath-hold diving.[13] Our patient experienced two lifetime episodes of dysbarism, yet a right-to-left intracardiac shunt was not found. It is possible that an unidentified risk factor for dysbarism following breath-hold diving may exist. For example, it is possible that right-to-left shunting via intrapulmonary arteriovenous anastomoses (IPAVA) may have occurred in our patient despite an unremarkable follow-up bubble contrast echocardiogram. Interestingly, shunting via IPAVA may be a gas-dependent mechanism, whereby hypoxic conditions exacerbate the right-to-left shunting. Compelling evidence can be found in a study on healthy adults exposed to a gas mixture with a reduced inspired oxygen fraction of 10%. This led to opening of the IPAVA in all subjects at rest.[14,15] Furthermore, another study in which subjects were exposed to hypoxic conditions during exercise reported all participants exhibited a hypoxia-induced intrapulmonary shunt.[16] It is also possible in the present case that a PFO existed but was unidentified due to pitfalls during the transthoracic echocardiogram. For example, the Eustachian valve can divert bubble contrast away from the interatrial septum posing challenges in identification of a PFO. This phenomenon may be reduced by Valsalva, inspiratory sniff or abdominal pressure manoeuvres which provoke an increase in pressure in the right atrium.[17]

It is plausible that our patient experienced anterograde amnesia secondary to dysbarism, with symptoms persisting 72 hours later. In one study the impact of long-term training in breath-hold diving on neurocognitive function in three different groups of men stratified by apnoea performance was investigated. A negative correlation was reported between neurocognitive test performance and length of diving career, as well as between neurocognitive test performance and static apnoea duration. This indicated short-term memory loss associated with the years of apnoea training.[18] Sub-clinical or frank Taravana syndrome may be an underreported contributing factor to these findings, however more studies are needed in this regard.

An important differential diagnosis to be considered is pulmonary barotrauma leading to arterial gas embolism. Cases of arterial gas embolism following breath-hold diving are rare, but have been documented.[19,20] The onset of symptoms beyond five minutes and the absence of other signs and symptoms suggestive of pulmonary barotrauma in the history and clinical examination make this diagnosis less likely. Typically, patients with AGE present acutely with loss of consciousness, altered mental status, hemiparesis, seizures, or focal neurological deficits immediately after surfacing.[21]

Conclusion

Dysbarism in some form is a rare but well-documented complication of breath-hold diving. This phenomenon is typically associated with repetitive deep breath-hold dives interspersed by short surface intervals. Delayed presentation for medical advice may occur, in particular, if symptoms are mild. It is possible that an unidentified risk factor for dysbarism following breath-hold diving may exist especially in recurrent cases. Neurological symptoms following breath-hold diving merit prompt recompression in a hyperbaric chamber using hyperbaric oxygen, and fluid resuscitation. Further efforts are required to raise awareness in the freediving community about the nature of this disease and its treatment.

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Takotsubo cardiomyopathy findings on cardiac magnetic resonance imaging following immersion pulmonary oedema

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Abstract

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Immersion pulmonary oedema (IPO) can affect sea swimmers, snorkelers, and scuba divers. It can be fatal and cases are often mistaken for drowning. There has been an association between IPO and the development of takotsubo cardiomyopathy. We present a case study of a diver rescued from the water with IPO, who was subsequently found to have takotsubo cardiomyopathy on cardiac magnetic resonance imaging (CMR). This case demonstrates CMR findings as well as follow-up investigation results. The diver's and instructor's perspective during the initial dive incident are also described.

Introduction

Immersion pulmonary oedema (IPO) has been implicated in several serious diving incidents over the past few years.[1–2] Although most divers recover fully once out of the water, there are some where impaired left ventricular function is identified, a feature not typically associated with IPO, but likely linked to a concurrent stress cardiomyopathy.[3–6] Takotsubo cardiomyopathy is a transient myocardial dysfunction that mimics an acute coronary syndrome, presenting with similar symptoms (chest pain, shortness of breath), ischaemic electrocardiograph (ECG) changes, and a troponin rise. Characteristically, there is a reversible left ventricular regional wall abnormality disassociated from the coronary arteries. It is most common in post-menopausal women and is sometimes associated with a physical or emotional trigger.[7]

Whilst the link between takotsubo cardiomyopathy and IPO is well documented, no reports have presented cardiac magnetic resonance imaging (CMR) findings. CMR provides the gold standard for functional imaging in suspected takotsubo cardiomyopathy providing assessment of left ventricular (LV) and right ventricular (RV) volume and function, regional wall motion abnormalities, and uniquely assessing myocardial tissue characterisation.[7]

Case report

The patient consented to the reporting of their case.

A 54-year-old female was diving off the south coast of England in 12°C water, wearing a 7 mm wetsuit and breathing air on open-circuit scuba. She was previously well and taking no regular medications. She descended to 9.4 metres of seawater for 36 minutes before experiencing difficulty inhaling from her regulator. She signalled out of air (despite having adequate gas supply), inducing panic and triggering ascent to the surface. At the surface she vomited, became cyanosed and voiced continuous fearful screaming. She was evacuated via helicopter to the nearest emergency department. On arrival, she was dyspnoeic with pink frothy sputum and widespread inspiratory crepitations throughout both lung fields. Chest X-ray showed changes consistent with pulmonary congestion (Figure 1).

Arterial blood gas analysis while breathing on simple face mask with delivery of 15 $L \cdot min^{-1}$ of oxygen showed (normal values in brackets): pH 7.31 (7.35–7.45); P_aO_2 9.7 (11.0–14.4) kPa; P_aCO_2 5.3 (4.6–6.4) kPa; HCO_3 19.4 (21–28) $mmol \cdot L^{-1}$; base excess -2.7 (-3–3) $mmol \cdot L^{-1}$; lactate 2.7 (< 2) $mmol \cdot L^{-1}$.

An initial ECG identified atrial fibrillation with a fast ventricular response (120 beats per minute), although the patient subsequently spontaneously reverted to sinus rhythm. Initial troponins were raised but improved the following day (Table 1).

A diagnosis of IPO was made, and intravenous diuretics were started to good effect. On day two a coronary angiogram

Figure 1
Day 1 chest X-ray showing pulmonary oedema

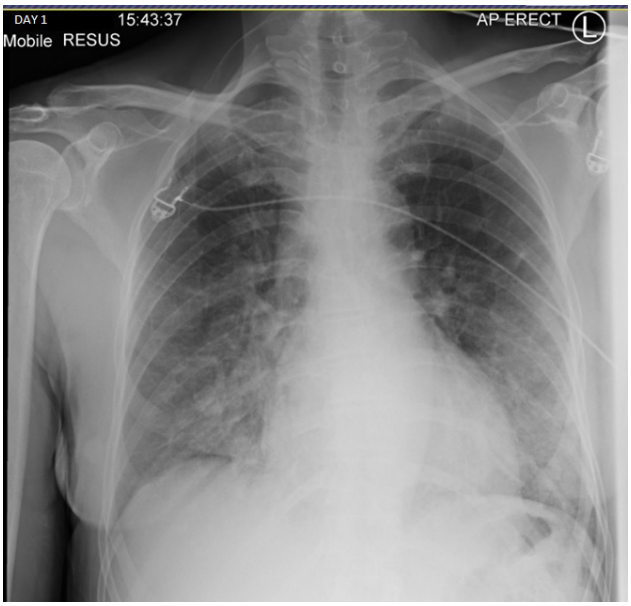


Table 1
Blood test results; CRP – C-reactive protein; GFR – glomerular filtration rate; Hb – haemoglobin

Parameter (normal values)	Day 1 02:37	Day 1 13:21	Day 2 08:12	Day 3 08:56
CRP (< 5 mg·L^{-1})			69	
GFR (> 90)				> 90
Sodium (135–145 mmol·L^{-1})				139
Potassium (3.5–5 mmol·L^{-1})				3.7
Urea (2.5–6.7 mmol·L^{-1})				3.1
Creatinine (62–106 µmol·L^{-1})				64
Troponin (0–16 ng·L^{-1})	1,879	2,082	786	
White cell count (4–11 x 10^{9}·L^{-1})				8.9
Hb (> 120 g·L^{-1})				147
Platelets (150–400 x 10^{9}·L^{-1})				200

identified normal coronary arteries. A transthoracic echocardiogram showed a LV at the upper limit of normal size, with mildly impaired systolic function (ejection fraction [EF] = 45%) and abnormal apical function.

A CMR scan on day six identified a LV at the upper limits of normal size and volume (left ventricular end diastolic volume index 60 ml·m^{-2}, EF 46%), with circumferential akinesia in the mid-apical segments, and some focal dyskinetic motion in the true apex. Myocardial oedema and subtle, patchy, low intensity, non-ischaemic late gadolinium enhancement was observed in the mid to apical segments; in keeping with takotsubo cardiomyopathy (Figure 2).

The diver was discharged on day seven on bisoprolol and ramipril. An implantable loop recorder was inserted to capture any further episodes of arrhythmia.

Two months later the diver had made a good recovery, running 5–10 km three times per week with no recurrence of symptoms. The ECG showed sinus rhythm with corrected QT interval at the upper limit of normal and deep T-wave inversion in leads I, II, aVL and V3–V6. Blood pressure monitoring revealed a range of 146–163 mmHg (systolic)/ 79–88 mmHg (diastolic). She reported occasional short palpitations, but her implanted loop recorder showed no further episodes of arrhythmia. Repeat echo showed normal LV systolic function (EF 63%) with no hypertrophy or dilatation. Her ramipril was stopped and switched over to losartan and amlodipine.

Seven months after the incident a repeat CMR was performed that showed a mildly dilated LV with normal systolic function and a RV at the upper limits of normal size. There was no late gadolinium enhancement, no residual wall motion abnormalities and no oedema; all in keeping with a resolved episode of takotsubo cardiomyopathy (Figure 2).

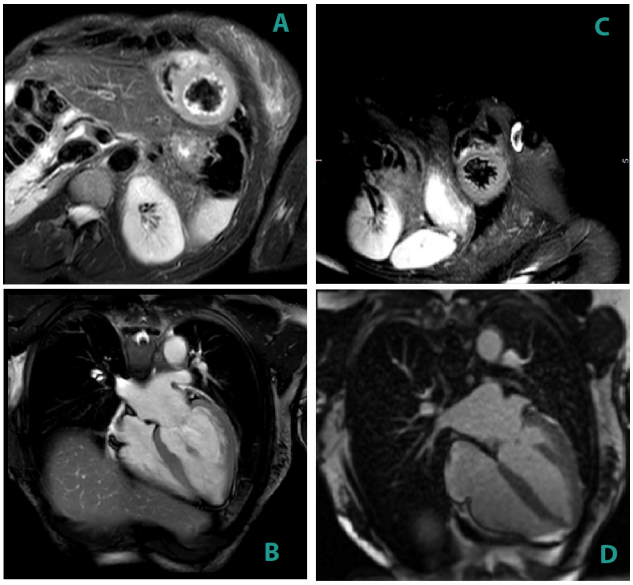
INSTRUCTOR'S PERSPECTIVE

We were 30 minutes into the dive at 8 msw when I gave the signal to ascend for a safety stop. I passed my surface marker buoy and she started to reel it in but forgot to deflate her BCD. I assisted her with this and we prepared to ascend, but she signalled out of air. I gave her my octopus and she signalled OK but was unable to link arms appropriately; she fell backwards, straining the octopus hose.

I helped her into an upright position, took the reel back, and checked her pressure gauge that said she had 90 bar. I tested her regulator and signalled to her to switch back. She made the switch and signalled that she was OK. She then got a blank look in her eyes and did not respond to my signal to ascend.

I performed a controlled ascent and inflated her BCD on the surface. She vomited, laid on her back and became unresponsive, her facial colour looked purple. I removed her equipment, and she was lifted onto the boat. She was placed into the recovery position, vomited further and then started screaming. She appeared to be responding to her husband, and so I asked if she was in pain. She did not reply verbally but she shook her head to indicate no. I administered oxygen and noticed that there were some bloody droplets in the mask. She became calm, and her facial colour improved. She was transferred to the emergency services.

Figure 2
Initial cardiac MRI images (A+B), along with images (C+D) from the follow-up cardiac MRI seven months later that showed full resolution; A shows T2/STIR image demonstrating circumferential high signal in the mid to apical segments in keeping with myocardial oedema; B shows subtle patchy low intensity late gadolinium enhancement in the mid lateral wall



DIVER'S PERSPECTIVE

I am PADI advanced open water qualified and have completed 15 dives in cold water. The dive was uneventful until I suddenly could not breathe, and my heart started racing. I thought I had a faulty regulator so I grabbed my instructor's octopus and from there on I cannot remember much until I was airlifted in the helicopter. I think I was in bad state when I first arrived in the hospital but, again, I cannot remember much of the first couple of hours.

I was short of breath the first two days after the accident but then it cleared up completely. I would say that I was fully recovered within two weeks. I am feeling good now and have resumed running and cycling. I still feel anxious going swimming as it brings back bad memories of the accident.

I previously worked as an airline pilot and had a medical every six months so I know that I was medically well before the accident. I am a non-smoker and drink minimal alcohol. I do not suffer from low mood or stress and did not take any medications. My father had a heart attack when he was 62 and suffered from high blood pressure and my mother has a normal heart and blood pressure. My fitness is good which I believe really helped my fast recovery.

I feel very grateful to the Royal National Lifeboat Institution, coastguard, doctors and nurses at the hospital.

Discussion

In IPO, the increased intrathoracic blood volume during immersion leads to a rise in preload. When combined with exertion and cold water-mediated peripheral vasoconstriction (increased afterload), the hydrostatic pressure gradient from pulmonary vessels to alveoli causes alveolar oedema, leading to symptoms such as shortness of breath and frothy haemoptysis.[3] Hypertension, cold water, beta-blockers, physical exertion and negative pressure breathing (rebreathers) have all been implicated as risk factors.[3,4]

The physical stress may, in some cases, trigger takotsubo cardiomyopathy as two-thirds of these cardiomyopathies are precipitated by extreme acute emotional or physical stress.[8] Over 50% of patients in the International Takotsubo Registry have a prior history of a psychiatric illness or a chronic neurological disorder.[9] Patients with such pathologies are less likely to be diving, and indeed, our patient had no history of these.

Takotsubo typically presents in post-menopausal women, although any gender and age group can be affected. Despite normal or non-obstructing coronary artery disease on angiography, ECG changes resemble myocardial ischemia with ST-elevation, T-wave inversion and QT prolongation with risk of ventricular arrhythmias. There is often a corresponding rise in cardiac biomarkers including troponins and cardiac brain natriuretic peptide.[10]

Postulated mechanisms include direct myocardial stunning induced by catecholamine release and vasoconstriction mediated ischaemia. Stress cardiomyopathies have been triggered by the direct administration of catecholamines and circulating levels in the acute phase have been found to be 10–20 x normal.[11]

The CMR findings here align with T2- short-tau inversion recovery (STIR) imaging seen in takotsubo cardiomyopathy patients; high signal, diffuse ventricular oedema distributed in the mid-apical planes of the LV and dissociated from the coronary arterial distribution.[12–14] Late gadolinium enhancement has been linked to takotsubo cardiomyopathy in more recent studies, thus the patchy low intensity enhancement correlates with this.[13] There was no basal hyperkinesia (octopus pot appearance) normally seen in 75–80% of Takotsubo cases, or mitral valve dysfunction, seen in 25% of Takotsubo cases.[13]

Resolution of the CMR findings, with no detectable late enhancement and return of normal ventricular function after the seven month follow up period, was anticipated. Reversibility is the hallmark of takotsubo cardiomyopathy as demonstrated previously with CMR.[12,13,15]

We postulate that this diver likely had essential primary hypertension predisposing to IPO during her dive which, in turn, resulted in the development of a takotsubo cardiomyopathy with associated atrial fibrillation. There has been much speculation as to whether cardiomyopathies in divers develop pre-dive or during the dive itself.[3] The description of events that the diver provided indicates that it occurred during the dive, in line with other case reports.[4,16]

Regarding medical management, an angiotensin receptor blocker was chosen as antihypertensive therapy over an angiotensin converting enzyme inhibitor to avoid the potential side effect of a cough. A calcium channel blocker was also chosen as, anecdotally, it has been shown reduce recurrence of IPO. This is thought to be due to a reduction in vasoconstrictive responses to physiological stimuli.[3,17,18]

The typical advice for divers who develop IPO is to avoid further diving due to risk of recurrence, although opinion is divided on this. If divers choose to return they would need to ensure that their hypertension is controlled. Other recommendations include; the use of open circuit equipment, diving with an experienced buddy, ensuring surface support (including oxygen) is available and a dive profile that would avoid obligatory decompression stops.

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Letters to the Editor

Comment regarding: Han K-H, Hyun G-S, Jee Y-S, Park J-M. Effect of water amount intake before scuba diving on the risk of decompression sickness. Int J Environ Res Publ Health. 2021;18:7601

This letter aims to correct the literature record in respect of serious flaws in a human study of water intake and decompression stress. Our letter was submitted as a Letter to the Editor to the journal publishing the original manuscript, but was not accepted for publication. We submit it here since the topic is within the primary scope of interest of *Diving and Hyperbaric Medicine*.

There are significant concerns with a recent report describing an effort to investigate the influence of pre-hydration on circulating bubble formation.[1] The research topic is of interest, but the paper suffered from serious flaws in methodology and unlikely data.

Recommendations on fluid intake are challenging since fluid is derived from both liquid and solid food intake. The critical goal is to ensure sufficient intake to maintain an appropriate state of hydration and optimal physiological function. State of hydration is most reliably assessed through direct measures of plasma volume. It can be estimated through analysis of a pooled sample of urine captured in a 24-hour collection, or more roughly estimated through analysis of the first waking sample of urine. It is a major shortcoming that there was no measure or estimate of state of hydration in the work under discussion. The described check for post-dive "*symptoms of dehydration*" is not a meaningful assessment. Without objective measures it is impossible to know whether individual subjects were dehydrated, euhydrated, or hyperhydrated with any of the four pre-hydration levels.

The two-day interval between dive exposures was sufficient for inert gas clearance, but it may be insufficient for resolution of secondary biochemical changes induced by diving. The fixed treatment order is a substantial shortcoming, potentially introducing a confounding effect. Similarly, measuring bubble scores only twice post-dive fails to meet the recommended practice to investigate decompression stress.[2] The authors' acknowledgment of the limitation does not overcome it.

The handling of the bubble data was also problematic. Most fundamental is the fact that bubble data are ordinal and as such cannot be subjected to parametric analysis. The data are also over-analysed by considering the individual parameters of the integrated Kisman-Masurel data separately.

The raw data described in the results are extremely troubling. It is difficult to believe that all baseline scores were grades I and II when the norm is to see grade 0 at baseline. This raises serious questions as to the validity of the bubble data.

The collective effect of the shortcomings described here is an inability to trust the interpretations or conclusions of the work. The absence of state of hydration measures makes it invalid to say that the effort confirms appropriate pre-hydration to minimise decompression stress. More carefully designed, conducted, and analysed research is needed to address the open questions. In the meantime, it is important to be mindful that while a state of dehydration can likely increase decompression stress, a state of hyperhydration can increase the risk of immersion pulmonary oedema, and extreme cases can lead to hyponatraemia, both serious conditions. Divers need to be thoughtful in balancing many risks, and should generally avoid extremes in any direction.

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Editorial note: the authors of the paper discussed[1] did not respond to an invitation to address the criticisms articulated in this letter.

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Associate Professor Neal Pollock is a member of the editorial board and Lesley Blogg is the Deputy Editor of *Diving and Hyperbaric Medicine*, but neither was involved in the peer review or publication decision-making process for this article.

Keywords
Decompression; Diving; Ultrasound; Safety; Physiology; Science publication

Validation of very mild COVID-19 illness criteria to guide successful return to occupational diving

COVID-19 has significantly impacted on diving operations globally. After initial major concerns about long term impact on diver health, 2022 has restored some sanity to assessment of divers seeking to return to diving after COVID-19. Australia and New Zealand have highly vaccinated populations and the omicron strain has proven less pathogenic but more infectious than previous strains. The South Pacific Underwater Medicine Society (SPUMS) first posted guidelines for return to diving after COVID on its website in March 2022 (https://www.spums.org.au/content/covid-19-updates). Before January 2022, there was minimal need for COVID-19 diving guidance in Australia and New Zealand because both countries had been isolated. After opening up, a dramatic rise in locally acquired infections necessitated guidance for members. A pragmatic approach was initially taken, using some key references from other groups.[1–3] However, SPUMS processes allowed for greater doctor discretion than procedures from the northern hemisphere which required high rates of mandated imaging and exercise testing. A management flowchart, COVID questionnaire and medical certificate were made available to SPUMS members in March 2022.

The author reports a quality assurance review of a single practice, following SPUMS guidance, which supports the category of 'very mild COVID illness' as being apparently low risk and having minimal impact on diver health and fitness. Sixty occupational divers, 52 male, eight female, mean age 33.1 years were assessed 2–4 weeks post-COVID over three months from 1 January 2022. Thirty-four had two vaccinations, 26 were triple vaccinated. Divers were assessed for suitability for returning to occupational diving using SPUMS guidance. At the time of these assessments the SPUMS 'mild' COVID-19 illness criteria required a pre-return-to-diving face-to-face medicine consultation after recovery including spirometry and measurement of peripheral oxygen saturation (S_pO_2), but imaging was not undertaken if spirometry was stable (when compared to the diver's most recent pre-COVID measurement).

Subsequently, these divers were retrospectively assessed against the 'very mild COVID illness' criteria promulgated by Sadler et al., on 31 March 2022,[4] and embraced in modified SPUMS guidelines promulgated in June 2022.[5] These criteria are:
1. Completed mandatory isolation (7 days), asymptomatic when assessed;
2. Symptoms < 7 days, solely outpatient management, no oxygen requirement;
3. No lower respiratory symptoms – no dyspnoea or productive cough; (but myalgia, headache, fever or fatigue were allowable);
4. Return to former full exercise capacity.

Fifty-seven of the 60 divers met the very mild criteria, had stable spirometry parameters (not ≥ 5% reduction) since the last medical and had an $S_pO_2 \geq 96\%$ at the time of the post-COVID diving consultation. All successfully returned to diving at one month. All divers continued to successfully dive through to three months post clearance. Direct return for review by the author was required if divers experienced difficulties after returning to diving but none were reported. No health issues were reported during telephone follow-up with dive supervisors to three months. Analysis of FEV_1, FVC and ratios measured at the post-COVID pre-diving consultation and compared to the most recent pre-COVID measurements revealed no significant difference for the population (*t*-test = NS). Correlation was linear for pre- and post–COVID measurements with coefficients of 1.0 ± 0.02 for FVC and 1.0 ± 0.006 for FEV_1.

Three divers (5%) had delayed return to diving. Two had persistent respiratory symptoms at the 4-week review, both had spirometry impairment 5–10%, but $S_pO_2 \geq 96\%$. Both became asymptomatic had normal clinical examinations and spirometry normalised by two months. No imaging was undertaken for these divers. It is acknowledged that other authors may not agree with this approach, and may mandate imaging.[6] One diver had chest pain and was cleared at two months after normal echocardiography, ECG and biochemistry. None of these delayed divers met the 'very mild' classification.

This quality assurance review supports the recent guideline update incorporating a 'very mild' category for COVID-ilness.[4] In vaccinated individuals COVID-19 is having less impact on divers than was initially feared, and this has resulted in introduction of the very mild classification. However, the data cannot be extrapolated to unvaccinated divers.

SPUMS has now updated its guidelines to permit clearance of divers who satisfy 'very mild' COVID illness criteria at two weeks, using a telephone questionnaire administered

by the diving doctor.[5,6] The most recent iterations of DMAC-33 (Rev.4 – June 2022) and Sadler's group broadly agree with SPUMS in accepting classifications of milder COVID illness.[2,4] This report contrasts with the much higher rates of detection of pathology by Mirasoglu et al.[6] Further research is required in this evolving diver health issue.

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Keywords
Diving Medicine; Health surveillance; Medicals-diving; SARS-CoV-2; Lung function

Recompression of a diver with decompression illness found to be COVID-19 positive

As the grip of the COVID-19 pandemic starts to ease and more divers return to the water, it is inevitable that hyperbaric centres will encounter divers with decompression illness (DCI) who also are found to be positive for COVID-19.

At DDRC Healthcare we have recently treated a diver with joint pain and neurological DCI symptoms of paraesthesia and mild weakness on dorsiflexion that was causing no functional deficit. On arrival at our centre, although asymptomatic, she was found to be positive for COVID-19 on a lateral flow test.

Prior to this, our practice had been guided by the European Underwater and Baromedical Society and European Committee for Hyperbaric Medicine position statement from March 2020, namely avoiding or postponing hyperbaric oxygen therapy (HBOT) in COVID-19 positive patients unless 'considered absolutely necessary to mitigate life-limb threatening or severe functional incapacity'.[1]

However, as the trajectory of COVID-19 has changed and more people are having asymptomatic or mild disease than before, treatment of those with less severe DCI found to be positive for COVID-19 should now be considered.

Our decision to treat this patient factored in two key considerations; the risk to the patient of treating versus not treating, and the risk to others in the centre, particularly the duty chamber attendant. The patient was asymptomatic for COVID-19, and had a normal respiratory examination and resting oxygen saturations. Conversely, her DCI symptoms were causing significant distress and anxiety. Whilst some studies have shown that computerised tomography lung changes are found even in asymptomatic patients[2] a recent literature review undertaken by ourselves and presented at the UK Diving Medical Committee and British Hyperbaric Association Conference (Oban, November 2021) found no case reports of COVID-19 related barotrauma or oxygen toxicity in divers or hyperbaric chambers. A recent meta-analysis reported purposive use of HBOT in treatment of pulmonary manifestations of COVID-19 in 224 patients with no reported adverse effects.[3] For this patient, it was felt the established potential benefits of recompression treatment outweighed a theoretical risk of harm.

The risk of infection to others was also carefully considered. Having spent the previous two years fastidiously ensuring that COVID-19 was kept out of our facility, understandably the idea of treating a patient who was known to be positive

caused some degree of consternation amongst the on-call team. This was not only in terms of the logistics with infection control and personal protective equipment (PPE), but also as to who would be the chamber attendant given personal and work reasons for wanting to avoid COVID-19. Many chamber staff also work as commercial divers and may be cautious with regards to their exposure risk and implications for fitness to work. Nevertheless, the COVID-19 pandemic has shown the efficacy of appropriate PPE and infection control policies for mitigating these risks.

Despite the patient having non-functionally limiting symptoms, the clinical team felt that in view of the neurological manifestation of DCI that HBOT was indicated. The patient was treated with a Royal Navy 62 table (284 kPa, 2.8 atmospheres absolute, 18 metres of seawater equivalent) wearing a hood with an isolated breathing supply throughout, with air breaks completed by switching external gas supplies rather than removing the hood. The chamber attendant wore a fluid-resistant surgical face mask and single-use apron and gloves, and then their own oxygen built-in breathing system for decompression. Other authors have reported infection control strategies in treatment of COVID-19 or suspected COVID-19 patients with non-diving emergency indications for HBOT.[4,5] The treatment went smoothly with an almost total resolution of DCI symptoms for the patient and as such no repeat treatments were warranted. No side effects of hyperbaric treatment were seen.

We hope that this our experience may be of use to other centres who find themselves in a similar position in the future.

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doi: 10.28920/dhm52.3.223-224. PMID: 36100937.

Louise Mallam,[1] Doug Watts[1]

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Keywords
Decompression sickness; Diving Medicine; Infection control; SARS-CoV-2

Obituary

Dr Cecilia Jacomina Roberts

Cecilia Roberts, or 'CJ' as we fondly call her in Australia and New Zealand, tragically died in a road traffic accident on 22 May 2022 at the age of only 43, in her home country South Africa. Her family lost a beloved daughter, sister, and aunt and our field lost a treasured colleague and one of its brightest ambassadors.

Cecilia qualified in medicine at Stellenbosch in 2002. She subsequently completed a Diploma in Anaesthetics, Postgrad Diploma in Conscious Sedation and Pain Control, and BMedSci (Hons) degrees in both underwater medicine and hyperbaric medicine (Stellenbosch). She took this eclectic suite of qualifications into a multifaceted medical career which included emergency medicine, anaesthesia, surgical assisting, and diving and hyperbaric medicine. Cecilia was known for bringing boundless enthusiasm and drive to everything she did (to an exacting standard!) and our field was a grateful beneficiary. She immersed herself in diving and hyperbaric medicine at a clinical, academic and societal level, serving (among other things) as a diving and hyperbaric physician at the Stellenbosch University Hyperbaric Facility, a lecturer on their related degree programs, and completing two terms as President of the South African Underwater and Hyperbaric Medical Association (SAUHMA).

Like me and many of us who found our way into this field, Cecilia followed her love for all things related to the ocean, with diving being one of her strongest passions. I recall diving with her at the shoals off Durban, famous for their raggy tooth sharks, and being moved by her conspicuous reverence for all the amazing things surrounding us, and by her infectious enthusiasm as she found more and more subjects for me to take photos of. Watching CJ in the water was to witness someone in their ultra-happy place.

It is a thinly veiled secret that we in New Zealand tried to steal Cecilia from South Africa when she showed interest in furthering her anaesthetic training here in 2015. Ultimately, and perhaps not surprisingly, the prospect of leaving her family far behind proved a bridge too far, but my wife Sian and I had the privilege of getting to know CJ well when she stayed with us for a month on her scoping visit. We did all the things that I thought would sell New Zealand; hiking, swimming, paddle boarding, mountain biking (typically with me languishing in her dust), and introducing her to colleagues and friends. The most insightful moments came from watching her with these people. It's an overused phrase, but it is absolutely true that CJ's smile could light up a room. Everywhere we went people were charmed by this starbright articulate woman, and I was immensely proud to watch her, time after time, make our field an engaging topic of conversation among people not familiar with it. It was certainly not difficult to understand her meteoric rise to leadership in SAUHMA. I had a copy of her CV at the time, and it included one of those algorithmic strength analyses that had interpreted her themes as 'Achiever', 'Developer', 'Empathy', 'Includer'; a near perfect summary.

I was teaching on a Divers Alert Network diving medicine course in the Caribbean at the time of CJ's accident. The news came literally a day after I had been told by the convenor of her stellar performance as a teacher on the same course a year earlier. It came as a seismic shock to all of us. I know I speak for many of my South African friends and colleagues when I say that we will never get used to a world without Cecilia. She will be remembered as a woman of remarkable warmth, integrity, faith and intellect; a massive loss to her family and friends, and to our field. Gone far too soon.

Kua hinga te tōtara i Te Waonui-a-Tāne.
A tōtara tree has fallen in Tāne's great forest.

Professor Simon Mitchell
Editor, Diving and Hyperbaric Medicine Journal
Auckland, New Zealand

Errata

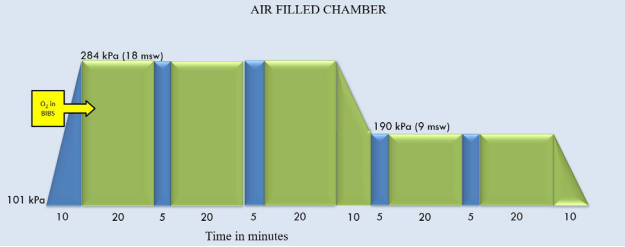
Correction in: Boet S, Burns JK, Jenisset E, Papp M, Bourbonnais S, Pignel R. A Delphi study to identify relevant scenarios as the first step toward an international hyperbaric medicine simulation curriculum. Diving and Hyperbaric Medicine. 2022 March 31;52(1):44–48. doi: 10.28920/dhm52.1.44-48. PMID: 35313372.

In the electronic copy of this article ***Appendix 1** was not linked in the main text and the web version of the Appendix was not visible, this is now available on the link below and showing on page 45 of the issue, most electronic versions have been updated. However, three copies were had already been processed by journal indexing organisations before the omission was picked up and therefore, an errata is required.

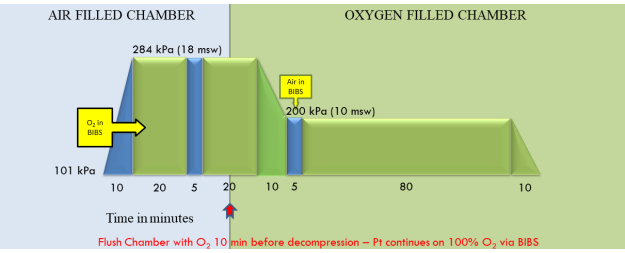
***Appendix 1** is available on DHM Journal's website: https://www.dhmjournal.com/index.php/journals?id=293.

Correction in: Banham N, Hawkings P, Gawthrope I. A prospective single-blind randomised clinical trial comparing two treatment tables for the initial management of mild decompression sickness. Diving and Hyperbaric Medicine. 2022 June 30;52(2):85–91. doi: 10.28920/dhm52.2.85-91. PMID: 35732279.

In the final stages of the editing Figures 2 and 3 were incorrectly labelled and therefore, inserted incorrectly. Page 86 should have Figure 2 showing as.



Page 87 should have Figure 3 showing as.



Most copies were corrected and are correctly circulating electronically.

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's message

Neil Banham

From 16 August 2022, SPUMS has a new website and logo! As well as upgraded graphics and functionality, the website will allow recurrent payment of membership and the ability to register and pay Annual Scientific Meeting (ASM) registration. The ASM functionality of the website is now live, please see the first notice over the page.Thanks to Xavier Vrijdag, Nicky Telles, David Smart and all those involved who worked very hard to make this happen.

The 2022 virtual ASM coordinated by Greg van der Hulst and his team was a great success, with many interesting talks of high academic quality presented.

The SPUMS 2023 ASM will be held in Cairns with the programme, registration details and form available on the SPUMS website: Register for the ASM.

Conference Theme:

Diver health and ocean health amidst the storm clouds of climate change. A shared vision for underwater medicine and marine science.

Convenors: David Smart and Cathy Meehan
Date: Sunday 4 June to Friday 9 June 2023
Venue: Crystal Brook Riley Hotel, Cairns, Australia

There will also be a workshop to develop a SPUMS Position Statement on paediatric diving.

The next introductory course in Diving and Hyperbaric Medicine will again be held in Fremantle from 27 February–10 March 2023, with strong interest already shown. This course is only held yearly and is always fully subscribed early, so if you want to register, don't delay. Course information: SPUMS approved courses for Doctors.

With the return of in person attendance at ASMs, I strongly encourage you to recommend to your colleagues to join SPUMS.

Neil Banham
SPUMS President

SPUMS Facebook page
Like us at:
SPUMS on Facebook

Royal Australian Navy Medical Officers' Underwater Medicine Course

Date: 17–28 October 2022 and 13–24 March 2023

Venue: HMAS Penguin, Sydney

Cost: The course cost remains at AUD$1,355.00 (excl GST).

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.

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*

The **NEW**

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
South Pacific Underwater Medicine Society

ANNUAL SCIENTIFIC MEETING 2023 – SAVE THE DATES

GET YOUR ABSTRACTS READY FOR SUBMISSION

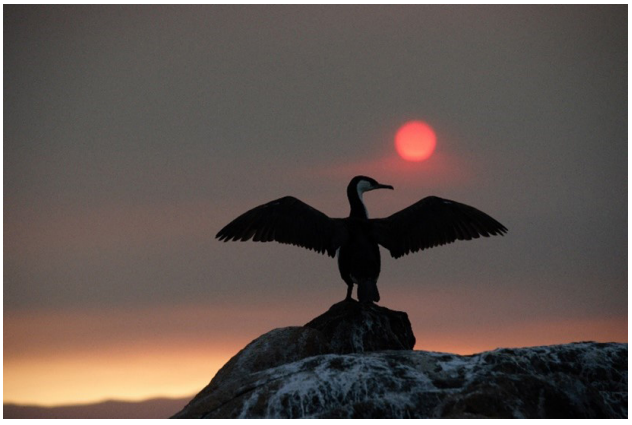
Sunday June 4th to Friday June 9th 2023
Crystal Brook Riley Hotel – Cairns, Australia AND the Great Barrier Reef

LETS GET TOGETHER, AT LAST!

Conference Theme:
Diver health and ocean health amid the storm clouds of climate change.
A shared vision for underwater medicine and marine science.

Scientific Programme Themes:

- The global impacts of climate change on coral reefs and temperate waters
- The human–marine environment interaction
- Health Impacts of climate change on land and in the ocean
- Temperate spread of tropical diseases
- Unexpected consequences – marine food poisons and envenomation
- Creative solutions for the impacts of climate change
- Marine Infections
- Paediatric Diving – workshop and position statement
- Underwater medicine and marine science – how can we join forces to create a shared vison for the future?



CLIMATE CHANGE AND A SHAG AT SUNSET
Sunset as Gondwana rainforest burns in Tasmania
Photo © David Smart 2019

Register NOW: *https://spums.au/index.php/asm-registration*

Keynote Speakers:

Professor Ove Hoegh-Guldberg FAA, University of Queensland

Professor Craig Johnson, Ecology & Biodiversity Centre, IMAS, University of Tasmania

Submission of Abstracts:

Abstract submissions open 1st October 2022 and must be submitted using the SPUMS 2023 ASM abstract form (accessible via the website) and forward the completed abstract to scientific.convenor@spums.org.au. Preference will be given to abstracts that are consistent with the conference theme, but there will also be free paper streams and also poster space available.

Preferred conference Travel Provider for 2023 SPUMS ASM: Diveplanit Travel Your personal dive travel agency

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
education@spums.org.au

Keywords
Qualifications; Underwater medicine; Hyperbaric oxygen; Research; Medical society

Notices and news

EUBS notices and news and all other society information can be found on:
http://www.eubs.org/

EUBS Member-at-Large elections

This year, the EUBS Elections were slightly different, with the election of two Members-at-Large (MAL) instead of one. Last year, the EUBS membership decided in its General Assembly to expand the Executive Committee with one MAL, so that from now on, each MAL would serve a four year term instead of three years.

We have two candidates for the position and both will be elected. Dr Charles Paul Azzopardi will stay for the three years term in the ExCom and Dr Anne Räisänen-Sokolowski will stay four years. Congratulations to both – we look forward to having you in our ExCom.

We will be saying goodbye to our 2019 MAL, Associate Professor Gerardo Bosco, we are certain he will remain active in the society.

Thanks to all EUBS members who voted and if you have any comments on the voting process or software used, please send us an email (secretary@eubs.org).

EUBS 2020 FINALLY happened in 2022

Because of the COVID-19 pandemic, our 2020 Annual Scientific Meeting could not take place, and also our plans for 2021 have had to be postponed. As this issue of *Diving and Hyperbaric Medicne* is published, we will have had the pleasure to unite again in Prague, Czech Republic, from 31 August to 3 September 2022. While this report was written before the meeting, we are certain it will have been a great pleasure to see our friends again after such a long time, and we are confident that the 46th Annual Scientific Meeting of EUBS will have been a great success.

Next year, the EUBS meeting will be in Porto, Portugal, from 13–16 September 2023, please keep these dates already free in your busy schedule. Make a plan to have some days off before and after the conference to enjoy beautiful Porto and Portugal.

EUBS General Assembly

This is a formal invitation to participate in our EUBS annual General Assembly, which will take place during the EUBS Annual Scientific Meeting, on Saturday 03 September from 09.30am to 10.30am in the main conference hall. It is customary to discuss all items relevant to the function of our society, as discussed by ExCom during their meeting on 31 August and will be posted on the information board. All EUBS members with voting rights are cordially invited.

Peter Bennett has passed away

EUBS ExCom was sad to hear of the passing of Peter Bennett, on 11 August 2022. Peter was truly one of the founders of diving medicine in the 20th century, having contributed to diving physiology, medicine, education and safety in so many ways that they too numerous to list here. A full obituary will be published in this journal, as well as in all the other circles where Peter has been active. His name will live on, not only as the co-founder of the Undersea Medical Society and Divers Alert Network, but also as the Editor, with David Elliott, of the seminal textbook "*Bennett and Elliot's Physiology and medicine of diving*" in 1969, now in its 5th Edition, still considered the 'bible' of diving medicine.
It seems that the year 2022, with the passing of giants like Alf Brubakk, David Elliott and now Peter Bennett, will remain a dark landmark in memories of diving and hyperbaric scientists.

EUBS website

As always, please visit the EUBS website (www.eubs.org) for the latest news and updates. Do not forget to renew your membership annually – each member will receive a personal renewal invitation one month before expiry; even if your membership has expired, you can easily renew it when trying to log in again. In case of problems, do not hesitate to contact the EUBS secretary at secretary@eubs.org.

EUBS website and OXYNET

The OXYNET database of hyperbaric centres is presented as an interactive map page on the EUBS website. ExCom is looking for member in each country help us to keep the database up to date, let us know if you are willing to help.

Occasionally, we use the EUBS website newsletter as a tool to seek help for our members, as it is a perfect way to reach all of the EUBS members and communication, networking and interaction are prime goals of our society.

A Help Requests page on our EUBS website has been created (EUBS Members Help Requests, under the "*Activities*" menu on the homepage). Please check this page and try to help out or if you need help at all and would like to use this service, please contact the webmaster (webmaster@eubs.org).You should also consult the page (http://www.eubs.org/?page_id=284) where research projects seeking collaborators and international participation are presented.

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.

Baltic Diving and Hyperbaric Medicine symposium 2022 – BIS_DHM, 8–11 June 2022

After being postponed for two years due to the COVID-19 pandemic, the Baltic Diving and Hyperbaric Medicine symposium was finally held from 8–11 June 2022 in Gdynia (Poland) to the delight of the participants and its organiser Jacek Kot from the National Center for Hyperbaric Medicine of Poland.

Like the first version in 2018, the symposium included three days of presentations in English on diving and hyperbaric medicine. The first half day of five hours was dedicated to a masterclass on diving medicine covering a variety of interesting topics. Experts from Italy, Belgium, Norway, Finland, Spain, Sweden, Israel, USA and Poland were invited to give lectures on advances in specific topics.

A presentation on pre-dive conditioning by Costantino Balestra, Belgium, summarised the effects of the different pre-conditionings explored in recent years on bubbles and oxidative stress. While the results of this research already allow a better understanding and possible pevention of diving-related diseases, diving fatalities still exist and deserve to be investigated. This is why two presentations were devoted to the investigation of these unfortunate accidents in Finland and Poland (Anne Räisänen-Sokolowski, Finland; Jacek Kot, Poland).

In parallel, technology is evolving and with it the implementation of telemonitoring for divers (Alessandro Marroni, Italy). Indeed, most studies focus on the state of the diver and his environment before and after the dive but it is difficult to understand what happens during the dive. Also, the development of monitoring research allows us to analyse all the physiological and environmental parameters of divers during the dive and not only after the dive. The technology now makes it possible to geolocate the diver, with a transmission to the surface by wireless and then send the data via internet to any researcher anywhere on the planet.

If monitoring will certainly be a help in the future to understand diving accidents, another part of the research focuses on biological responses by analysing transcriptomics, molecules that deal with the transcription of DNA into RNA (Ingrid Eftedal, Norway). Indeed, a modification of certain genes and the immune system has been observed after apnea or scuba dives. The conclusion of this genetic analysis is that varying oxygen levels in the cell are a potent driver for gene transcription. Diving medicine relates thus more and more to 'oxygen medicine', utilising increased levels of oxygen as 'a stimulus, not only a drug'.[1]

The second day mixed presentations of diving medicine and hyperbaric medicine.

Peter Germonpré (Belgium) was asked to summarise the ever-popular topic of 'Patent Foramen Ovale (PFO) and diving'. His first paper on the topic was published in 1998 and jokingly, he expressed the wish to finally 'close' the PFO topic, after more than 24 years of research. However, he discussed also the hypothesis that skin DCS can be in many cases attributed to brainstem inert gas bubble embolisation. Therefore, the PFO story will somehow continue.

The presentations on hyperbaric medicine focused primarily on how hyperbaric centers had managed patients during the COVID-19 pandemic and the effects of hyperbaric oxygen therapy (HBOT) on asymptomatic divers (Pasquale Longobardi, Italy). This presentation was extended by two preliminary reports from randomised control trials on using HBOT in COVID-19 patients, one from Sweden (Andres Kjellberg) and the other one from Poland (Jacek Kot). The afternoon of the second day was dedicated to HBOT in different pathologies. Jordi Desola from Spain presented his experience with using HBOT in patients with occlusion of the central retinal artery (CRAO). At the same time, Nicklas Oscarsson from Sweden reported using HBOT in radiation injuries of the pelvic organs, mainly the urinary bladder (RICH-ART study), and Jacek Kot presented a review of the latest publications on HBOT in inflammatory bowel disease (IBD). This session ended with a presentation on Arctic diving (Anne Räisänen-Sokolowski, Finland) and another about an algorithm for predicting cerebral oxygen toxicity (Ran Arieli, Israel).

The second masterclass, on the third day, was dedicated to complications in hyperbaric medicine, including a presentation on the implementation of a HBOT registry in

the Nordic countries (Nicklas Oskarsson, Sweden) and one on fires in the hyperbaric chamber (Francois Burman, USA). To finish this symposium in beauty, the participants had the opportunity to visit the hyperbaric center in Gdynia guided by Dr. Jacek Kot.

This symposium was held in the beautiful location of Gdynia on the seaside and near the harbour where several historical ships are moored. Even if priority was given to live participation, allowing discussions and future collaborations between countries, this symposium had an hybrid form (live – online) it allowed at the end of the pandemic, to welcome participants from all horizons and allow the speakers to present their knowledge from their country of origin, even from the airport of Gdańsk where one of the speakers waited for his rebooked flight at the time he was supposed to present.

This symposium, organised every two years in an exemplary way by Jacek Kot, allows a good update of the latest research in the field of diving and hyperbaric medicine.

Sigrid Theunissen, MSc, PhD
Environmental, Occupational, Aging (Integrative) Physiology Laboratory, Haute Ecole Bruxelles-Brabant (HE2B), 1160 Brussels, Belgium
Secretary, Belgian Society for Diving and Hyperbaric Medicine

Reference

1 Balestra C, Kot J. Oxygen: a stimulus, not "only" a drug. Medicina (Kaunas). 2021;57(11):1161. doi: 10.3390/medicina57111161. PMID: 34833379. PMCID: PMC8623056.

SIMSI Società Italiana di Medicina Subacquea ed Iperbarica

The Italian Society of Underwater and Hyperbaric Medicine (SIMSI) is still confident to grant those expected educational and training opportunities.

Date: 02–04 December 2022, Padua
"*SIMSI XXV Biennial Congress*", University of Padova

Coinciding with the celebrations for the 800th anniversary of the University of Padua.

To take advantage of an early-bird fare, please keep up-to-date with 'Your membership' and 'Your invite', by regularly visiting https://simsi.it/. Here you will find the latest updates on news, meetings, initiatives, sector events under the aegis of SIMSI.

Remember your SIMSI membership means you are entitled to a 10% discount for your EUBS membership.

Gerardo Bosco and Vincenzo Zanon

Courses and meetings

Scott Haldane Foundation

As an institute dedicated to education in diving medicine, the Scott Haldane Foundation has organized more than 300 courses all over the world, over the past 30 years. SHF is targeting on an international audience with courses worldwide.

We are happy that the world has reopened after the COVID-19 pandemic and we can announce courses around the world again. Below the schedule of upcoming SHF-courses in 2022/2023.

The courses Medical Examiner of Diver (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).

2022

06–07 October	In-depth course Psyche under pressure (level 2d) Loosdrecht (NL)
05–12 November	In-depth course Nightmares for the diving doc (level 2d) Bali, Indonesia
12–19 November	In-depth course Nightmares for the diving doc (level 2d) Bali, Indonesia
19–26 November	In-depth course Nightmares for the diving doc (level 2d) Bali, Indonesia

2023

24–25 March	Medical Examiner of Divers part 1 (level 1) Zeist, The Netherlands
30 March – 1 April	Medical Examiner of Divers part 2 (level 1) Amsterdam, The Netherlands
May	Medical Examiner of Divers part 2 (level 1) Bonaire, Dutch Caribbean

In planning	Decompression,recompression and HBOT (level 2d), tbd In-depth course Diving after (long) Covid (level 2d), tbd
On request	Internship HBOt (level 2d certification), NL/Belgium

The course calendar will be supplemented regularly. For the latest information see: https://www.scotthaldane.nl/en/.

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. SPUMS members should log into the SPUMS website, click on 'Resources' then on 'GTÜM database' in the pull-down menu. In the new window, click on the link provided and enter the user name and password listed on the page that appears in order to access the database.

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

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https://www.facebook.com/divingandhyperbaricmedicine

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/

Diving and Hyperbaric Medicine: Instructions for authors (summary)

(updated August 2021)

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 accompaniesthe manuscript. All manuscripts will be subject to peer review. Accepted contributions will also be subject to editing.

***Address*:** The Editor, Diving and Hyperbaric Medicine, Department of Anaesthesiology, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand
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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 user name 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 the instructions are followed carefully. The submitting author must remain the same throughout the peer review process.

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 will be considered. 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 word count); include an informative **Abstract** of no more than 300 words (excluded from 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 word count); include an informative **Abstract** (structure at author's discretion) of no more than 200 words (excluded from word count).

Educational articles, Commentaries and C**onsensus 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.

Formatting of manuscripts

All submissions must comply with the requirements outlined in the full version of the Instructions for authors. 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 above.

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)
DHM Key words 2021
DHM Mandatory Submission Form 2020
Trial design analysis and presentation
English as a second language
Guideline to authorship in DHM 2015
Helsinki Declaration revised 2013
Is ethics approval needed?

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ADSF
AUSTRALASIAN DIVING SAFETY FOUNDATION

Scholarships for Diving Medical Training for Doctors

The Australasian Diving Safety Foundation is proud to offer a series of annual Diving Medical Training scholarships. We are offering these scholarships to qualified medical doctors to increase their knowledge of diving medicine by participating in an approved diving medicine training programme. These scholarships are mainly available to doctors who reside in Australia. However, exceptions may be considered for regional overseas residents, especially in places frequented by Australian divers. The awarding of such a scholarship will be at the sole discretion of the ADSF. It will be based on a variety of criteria such as the location of the applicant, their working environment, financial need and the perception of where and how the training would likely be utilised to reduce diving morbidity and mortality. Each scholarship is to the value of AUD5,000.00.

There are two categories of scholarships:

1. ADSF scholarships for any approved diving medical training program such as the annual ANZHMG course at Fiona Stanley Hospital in Perth, Western Australia.
2. The Carl Edmonds Memorial Diving Medicine Scholarship specifically for training at the Royal Australian Navy Medical Officers' Underwater Medicine Course, HMAS Penguin, Sydney, Australia.

Interested persons should first enrol in the chosen course, then complete the relevant ADSF Scholarship application form available at: https://www.adsf.org.au/r/diving-medical-training-scholarships and send it by email to John Lippmann at johnl@adsf.org.au.
