Diving and Hyperbaric Medicine

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EUBS

Dr Carl Edmonds 1935–2019

Hyperoxic myopia: worse with a mask or hood?

Hyperbaric oxygen and mesenteric reperfusion injury

Twenty years of decompression illness in Finland

Are thin wetsuits adequate in temperate water?

Inhibition of NMDA receptors during nitrogen narcosis

Effect of long term navy diving on hearing

Benefits and risks of diving with mental health issues

Granular vs. cartridge CO_2 absorbent in diving rebreathers

Arterial gas embolism in a breath-hold diver

Löfgren's syndrome confused with decompression sickness

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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

Welcome to the final issue of Diving and Hyperbaric Medicine for 2019; a year notable for the change in editorship from Associate Professor Mike Davis to myself. The transition has for the most part gone smoothly and thanks are due to Mike himself, Ole Hyldegaard and David Smart (Presidents of EUBS and SPUMS respectively), and to Nicky Telles our Editorial Assistant for their hard work and support over this period of change. I must also sincerely thank those members and non-members who have undertaken peer review of submitted manuscripts over this first year of my tenure. High quality peer review and strong author engagement in the revision process are the keys to publishing sound science, and everyone's efforts in that regard have been deeply appreciated. A full list of reviewers for 2019 will appear in the March edition 2020.

This issue is sadly notable in containing three obituaries for prominent figures in the diving and hyperbaric medicine world. The passing of Dr Carl Edmonds marks the loss of a true giant in diving medicine. Carl was a founding member of SPUMS and the first editor of this journal in 1971. He made extensive original contributions to the science of diving over a very long career, and the 2016 (fifth) edition of his textbook "*Diving and Subaquatic Medicine*" stands as the only remaining contemporary reference work in the field. Carl was a forthright individual who did not shy away from debate, but he was also caring and supportive. A month after my own first ever diving medicine publication in 1995 I received a letter from Carl congratulating me on the work. I cannot describe how inspiring it was for an early career researcher to receive such a letter from someone of his standing.

SPUMS and the wider diving medicine world lost one of its characters with the tragic death of Dr Fiona Sharp in a diving accident in October. Fiona was an inveterate attender of all things related to diving and diving science world-wide, and members of both societies will remember her unbridled enthusiasm for the field. Future meetings will not be quite the same in her absence. We also lost Mr Bob Ramsey, a former commercial diver and prominent hyperbaric technician in Australasia after a long illness. Bob was a founding member of the Hyperbaric Technicians and Nurses Association (HTNA) of Australia, and had a prominent role in improving the engineering safety of hyperbaric chambers in the Asia – Pacific region. I was privileged to hear his courageous final presentation to the HTNA just a month before his passing.

This issue contains a variety of interesting original articles of relevance to both diving and hyperbaric medicine.

Thanks to Mike Bennett and his team from Sydney we finally have an answer to the question of whether the magnitude of hyperoxic myopia developing during a course of hyperbaric oxygen treatment (HBOT) is influenced by the method of oxygen delivery. In a randomized trial of patients receiving HBOT they showed that the use of a hood was associated with greater myopic change. This finding may inform future choices of oxygen delivery modality in HBOT.

Kurtulus Açiksari and the Istanbul group demonstrated a protective effect of HBOT administered after intestinal ischaemia-reperfusion (IR) injury in rats. This further corroborates the benefit of HBOT in IR injuries across many *in vitro* and *in vivo* models. What remains is to demonstrate benefit in relevant human injuries which can arise in clinical scenarios such as high risk abdominal aortic surgery.

The study by Thijs Wingelaar and colleagues from the Netherlands challenges the prevalent belief that long-term occupational diving (in this case navy diving) is injurious to hearing. They corroborate the findings of another study recently published in *Diving and Hyperbaric Medicine* which reported similar results in non-military occupational divers.[1]

Bin Peng and a team from Nantong, China provide another piece in the jigsaw that is the mechanism of inert gas narcosis, with their finding of NMDA receptor inhibition during exposure of mice to hyperbaric nitrox. Richard Lundell and colleagues report an evaluation of decompression illness cases recompressed in Finland over a 20-year period up to 2018. This work complements, and provides an interesting contrast to, recently published studies from other European locations.[2,3] Marguerite St Leger Dowse and the UK Diving Diseases Research Centre group describe the results of a survey designed to elicit information about mental health issues among recreational divers. This study is a timely exposition on a subject that receives all too little attention. Dror Ofir and colleagues from the Israeli Navy Medical Institute demonstrate that a thin wetsuit provides adequate thermal protection for navy divers exercising in temperate water, and Nick Gant and the Auckland group find little difference in the performance of granular and cartridge CO_2 absorbent systems in a diving rebreather.

There are also two interesting case reports in this issue: one describing a fatal arterial gas embolism in a breath hold diver who breathed from scuba at depth; and another in which Löfgren's Syndrome was mistaken for decompression sickness (DCS). The issue is completed by a letter from Dr Ran Arieli in which he takes up the debate with Dr David Doolette about the potential role of nanobubbles in the pathophysiology of DCS. The title of the letter is his and not the journal's position on the matter, which is a complex subject. Those interested are urged to read both letters, and some of the cited articles in order to form their own opinion.

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Professor Simon Mitchell
Editor, Diving and Hyperbaric Medicine Journal

Front cover:
Dr Carl Edmonds 1935–2019. Photo kindly provided by his family.

Original articles

The myopic shift associated with hyperbaric oxygen administration is reduced when using a mask delivery system compared to a hood – a randomised controlled trial

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Key words
Side effects; Hyperbaric oxygen; Ophthalmology; Myopia; Vision

Abstract
(Bennett MH, Hui CF, See HG, Au-Yeung KL, Tan C, Watson S. The myopic shift associated with hyperbaric oxygen administration is reduced when using a mask delivery system compared to a hood – a randomised controlled trial. Diving and Hyperbaric Medicine. 2019 December 20;49(4):245–252. doi: 10.28920/dhm49.4.245-252. PMID: 31828742.)
Introduction: A temporary myopic shift is a well-recognized complication of hyperbaric oxygen treatment (HBOT). Oxidation of proteins in the crystalline lens is the likely cause. Direct exposure of the eye to hyperbaric oxygen may exacerbate the effect. Our aim was to measure the magnitude of the myopic shift over a course of HBOT when using two different methods of oxygen delivery.
Methods: We conducted a randomised trial of oxygen delivery via hood versus oronasal mask during a course of 20 and 30 HBOT sessions. Subjective refraction was performed at baseline and after 20 and 30 sessions. We repeated these measurements at four and 12 weeks after completion of the course in those available for assessment.
Results: We enrolled 120 patients (mean age 57.6 (SD 11.2) years; 81% male). The myopic shift was significantly greater after both 20 and 30 sessions in those patients using the hood. At 20 treatments: refractory change was -0.92 D with hood versus -0.52 D with mask, difference 0.40 D (95% CI 0.22 to 0.57, $P < 0.0001$); at 30 treatments: -1.25 D with hood versus -0.63 with mask, difference 0.62 D (95% CI 0.39 to 0.84, $P < 0.0001$). Recovery was slower and less complete in the hood group at both four and 12 weeks.
Conclusions: Myopic shift is common following HBOT and more pronounced using a hood system than an oronasal mask. Recovery may be slower and less complete using a hood. Our data support the use of an oronasal mask in an air environment when possible.

Introduction

Hyperbaric oxygen treatment (HBOT) is used for the treatment of both decompression illness (DCI) following compressed gas breathing and a range of other indications where the administration of high oxygen pressures has been shown to improve outcome.[1,2] While HBOT is generally considered safe, as with most medical procedures, adverse effects can occur.[3] Although not always documented, the most common adverse effect following HBOT is the development of a temporary myopic shift (a negative change in refraction on formal assessment). Previous reports suggest the expected refractive change in phakic eyes (natural lens present) is about -0.5 to -0.74 dioptres (D) over a typical course of treatment, with about 75% of individuals experiencing a measurable shift in at least one eye.[4,5]

It is our experience that a substantial proportion of patients are significantly impacted by this change, being unable to easily view the television or safely drive a motor vehicle. In most cases this refractory change is temporary but most reports suggest this may take several weeks to resolve.[6]

HBOT can be administered in a multiplace chamber via a hood or an oronasal mask, the choice of which may influence the degree of myopic shift in the patient.[6] The aim of this

Figure 1
Hood (A) and mask (B) delivery systems. This oronasal circuit is assembled on-site from components manufactured by Hudson RCI®, NC, USA

trial was to compare the development of refractive changes in patients allocated randomly to receive HBOT via oronasal mask or hood over a treatment course of at least 20 sessions, and to document the rate of recovery in those who returned for review.

Methods

Following local ethics committee approval (South Eastern Sydney Area Health Service 10/128), we conducted an open (unmasked) randomised controlled trial comparing a course of HBOT using a hood administration system (Amron Oxygen Treatment Hood, Amron International, Vista, CA) versus an oronasal mask system assembled in our treatment centre (see Figure 1). This trial is registered on the Australian New Zealand Clinical Trials Registry (Trial ID: ACTRN12609000619246).

We included any patient where the treating hyperbaric physician planned a course of HBOT between 20 and 30 treatment sessions at 243 kPa (2.43 atmospheres absolute (atm abs)) for 90 minutes administered once daily, Monday to Friday over a four or six-week period. In our facility, some indications routinely receive 20 and others 30 sessions. Exclusion criteria were the inability to comfortably and effectively use either delivery system, a corrected visual acuity of less than 6/12 on initial assessment for treatment or the presence of non-native lenses in both eyes following intra-ocular implant surgery.

Following informed consent, each patient was assessed for visual acuity using a standard Snellen Chart, then auto-refraction and keratometry (measuring the curvature of the anterior surface of the cornea and calculating the refractory power of the cornea) were performed (Zeiss VISUREF 100, Carl Zeiss Pty Ltd, North Ryde). One of the investigators then formally assessed subjective refraction of both eyes using standard techniques with a trial frame, Jackson Cross Cylinder Lens and both cylinder and spherical lenses.[7] The auto-refraction settings were used as the starting point for this procedure. The final best subjective refraction was recorded for all phakic eyes.

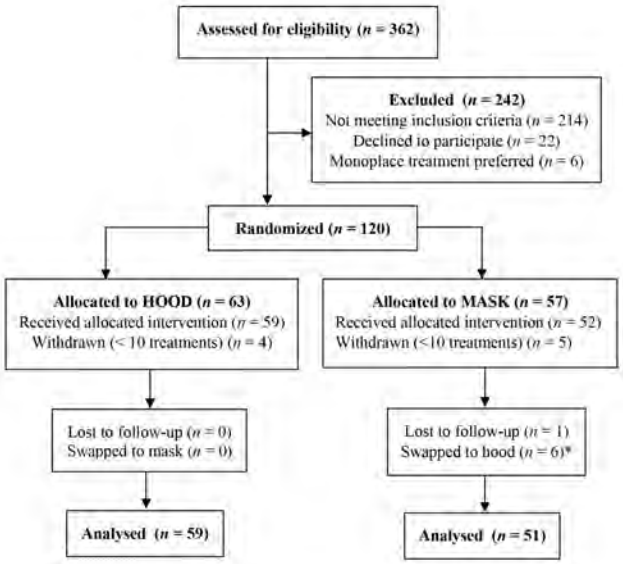
Prior to the first therapeutic compression, one of the investigators (MB) consulted a computer-generated randomisation schedule to determine group allocation.[8] All treatments were conducted on a standard treatment protocol at 243 kPa for a total of 90 minutes breathing oxygen in a multiplace chamber (Fink Engineering, Warana, Queensland). On reaching treatment pressure, each patient was assisted to correctly apply the randomised delivery system for the duration of the treatment.

The primary outcome was the comparative change in the mean subjective refraction (myopic shift) of all eyes between groups at completion of 20 and 30 HBOT sessions according to the allocation to group (intention to treat). Secondary outcomes were myopic shift using a per protocol received approach, the proportion of eyes with a deterioration in subjective refraction of ≥ one diopter (D), changes in keratometry, changes in eye-related symptoms using a five-point scale (0-none to 4-very severe) for each of six dimensions (blurred vision, discomfort, difficulty with street signs/shop names, daytime driving, night driving and reading)[9] and any oxygen-related adverse effects of treatment. In addition, we estimated the rate of recovery of subjective refraction in those subjects available for examination at four and 12 weeks following the final treatment session.

STATISTICAL METHODS AND SAMPLE SIZE

Sample size was estimated based on the results of Evanger 2004 and on defining a myopic shift of ≥ 0.5 D as clinically significant.[6] We estimated 60% and 83% of eyes in the mask and hood group respectively would develop a myopic shift

Figure 2
PRISMA flow diagram for the study. Patients were formally withdrawn from the study if they received fewer than ten treatment sessions. *Patients swapping from mask to hood during the course of treatment were analysed as allocated for intention to treat and moved to the hood group for a secondary per protocol analysis



of at least 0.5 D, and power calculations suggested that for an 80% chance of finding a difference of 20% between the groups at significance level of $P < 0.05$, a sample size of 120 subjects would be required (60 in each group). After plotting all continuous variables to visually examine distributions, we analysed any differences between groups using Student's *t*-test where data were approximately normally distributed and the Mann-Whitney U test (MWUT) when the normal assumption was not sustainable. One-way ANOVA was used to compare multiple groups where appropriate. Results are presented as mean with standard deviation (SD) or 95% confidence intervals (CI), or as median and inter-quartile range (IQR) as appropriate. One-way ANOVA results were presented with the F-test and *P*-value. Differences in proportions were analysed using Chi-squared testing and presented with 95% CI. All statistical calculations were made using StatsDirect software package 3.1.22 (StatsDirect Ltd, UK).

Results

One-hundred-and-twenty patients met all inclusion criteria and none of the exclusion criteria (63 allocated to oxygen administration via the hood and 57 via the mask). Nine patients were withdrawn from the study as they received fewer than ten HBOT sessions (four in the hood and five in the mask group). Six patients elected to change from using a mask to using a hood for oxygen delivery during their course of treatment. These patients were included in the primary intention to treat analysis as allocated, but swapped groups for the 'per protocol' secondary analysis. Figure 2 details the patient flow through the study.

Table 1
Demographic data and co-morbidities in each group. Data are *n* (%) other than age reported as mean (SD)

Characteristic	Hood (*n* = 59)	Mask (*n* = 51)
Mean age in years (SD)	58.9 (11.1)	57.9 (11.5)
Sex female	17 (28.8)	22 (43)
> 4 pack year smoker	25 (42)	19 (37)
Diabetes mellitus	8 (14)	4 (8)
Hypertension	26 (44)	19 (37)
Hypercholesterolaemia	19 (32)	13 (26)
Radiotherapy in past	49 (83)	43 (84)
Eye pathology	3 (5)	2 (4)
Indication for treatment:		
Soft tissue radiation injury	29 (48)	26 (51)
Osteoradionecrosis	20 (33)	17 (33)
Problem wound	7 (12)	5 (10)
Other	4 (7)	3 (6)

In total, data from 210 eyes of 104 patients are included in our analysis after 20 treatments (55 patients in the hood group versus 49 in the mask group) and 80 patients after 30 treatments (43 in the hood group and 37 in the mask group) contributing data from 155 eyes.

The patient characteristics in each group are presented in Table 1. There were no clearly important differences between groups in demographics, comorbidities or indication for hyperbaric treatment with the exception of the sex ratio (29% female in the hood group versus 43% in the mask group).

For the primary outcome, a myopic shift was confirmed in both groups after both 20 and 30 treatments and this change was statistically significantly greater in those patients using the hood versus the mask (at 20 treatments: mean subjective refractory change -0.92 D with the hood versus -0.52 D with the mask, difference between groups 0.40 D (95% CI 0.22 to 0.57, $P < 0.0001$); at 30 treatments: -1.25 D with the hood versus -0.63 with the mask, difference 0.62 D (95% CI 0.39 to 0.84), $P < 0.0001$). The per-protocol analysis produced similar results. The intention to treat and per-protocol results are shown in detail in Table 2. The mean myopic shift was not statistically different between males and females (mean in males -1.3 D versus -0.9 D. $P = 0.2$ after 30 treatments).

Patients using the hood system were significantly more likely to have a clinically important change in refraction over the course of treatment of ≥ 1.0 D in either one or both eyes (for example, after 30 treatments: hood group proportion with both eyes affected 24/45 (53%), mask group 5/33 (15%), relative risk 3.5 (95% CI 1.6 to 8.3), $P = 0.0006$). The results are detailed in Table 3.

A high proportion of individuals in both groups had an eye-related symptom score of zero at baseline, indicating

Table 2
Mean refractory change with hood and mask oxygen delivery systems at completion of both 20 and 30 hyperbaric treatments. Both the primary (intention to treat) and per protocol analyses are shown; D = dioptres

Comparison (*n* eyes)	Hood mean (D) (95% CI)	Mask mean (D) (95% CI)	Difference mean (D) (95% CI)	*P*-value
Intention to treat analysis				
Baseline to 20 treatments (117 hood / mask 93)	-0.92 (-1.05 to -0.78)	-0.52 (-0.63 to -0.41)	0.40 (0.22 to 0.57)	0.0001
Baseline to 30 treatments (84 hood / mask 71)	-1.25 (-1.41 to -1.08)	-0.63 (-0.78 to -0.48)	0.62 (0.39 to 0.84)	0.0001
Per protocol analysis				
Baseline to 20 treatments (108 hood / mask 85)	-0.93 (-1.06 to -0.80)	-0.42 (-0.53 to -0.32)	0.51 (0.35 to 0.68)	0.0001
Baseline to 30 treatments (hood 90 / mask 65)	-1.22 (-1.38 to -1.06)	-0.60 (-0.74 to -0.46)	0.62 (0.40 to 0.82)	0.0001

Table 3
Proportions of eyes with at least one D myopic shift after 20 and 30 treatments, between group comparison and relative risk in hood group compared to mask

Comparison	Eyes with ≥ one D myopic shift	*n* / denominator (%)		Chi^2 and *P*-value	Relative risk (95% CI)
		Hood	Mask		
After 20 treatments	One or both eyes	40/59 (68)	9/43 (21)	21.9 $P < 0.0001$	3.2 (1.9 to 6.1)
	Both eyes	18/59 (31)	3/43 (9)	8.4 $P = 0.004$	4.4 (1.5 to 13.4)
After 30 treatments	One or both eyes	37/45 (82)	13/33 (39)	15.2 $P < 0.0001$	2.1 (1.4 to 3.4)
	Both eyes	24/45 (53)	5/33 (15)	11.9 $P = 0.0006$	3.5 (1.6 to 8.3)

Table 4
Keratometry in both groups at baseline, 20 treatments and 30 treatments. CRC = corneal radius of curvature in millimetres; RPC = refractive power of the cornea in Dioptres

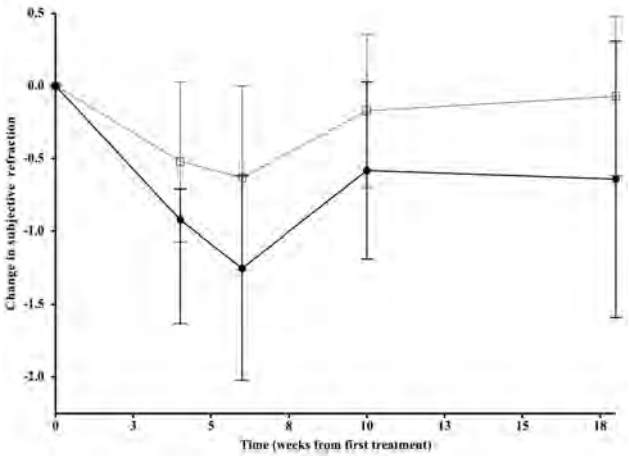
Group	CRC; baseline Mean (95% CI)	CRC; 20 treatments Mean (95% CI)	CRC; 30 treatments Mean (95% CI)	One-way ANOVA and *P*-value
Hood	7.82 (7.76 to 7.87)	7.81 (7.75 to 7.86)	7.83 (7.76 to 7.91)	F = 0.19, $P = 0.83$
Mask	7.69 (7.54 to 7.84)	7.70 (7.60 to 7.80)	8.02 (7.55 to 8.49)	F = 2.04, $P = 0.13$
	RPC; baseline Mean (95% CI)	**RPC; 20 treatments Mean (95% CI)**	**RPC; 30 treatments Mean (95% CI)**	
Hood	43.3 (43.0 to 43.6)	43.3 (43.0 to 43.6)	43.2 (42.7 to 43.6)	F = 0.10, $P = 0.90$
Mask	43.2 (42.4 to 44.0)	43.4 (42.9 to 43.9)	43.5 (43.2 to 43.9)	F = 0.14, $P = 0.90$

no problematic issues with vision (hood 50/63 (79%), mask 38/55 (69%). There was evidence of a deterioration in scores in the hood group after both 20 and 30 treatments: baseline median 0 (IQR 0 to 0); after 20 treatments median 0 (IQR 0 to 4), MWUT using exact probabilities $P < 0.0001$; and after 30 treatments median 2 (IQR 0 to 2), MWUT $P < 0.0001$. There was a difference in median scores of 2 (95% CI 0 to 4). There was no statistically significant deterioration in scores at either time in the mask group: baseline median 0 (95%CI 0 to 1); after 20 treatments 0 (0 to 2), MWUT $P = 0.18$; after 30 treatments 0 (0 to 1.5), MWUT $P = 0.75$.

There were no important changes in keratometry over the course of treatment in either group. For example, the mean corneal radii of curvature in the hood group at baseline, 20 and 30 treatments were 7.82 (95% CI 7.76 to 7.87), 7.81 (7.75 to 7.87) and 7.83 (7.76 to 7.91) respectively, and one-way analysis of variance suggested no statistically significant differences (F = 0.19, $P = 0.83$; Table 4).

In order to obtain some idea of the rate of improvement in myopic shift after cessation of treatment, we re-examined those patients who returned for review at four and 12 weeks (Figure 3). At four weeks the hood group ($n = 24$) had improved from values obtained after both 20 and 30 treatments to a mean shift of -0.58 D (95% CI -0.74 to -0.42) while at 12 weeks ($n = 14$) there was little further change (mean shift -0.64 D, 95% CI -1.02 to -0.26). For the mask group, there was an improvement at four weeks to a mean shift of -0.17 D (95% CI -0.31 to -0.02, $n = 23$) and at 12 weeks the mean shift was -0.07 D (95% CI -0.33 to 0.19, $n = 10$).

Figure 3
Mean myopic shift over time in mask and hood groups. Open squares = mask group; Closed circles = hood group. Error bars show standard deviation



Discussion

This study demonstrated myopic shift is more pronounced when using a hood system to deliver hyperbaric oxygen compared to using a mask during a standard 90 minute HBOT protocol at 243 kPa daily, Monday to Friday. The shift is about twice the magnitude with a hood after both 20 and 30 treatments and the risk of developing a shift of ≥ 1 D in at least one eye was about three times higher using a hood than a mask. The available data at four and 12 weeks after completion of treatment suggest recovery may be considerably slower and perhaps less complete after using a hood system.

Individuals with myopic shift experience poorer distance vision. This may impact considerably on many activities of daily living such as driving, playing sports, reading street signs, and watching television.[9] It is our practice to recommend correction of any myopia by the purchase of widely available cheap, temporary non-prescription spectacles. There are also adjustable-power spectacles available as an alternative. Even in hyperopic individuals, where a myopic shift can technically correct the refractive error to some degree, the refractive change can cause their prescription glasses to be incompatible with good vision for the duration of the myopic shift. Further, as the myopic shift is generally temporary and variable, it is impractical for patients to obtain new prescription glasses as required.

HBOT induced myopia was first reported in 1978 in a series of ten patients who had received 40 sessions of HBOT at 203 kPa (2 atm abs) for two hours daily, Monday to Friday.[10] The mean myopic shift was -1.6 D (95%CI -0.5 to -2.5). Since then, a succession of studies have published similar results that together suggest: masks produce smaller myopic shifts than either hoods or monoplace treatments in 100% oxygen-filled chambers; that this problem is evident in phakic eyes rather than those with intra-ocular lens replacements; and that the degree of myopic shift is positively correlated with the number of treatment sessions (Table 5).

On this basis, myopia is widely acknowledged as a common side effect of HBOT. In our facility, patients are routinely advised of this possibility and we suggest the myopic shift will resolve over a period of weeks, although after extreme exposures Palmquist 1978 reported that some patients never return to baseline and a small number develop formal cataracts.[12] The authors of a large, prospective cohort of elderly individuals have independently postulated a myopic shift itself can predispose to the development of cataracts.[15]

The exact mechanism by which HBOT causes myopia is not known with certainty. Several models have been hypothesized to explain the anatomical basis of refractive change, but many of these have little support from the evidence available. To date, no changes in corneal curvature (confirmed in the present study), anterior chamber depth, axial eye length or lens diameter have been identified in patients with HBOT induced myopia.[4,13,16]

By elimination, these findings are highly suggestive of a lenticular etiology for refractive change and there is corroborating evidence available to support this proposition. Both Khan 2003 and Evanger 2011 demonstrated a much higher incidence of myopia in phakic eyes over pseudophakic eyes following HBOT; indeed none of the pseudophakic eyes developed significant myopia.[5,14] The evidence, confirmed in our study, that hoods produce greater myopic shifts than the same oxygen dose delivered by oronasal mask suggests the exposure of the eye directly to 100% oxygen at pressure is the primary causative factor. During a typical hyperbaric treatment, unlike hoods or 100% oxygen-filled monoplace treatments where the eye is exposed to 203 to 243 kPa of oxygen, wearing an oronasal mask only exposes the eye to air at pressure – approximately 40 to 50 kPa of oxygen.

While hyperbaric practitioners are quick to invoke high arterial oxygen tensions as the primary driver of therapeutic mechanisms for HBOT, there are anatomical and physiological reasons to suggest it is direct exposure of the anterior chamber of the eye to high oxygen tensions that produces the observed effects on refraction. The cornea and lens are avascular structures and receive a significant proportion of oxygen by passive diffusion from the air. Oxygen diffuses down a gradient from the pre-corneal tear film, through the cornea, into the anterior chamber and thence to the lens.[17] There is also some diffusion to the rear of the lens from the retinal artery through the vitreous humour as well as a component from the choroidal circulation. Increased oxygen tension in the aqueous humour has been reported in studies when rabbit corneal surfaces were exposed to HBO while maintaining normal respiration with ambient air.[18]

Structural changes in the lens after HBO exposure have also been reported, including altered phospholipid composition in lens epithelial cells, decreased protein sulfhydryl groups

Table 5
Summary of studies examining the myopic shift associated with hyperbaric oxygen. RCT = randomised controlled trial; * = duration of hyperbaric treatments not specified

Study	Type and exposure	Delivery system	Myopic shift
Anderson and Farmer 1978[10]	Case series *n* = 10 40 x 203 kPa x 120min	Hood	Mean -1.6 D (95% CI -0.5 to -2.5)
Lyne 1978[11]	Case series *n* = 26 20–260 x 243 kPa x 120min	Monoplace 100% oxygen environment	Range -0.5 D to -5.5 D
Palmquist et al. 1978[12]	Non randomised cohorts *n* = 25: 75–425 x 203–243 kPa x 120min *n* = 19: 'control' on waitlist	Monoplace 100% oxygen environment	24/25 treated pts ≥ 1 D vs none in control pts Mean -3.0 D (no CI or SD given) in treated pts
Ross et al. 1996[13]	Case series *n* = 8 20 x 253 kPa x 120min	Monoplace 100% oxygen environment	2/8 had shift of ≥ -0.5 D
Fledelius et al. 2002[4]	Case series *n* = 17 20 x 253 kPa x 95min	Mask	Mean -0.49 (no CI or SD given)
Khan et al. 2003[5]	Cohort *n* = 43 (75 phakic eyes versus 11 pseudophakic eyes) 30-40 x 203–243 kPa x ?*	Monoplace 100% oxygen environment	Means: Phakic: -0.74 D (SE 0.12) Pseudophakic: -0.03 D (SE 0.05)
Evanger et al. 2004[6]	RCT *n* = 32 21 x 243 kPa x 90min	Hood *n* = 12 Mask *n* = 20	Mean -1.08 D (SD 0.54) Mean -0.54 D (SD 0.41)
Evanger et al. 2011[14]	Cohort *n* = 22 (32 phakic eyes versus 12 pseudophakic eyes) 20 x 243 kPa x 90min	Monoplace 100% oxygen environment	Phakic: median -0.63D (Range -0.25 D to -1.88 D) Pseudophakic: median 0.06 D (Range -0.13 to 0.25 D)

and increased disulfide formation, and loss of cytoskeleton proteins.[19–21] The refractive index of the lens is highly dependent on the protein concentration within the lens and changes resulting from oxidative damage to lens proteins are likely to have direct effects on the refractive power of the lens.[22]

These effects suggest an increased oxidative stress induced by prolonged exposure to elevated oxygen tension. Interestingly, there are some similarities with changes described in the lens during nuclear cataract formation and it may be that both these processes are due to oxidative changes over different time courses.

Overall, the prevailing evidence strongly implies a lenticular etiology for HBOT-induced myopic shift, with the effects of oxidative stress being the primary mechanism. The current study supports a lenticular etiology.

Our study does have limitations. Several patients elected to switch from the mask to the hood, particularly during the early part of the recruitment phase. This was most likely due to the lower familiarity with the mask system at that time, along with the potential observation by the patient that most others were using the hood. Our per-protocol and intention to treat analyses were very similar and we do not believe these decisions affected our overall conclusions. A second potential problem was the open nature of the intervention. This introduced the potential for bias into the trial, although it is hard to envision how the subjects could influence the subjective refraction estimation in a systematic way. More important is the potential for bias due to the investigator performing the subjective refraction being aware of allocation. However, the investigators were asked not to discuss the method of oxygen delivery with the patient and were generally not otherwise involved in patient treatment. The exceptions were some evaluations performed by the first three authors when no other trained individual was available.

A higher proportion of females were enrolled in the mask group than the hood group (43% and 29% respectively). Although not statistically significantly different, the myopic shift in females was less than in males (mean -0.9 D versus -1.3 D respectively). While any systematic bias due to gender difference would tend to exaggerate the difference between oxygen delivery groups, it is also possible the observed difference between the sexes is the result of that allocation. No sex differences in myopic shift have been previously observed and we believe confounding by gender is unlikely.

It is also possible the observed changes were reflective of nothing more than a lower dose of oxygen in those using an oronasal mask. It has long been observed that entrainment of air while using an oronasal mask results in a lower effective inspired fraction of oxygen compared to the use of a hood.[23] Stephenson showed the oxygen concentration in a hood when using flows of 30 to 50 litres per minute approaches 100%, and individuals using a hood are more likely to achieve an oxygen fraction of > 0.8 within the hood than when using an oronasal mask, even when the latter are supervised by a trained nurse. These authors noted the fraction of oxygen measured in the dead space of the mask

could not be regarded as an accurate measure of the inspired fraction, influenced as it would be by the exhaled fraction. On the other hand, Sheffield had previously demonstrated that a well-fitting oronasal mask delivered a mean end-inspiratory of oxygen of 97.8 % (range 96 to 99) and this was considered satisfactory oxygen delivery.[24] Given many centres employing monoplace chambers routinely treat at 203 kPa, the equivalent oxygen dose at 243 kPa can be achieved with an inspired fraction of about 0.83. While we are confident therapeutic oxygen doses are delivered with our current oronasal mask, we are nevertheless currently evaluating the effective dose delivered to confirm this.

While it is likely recovery will take longer in those using the hood because of the greater magnitude of change, the suggestion this group achieves incomplete recovery of refraction should be interpreted with caution. These patients were re-examined at four and 12 weeks in an opportunistic way and it is quite possible those with persisting myopic shift were more likely to present at these times.

Conclusion

The use of a hood system to deliver hyperbaric oxygen results in a more profound myopic shift than when using an oronasal mask. The mean refractory change is approximately twice the magnitude with the hood and there is some indication from follow-up that the shift resolves after treatment more slowly and perhaps less completely when using the hood. The changes support a lenticular etiology to explain myopic shift associated with HBO exposure. Consideration should be given to discussing these implications with individual patients during the consent process prior to commencing HBOT and to selecting an oronasal mask as the default delivery system.

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Protective effect of hyperbaric oxygen treatment on rat intestinal mucosa after mesenteric ischaemia and reperfusion

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Mesenteric ischaemia; Ischaemia-reperfusion injury; Histology; Experimental study

Abstract
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Introduction: Mesenteric ischaemia results from a lack of adequate blood flow to and oxygenation of the mesentery and intestines. The aim of the present study was to evaluate the effect of hyperbaric oxygen treatment (HBOT) on the healing process in intestinal mucosa of rats undergoing mesenteric ischaemia and reperfusion.

Methods: Thirty-two Wistar-Albino rats were divided into four groups of eight: 1) ischaemia/reperfusion (I/R); 2) sham operation; 3) I/R+HBOT started 6 hours after reperfusion; 4) I/R+HBOT started 12 hours after reperfusion. In the I/R groups, a vascular clamp was placed across the superior mesenteric artery to occlude arterial circulation for 60 minutes, followed by reperfusion. A dose of HBOT consisted of 100% oxygen breathing for 90 minutes at 2.5 atmospheres absolute pressure. Thirteen doses of HBOT were administered after ischaemia. The rats were sacrificed on the eighth day, and their intestinal tissues were harvested for histopathologic analysis. The tissue levels of catalase, malondialdehyde, and glutathione were determined.

Results: The histopathological scores (HSCORE) were consistent with macroscopic examinations. The scores were significantly higher (worse) in Group 1 compared to Group 2, Group 3, and Group 4 (for all comparisons, $P < 0.05$). Group 4's HSCORE was significantly higher than those of Group 2 and Group 3 (for both comparisons $P < 0.05$). Group 3's HSCOREs were only marginally higher than Group 2. Group 3 exhibited higher glutathione levels than Group 1 ($P < 0.05$). There were no significant differences across the groups with respect to malondialdehyde and catalase levels.

Conclusion: A beneficial effect of HBOT was observed on oxidative stress and inflammation in acute mesenteric ischaemia-reperfusion.

Introduction

Mesenteric ischaemia is caused by an insufficient blood flow and oxygenation through the mesentery and intestines. Acute mesenteric ischaemia (AMI) followed by reperfusion leads to ischemia reperfusion (I/R) injury and is a very serious life-threatening syndrome that can cause disseminated tissue injury or multi-organ failure.

One per thousand cases seen at emergency departments in Europe and the USA are AMI events.[1] The occurrence of AMI is increasing in parallel to the increase in the prevalence of co-morbid diseases in an aging population. Pre-existing diseases worsen the prognosis in intestinal necrosis.[2] If AMI is not treated, it may result in infarction of the mesenteric region, intestinal necrosis, augmented inflammatory responses, and death. Through early intervention this process

might be stopped and reversed, though reperfusion itself can be associated with injury. The diagnosis of AMI is difficult and failure to diagnose it before the development of intestinal necrosis is responsible for its high mortality rate.[3–5]

Hyperbaric oxygen treatment (HBOT) is used for the treatment of various diseases such as carbon monoxide poisoning, decompression illness, osteomyelitis, and diabetic foot wounds.[6] HBOT entails 100% oxygen inhalation for periods of 1–2 hours intermittently under a higher than normal ambient pressure. This increases the dissolved oxygen concentration within arterial blood and, hence, increases oxygen diffusion rates in tissues with poor perfusion.[7] Recently, it has been found that it may have a protective effect in central nervous system ischaemic conditions such as stroke,[8] acute cerebral ischaemia,[9] and in cardiovascular ischaemic events.[10,11]

The aim of this study was to evaluate the effect of HBOT on the healing process of intestinal mucosa of rats undergoing mesenteric ischaemia and reperfusion procedures.

Methods

STUDY DESIGN AND SETTINGS

This study was conducted at the Experimental Medical Center of Istanbul University after approval from the local ethical committee for animal studies of the same institution (Process number: 96, 2013). HBOT was conducted under the supervision of an underwater medicine expert from Istanbul University's Underwater Medicine Department.

EXPERIMENTAL ANIMALS

Thirty-two male Wistar-Albino rats, each weighing between 250 and 300 g, were included. They were housed in stainless steel cages at a constant temperature (22°C) and a 12-h day/night cycle. The rats were fasted but had free access to water the night before the experiment. They were fed commercial rat chow and accessed water *ad libitum* at other times.

INTESTINAL ISCHAEMIA / REPERFUSION (I/R) MODEL

Rats were anaesthetized using 0.1 ml·100g^{-1} intraperitoneal ketamine hydrochloride 50 mg·ml^{-1} and xylazine hydrochloride 20 mg·ml^{-1} mixed at a ratio of 2:1 respectively. After anaesthesia a 4 cm median laparotomy incision was made aseptically. The small intestine was exposed and the mesenteric artery was located and isolated without harming the mesenteric vein. The mesenteric artery was obstructed with a vascular clamp (ischaemic process). After clamping the artery, the small intestine was placed into the abdominal cavity again for 60 minutes and the surgical wound was stitched using 4-0 monofibre nylon stitches. After 60 minutes of ischaemia the abdominal cavity was reopened, and the vascular clamp was removed, starting the reperfusion process. At this time, the abdomen was again closed with 4-0 monofibre nylon until the experiment was completed.

HYPERBARIC OXYGEN TREATMENT

HBOT was administered in an experimental hyperbaric chamber as follows. The rats were pressurized over 15 minutes to 2.5 atmospheres absolute (atm abs) pressure. They breathed 100% oxygen at this pressure for 90 minutes before being decompressed back to 1 atm abs over 15 minutes. Every treatment commenced at the same hour in the morning (10:00 AM) in order to minimize any effect of biological rhythm changes. Rats receiving HBOT underwent a seven day course as follows: three sessions per day in the first two days (starting at six or 12 hours after reperfusion on day one as above); two sessions per day in the third and fourth days, and one session in each of the subsequent three days.

EXPERIMENTAL GROUPS

The animals were divided into four groups consisting of equal numbers of rats (n = 8).

Group 1, Ischaemia/reperfusion (I/R): Ischaemia and reperfusion procedures were performed without HBOT.

Group 2, Sham operation: Small intestines were exposed, and mesenteric arteries were located and dissected. When the process ended, the abdomen was stitched with 4-0 monofibre nylon stitches and remained stitched until the experiment was completed.

Group 3, I/R + HBOT started 6 h after reperfusion: HBOT was initiated 6 h after the beginning of reperfusion. All animals in this group received HBOT for seven days.

Group 4, I/R + HBOT started 12 h after reperfusion: HBOT was initiated 12 h after the beginning of reperfusion. All animals in this group also received HBOT for seven days.

COLLECTION OF SAMPLES

All rats were sacrificed on the eighth day by administering an excessive amount of an anaesthetic into the heart (2 ml of ketamine hydrochloride 50 mg·ml^{-1}). Ten centimetres of small intestine proximal to the ileocaecal area was removed for histopathological analysis.

HISTOLOGICAL PREPARATION

Histopathology was conducted with the laboratory staff blinded to the study groups. One centimetre segments from the third, fifth, and seventh cm of the 10 cm small intestine specimen were placed in 10% neutral buffered formalin for at least 24 h. Paraffin-embedded cross-sections (3 mm) were stained with haematoxylin-eosin (H + E) and Azan.

Table 1
Scoring system for I/R injury as described by Verhaegh et al.[12]

Grade	Appearance
0	Normal mucosa
1	Subepithelial Gruenhagen space capillary congestion
2	Extension of subepithelial space with moderate epithelial lifting
3	Massive epithelial lifting down the sides of villi, few tips denuded
4	Denuded villi
5	Loss (destruction) of villi, haemorrhage
6	Crypt layer injury
7	Transmucosal infarction
8	Transmural infarction

I/R INJURY HISTOLOGY

Specimens were evaluated and photographed by a bright field microscope (Olympus BX61, Tokyo, Japan) under magnifications of 10 or 20 times (see figure captions). Histopathologic changes were evaluated by a single independent assessor blinded to study group. The degree of I/R injury was scored on a scale from 0–8 as described by Verhaegh et al.[12] (Table 1).

ANTIOXIDANT / OXIDATIVE STRESS MARKERS

Tissue specimens were weighed and homogenized in cold 0.1 M phosphate buffer (pH 7.4) using an automatic homogenizer. The homogenates were then centrifuged at 15,000 rpm at 4°C for 15 min. Clear supernatants were used for the catalase (CAT), glutathione (GSH), and malondialdehyde (MDA) assays. Tissue protein levels were also measured at this step using the method described by Lowry et al.[13]

Catalase enzyme converts hydrogen peroxide to water and oxygen. Catalase activity was measured by the Aebi method.[14] This method is based on the hydrolyzation of H_2O_2 and reduced absorbance at 240 nm. The results are expressed as $U \cdot mg^{-1}$ of protein tissue.

Malondialdehyde (MDA) is a product of lipid peroxidation. Tissue MDA assays were performed according to the method described by Ohkawa et al.[15] MDA reacts with thiobarbituric acid under acidic conditions at 95°C, forming a pink complex that absorbs at 532 nm. 1,1,3,3-tetraethoxypropane was used as the standard. The results are expressed in $nmol \cdot ml^{-1}$.

Glutathione (GSH) levels were determined according to Beutler's method using Ellman's reagent.[16] The procedure is based on the reduction of Ellman's reagent by sulfhydryl groups to form 5,5′-dithiobis (2-nitrobenzoic acid) with an intense yellow colour, measured spectrophotometrically at 412 nm. The results were expressed as $nmol \cdot mg^{-1}$ of protein.

Table 2
Histopathological scoring of intestinal injuries by experimental group. Group 1 = I/R injury. Group 2 = sham operation. Group 3 = I/R + HBOT started at 6 hours after I/R. Group 4 = I/R + HBOT started at 12 hours after I/R. * = $P < 0.005$ compared to Group 1. # = $P < 0.005$ compared to Group 4

Group	Mean (SD)	Median	Range
1	7.0 (0.5)	7.1	6.4–7.8
2	0.3 (0.2)*#	0.3	0.0–0.6
3	0.4 (0.3)*#	0.3	0.0–1.0
4	1.1 (0.7)*	1.1	0.2–2.4

STATISTICAL ANALYSIS

The distribution of the variables was tested using the Kolmogorov Smirnov test. Descriptive statistics included mean, standard deviation, median, maximum and minimum values where appropriate. Kruskal-Wallis and Mann-Whitney U tests were used for the analysis of quantitative data. Sample size was determined based on an anticipated effect of HBOT derived from similar study by Bertoletto et al.[17] With alpha set at 0.05 and with eight rats per group the study power was 86%. SPSS 22.0 software package (IBM, New York, USA) was used for all statistical analyses.

Results

HISTOPATHOLOGICAL FINDINGS

The histopathological scores (HSCORE) of the intestinal injuries are shown in Table 2. HSCOREs were significantly higher (worse) in Group 1 compared to Groups 2, 3, and 4 ($P < 0.05$). Group 4's HSCORE was significantly higher than those of Group 2 and Group 3 ($P < 0.05$). There was a small but significant difference between Group 2 and 3 (the latter being higher) ($P < 0.05$). Initial HBOT at 6 h after I/R injury (Group 3) resulted in a better HSCORE when compared to HBOT started at 12 h (Group 4).

The histological examination of Group I (I/R) demonstrated injured intestinal mucosae with moderate epithelial lifting, destruction or loss of villi, haemorrhage and also crypt layer injuries (Figure 1 a, b, c, d). Normal histological structures were observed in Group II (sham operation) (Figure 2 a, b, c, d). Group III (I/R + HBO at 6 hours) (Figure 3 a, b, c, d), and Group IV (I/R + HBO at 12 hours) (Figure 4 a, b, c, d) exhibited near normal intestinal mucosae, intact villi and epithelial layers with the goblet cells between columnar epithelial cells.

BIOCHEMICAL ANALYSIS

Oxidative stress marker assays are presented in Table 3. There were no differences between the study groups with respect to MDA and CAT levels that reached statistical significance. A significant difference was found between Group 1 and Group 3 with respect to GSH levels ($P < 0.05$). In Groups 3 and 4 there were increases in GSH

Figure 1
Group 1 – I/R group. Injured intestinal mucosae with moderate epithelial lifting, loss of villi, haemorrhage and also crypt layer injuries. Panels A, B, C 10 x magnification; panel D 20 x magnification

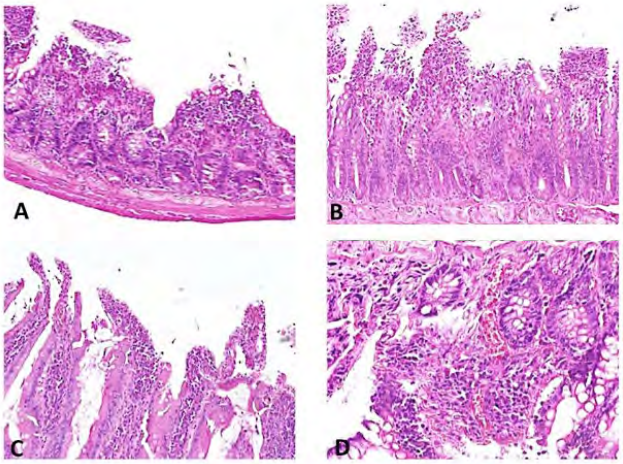


Figure 2
Group 2 – sham operation. Normal intestinal mucosae with intact villi and epithelial layers. Goblet cells easily seen between the columnar epithelial cells. Panels A, B 10 x magnification; panels C, D 20 x magnification

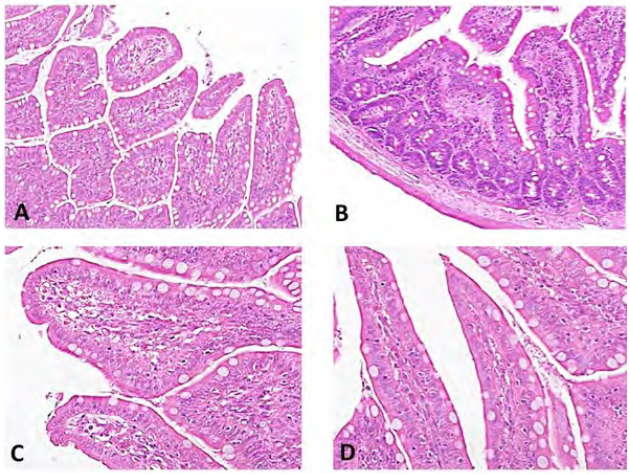


Figure 3
Group 3 – I/R+HBO at 6 h. Normal intestinal mucosae similar to the sham group. Intact villi and epithelial layers with goblet cells easily seen. Panel A 10 x magnification; panels B, C, D 20 x magnification

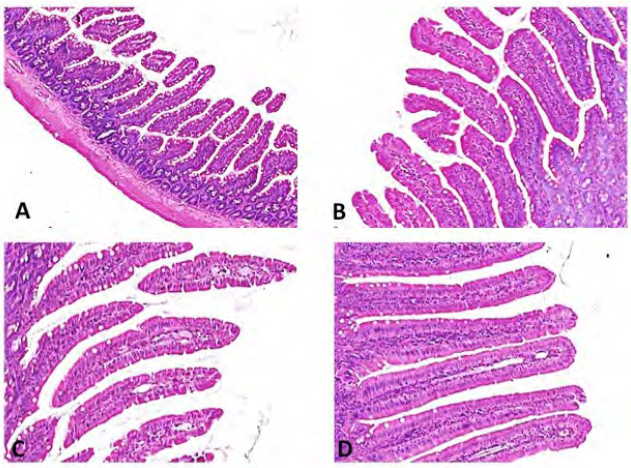
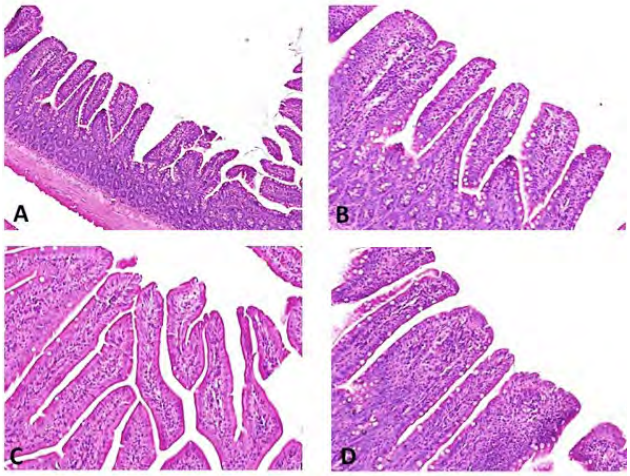


Figure 4
Group 4 – I/R+HBO at 12 h. Normal intestinal mucosae similar to the sham group. Intact villi and epithelial layers with goblet cells easily seen. Panel A 10 x magnification; panels B, C, D 20 x magnification



levels and CAT enzyme activity compared to the other groups (Group 3 > Group 4). The tissue MDA levels in Groups 3 and 4 were higher than the other groups. However, these differences did not reach statistical significance.

Discussion

HBOT significantly decreased intestinal damage in this animal model of I/R injury. In particular, HBOT initiated 6 h following the I/R injury markedly reduced histological damage scores compared to the untreated I/R group. In addition, there were increased levels of GSH and CAT enzyme activity in the HBOT groups, suggesting that HBOT positively affected antioxidant capacity, though at different levels.

It is thought that HBOT after I/R may ameliorate both ischaemia and the adverse effects of reperfusion.[18] The beneficial effects of high oxygen concentration on ischaemic or I/R damage have inspired many studies over the years. In experimental studies, intraluminal oxygen administration was tried before the use of HBOT in this area. In a 1976 study using rats, it was found that mortality rates decreased by 50% when oxygen was administered into the lumen of ischaemic intestine. The authors suggested that the administration of intraluminal oxygen to protect the mucosal integrity until

Table 3
Mean (SD) assays of glutathione, malonaldehyde and catalase in intestinal tissue by experimental group. Group 1 = I/R injury. Group 2 = sham operation. Group 3 = I/R + HBOT started at 6 h after I/R. Group 4 = I/R + HBOT started at 12 h after I/R. * = $P < 0.05$ compared to Group 1

Group	Glutathione nmol·mg^{-1} protein	Malondialdehyde nmol·ml^{-1}	Catalase U·mg^{-1} protein
1	11.50 (7.43)	1.39 (1.13)	2.47 (0.59)
2	16.00 (5.46)	1.32 (1.33)	1.96 (2.04)
3	36.00 (26.69)*	2.72 (1.33)	6.84 (5.49)
4	25.33 (11.57)	2.71 (0.83)	2.47 (1.30)

sufficient blood flow was restored would increase survival rates in humans.[19]

A beneficial effect of HBOT in ischaemic or I/R injuries has been demonstrated in different tissues and organs.[20–22] In our study, we found that HBOT initiated 6 h after reperfusion of ischaemic bowel was more protective than the same treatment initiated after 12 h. Whether even earlier initiation of HBOT after the injury might be more beneficial requires additional study.

Although there are small number of reports of a beneficial effect of HBOT in the treatment of ischaemia and ischaemic ulcers at colonic anastomoses following the resection of colon, data describing HBOT for the treatment of these conditions in humans are scarce.[23,24] Thus, defining an HBOT paradigm for optimum benefit needs further study on different injury types and patient age groups, including patients with comorbidities. However, for the treatment of I/R injuries, HBOT might be an alternative or adjunct to conventional treatment choices.

The evaluation of the GSH and CAT levels of Group 3 suggested that HBOT at 6 h increased antioxidant levels/activity more than the same treatment administered at 12 h. It was thought that HBOT started after 12 h might have prevented the necessary responses from occurring since, by that time, the critical time necessary for activation of the antioxidant system passes. These results may be a guide for determining the timing of treatment after I/R.

As an end product of lipid peroxidation, MDA is regarded as an indicator of oxidative stress. Ilhan et al.[25] found that HBOT administered prior to ischaemia elicited a beneficial effect on renal I/R by reducing oxygen radical peroxidation of lipid membranes. In our study, the MDA levels of the groups that received HBOT (Groups 3 and 4) were higher than those of the other groups, although this did not reach to statistically significant level. The rise of the MDA levels may be considered to be a sign of oxidative damage thought to develop as a result of increased oxygen in a cellular level after HBOT. However, the elevation of antioxidant levels in the same groups may have mitigated peroxidative damage, providing a balance between the oxidant and antioxidant systems.

This study has several limitations. Firstly, the follow-up time is relatively short. However, the histology in the HBO treated animals was little different compared to the surgical controls, so complications arising after longer follow-up seems unlikely. Secondly, the rats received HBOT based on only one dosing regimen. Other dosing regimens might yield more beneficial results, and whether the treatment used here was optimal for achieving maximum benefit from HBOT is unknown. Unfortunately, studies on the dose, duration, timing, and number of repetitions for HBOT are very limited in all its indications. Finally, observations gained from experimental animal models may not translate successfully to humans with similar clinical conditions.

The strengths of this study include being a very thoroughly planned and standardized experiment with blinded evaluation of eventual outcomes. Additionally, significant amelioration of tissue injury in our study group might add extra data to the literature on potential benefits of HBOT after I/R injury.

Conclusion

Tissue histology and oxidative stress parameters demonstrated a protective effect of HBOT against mesenteric I/R injury in this rat model, especially when initiated at 6 h after reperfusion. HBOT may ameliorate tissue injury as a supplementary intervention in mesenteric I/R scenarios.

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Decompression illness (DCI) in Finland 1999–2018: Special emphasis on technical diving

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Abstract
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Introduction: This is the first published study on decompression illness (DCI) and its treatment in Finland. Diving conditions are demanding, as even in the summer the water temperature below 20 meters' sea/fresh water (msw/mfw) is 4–10°C. Technical diving has become more popular over the years, so the emphasis of this study was to describe DCI in technical divers and compare it with non-technical recreational divers.

Methods: This study includes by estimation over 95% of all hyperbaric oxygen-treated DCI patients during the years 1999–2018 ($n = 571$). The cases were divided into technical divers ($n = 200$) and non-technical divers ($n = 371$). We focused on the differences between these two groups. Technical diving was defined as the usage of mixed breathing gases, closed circuit rebreather diving or planned decompression diving.

Results: The mean annual number of treated DCI cases in Finland was 29 (range 16–38). The number of divers treated possibly indicate a shift towards technical diving. Technical dives were deeper and longer and were mainly performed in cold water or an overhead environment. Technical divers were more likely to utilize first aid 100% oxygen (FAO_2) and sought medical attention earlier than non-technical divers. Symptom profiles were similar in both groups. Recompression was performed using USN Treatment Table Six in the majority of the cases and resulted in good final outcome. Eighty two percent were asymptomatic on completion of all recompression treatment(s).

Conclusion: This 20-year observational study indicates a shift towards technical diving, and hence a more demanding and challenging style of diving among Finnish divers, with a surprisingly constant number of DCI cases over the years. There is still need for improvement in divers' education in use of FAO_2 for DCI symptoms. Fortunately, the outcome after recompression therapy is generally successful.

Introduction

Decompression illness (DCI) is a collective term embracing two dysbaric disorders.[1] Decompression sickness (DCS – caused by evolution of bubbles from dissolved inert gas) is the most common based on symptomatology.[1,2] In addition, arterial gas embolism (AGE – caused by introduction of air to the systemic circulation by pulmonary barotrauma) can cause serious neurological manifestations (typically multifocal cerebral dysfunction). Because of concerns that it may be difficult to distinguish clinically between DCS and AGE in some cases, the collective term DCI is often used in clinical studies such as this.[3] Thus, the DCI terminology is adopted here, although it is acknowledged the vast majority of cases in this series almost certainly have DCS as the underlying pathology.

The incidence of DCI (per dive) varies from 0.010% to 0.095% in different diver populations[1] and was recently reported as 0.0041% in a cohort of recreational divers.[4] The gold standard treatment for DCI is recompression in a hyperbaric chamber with administration of hyperbaric oxygen during the treatment.[1] Different treatment protocols have been suggested but the most commonly used one includes intermittent breathing of pure medical oxygen at a pressure of 284 kPa.[5,6] In Finland the US Navy Treatment Table 6 (USN TT6)[1] and an extended version of the same table, are the most commonly used. Hyperbaric oxygen treatment (HBOT) decreases the size of and removes inert gas bubbles, by increasing the off-gassing gradient.[1] It also increases tissue oxygenation in potentially injured tissues. HBOT for DCI is effective when instituted promptly. Most

patients become asymptomatic or have only minor residual symptoms after the treatment.[1]

To our knowledge, there are no previous studies describing the diving, contributing factors, or the outcome after recompression among divers treated for DCI in Finland. The unique characteristic of this population is that the majority of dives were performed in arctic conditions that differ significantly from those in most other parts of the world; even in summer, the water temperature is 4–10°C in the usual recreational diving depths, i.e., below 20 metres' sea/fresh water (msw/mfw). Cold is an acknowledged risk factor for DCI[7,8] as it impairs peripheral blood circulation and thus off-gassing of inert breathing gas.

The purpose of this study was to describe different factors associated with DCI in Finland for a 20-year time period between 1999 and 2018. During this time the popularity of technical diving has increased in the recreational diving community; since the divers and diving profiles in technical and non-technical recreational diving differ significantly from each other, we studied the difference between these two groups.

Methods

PATIENT POPULATION

This retrospective study examined treated DCI cases over the period 1999 to 2018. Until 2015 over half (60%) of these patients were treated at the Hyperbaric Center Medioxygen in Helsinki, and the remaining patients at Turku University Hospital, especially if the patients required critical care. Since 2016 practically all Finnish DCI patients requiring recompression were treated at Turku University Hospital. During the study follow-up time, there have been only sporadic anecdotal DCI cases that were treated in the Finnish military facilities, in the Rescue Department or in private recompression chambers. The exact number of these patients is unknown, but they are less than 5% of the total Finnish DCI cases.

DATA COLLECTION

Ethical approval for the study was granted by National Institute for Health and Welfare, Helsinki, Finland (THL/285/5.05.00/2016). The study is compliant with the latest version of Declaration of Helsinki.

Data were collected from the medical records of the two aforementioned medical facilities. Previously, case record data collection was less systematic, with missing data, but later became more structured. The total number of retrieved DCI patient cases was 581, but 10 patients were excluded: in two patients the diagnosis of DCI could not be confirmed, in two patients data were missing from the case summary, and six patients were breath-hold divers who were treated for DCI-resembling symptoms. Hence, the final number of cases was 571.

DIVER POPULATION AND GROUPS

For the sake of this analysis these patients were divided to two groups: technical divers (tech; n = 200) and non-technical divers (non-tech; n = 371). A technical diver was defined as: 1) using mixed breathing gases (trimix, n = 71), 2) using a closed circuit rebreather (CCR, n = 39), 3) using air or nitrox and performing planned decompression diving with decompression stops using either air, nitrox or oxygen as an accelerated decompression gas (n = 90). A highly qualified diver (n = 307) was defined as a certification level of Confédération Mondeale des Activitiés Subaquatiques (CMAS) P3 or equivalent or higher, e.g., dive master, instructor, cave, trimix, etc. Less qualified divers (n = 203) possessed CMAS P1-2 (open water diver, advanced open water diver, rescue diver) level certification. In 61 cases there was no information about the certification level.

DIVING ENVIRONMENT

In this study the cold-water diving was performed in areas where water temperature in the diving depths is 4–10°C even in summer, i.e., Scandinavia. Warm water diving was defined as dives in Southern Europe, Asia or Africa. The diving environment was described as either as open water or overhead environment (waterfilled mine or cave).

STATISTICAL ANALYSIS

Statistical analyses were conducted with the IBM SPSS Statistics program (IBM Corp, Armonk (NY), USA), version 24. Continuous variables were assessed for normality using the Shapiro-Wilk test, group comparisons were done using Student's t-test for normally distributed variables and the Mann-Whitney U test for non-normally distributed variables. Dichotomous variables were compared using the Chi-square test. A P-value of 0.05 or smaller was considered significant.

Results

EPIDEMIOLOGY

During the study period of 1999 to 2018 the number of recompressed DCI patients in Finland has varied in the range of 16 to 38 cases annually, with an average of 29 cases requiring recompression per year. A noteworthy trend is the increasing number of cases in technical divers over the years, as shown in Table 1. This probably reflects an increasing popularity of technical diving in the Finnish cohort diving community.

Table 1

The number of divers treated for DCI during the study in two-yearly groups, with specification of dive type and gas used during the incident dive. There was a shift towards technical diving in the later years seen in the number of technical divers treated for DCI. Complete data was available from all divers in this study: $n = 571$

Divers	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018
Non-technical										
Air	37	32	44	33	30	36	35	25	26	30
Nitrox	0	0	1	7	6	6	11	7	4	1
Total	37	32	45	40	36	42	46	32	30	31
Technical										
Air	1	1	3	3	4	3	3	2	6	5
Nitrox	2	3	2	9	8	3	2	3	14	13
Trimix	1	4	6	9	11	8	9	4	7	12
Rebreather	0	1	0	2	6	5	9	3	6	7
Total	4	9	11	23	29	19	23	12	33	37

Table 2

Baseline characteristics for divers treated for DCI in Finland 1999–2018. Data are *n* (%) unless otherwise specified. Information on '*previous DCI*' was available for technical: $n = 135$ and non-technical divers: $n = 194$, and on '*qualification level ≥ P3*' for technical: $n = 175$ and non-technical divers: $n = 132$. Percentages for these two parameters are based on these available data. For other parameters information was available from all divers in this study: $n = 571$

	Males	Age mean (range)	Qualification ≥ P3	Underlying disease	Medical treatment	Smoking	Previous DCI
All	446 (78)	36 (18–62)	307 (60)	82 (14)	65 (11)	51 (9)	123 (37)
Non-technical	272 (73)	35 (18–62)	132 (41)	56 (15)	40 (11)	32 (9)	65 (34)
Technical	174 (87)	38 (18–62)	175 (93)	26 (13)	25 (13)	19 (10)	58 (43)

DIVERS

Demographic data are shown in Table 2. When compared to non-technical divers, technical divers were more likely to be male (87% vs. 73%, $P < 0.001$), older (mean (SD): 38 (8) years vs. 35 (8) years, $P < 0.001$) and more highly qualified (93% vs. 41%, $P < 0.001$). There was no difference in between the groups in underlying medical conditions that would normally prohibit diving nor in previous medication use. Smoking was similar in both groups, and was comparable to the general population.[9] The rate of previously treated DCI was rather high in both groups (43% vs. 34%, $P = 0.081$), showing that divers continue diving after successful treatment of DCI.

INCIDENT DIVE

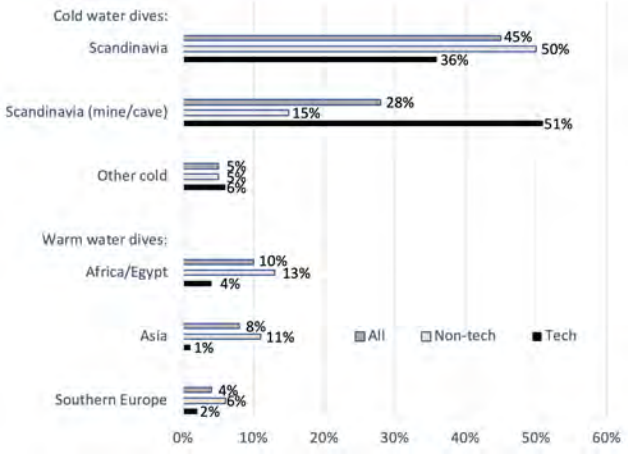
Detailed information of the diving location is given separately for technical and non-technical divers in Figure 1. The incident dive that resulted in DCI was defined as a technical dive in 35% of the cases. Divers were using trimix (36%) or CCR (20%) in 56% of these cases. Technical divers were diving in a cold-water environment in 93% of cases compared to 70 % of non-technical divers ($P < 0.001$). The median maximum depth of the dive was 45 msw/mfw for technical divers (range: 11–209) vs. 25 msw/mfw (range 4–56) for non-technical divers ($P < 0.001$), and the median duration of the dive for technical dives was 65.5 minutes (range: 17–420) vs. 35 minutes (range: 4–238) for non-technical dives ($P < 0.001$). A particular feature in Finnish diving is the large number of dives performed in overhead flooded old mines or quarries. The popularity of these diving locations is explained by the improved visibility in water as compared to seaside or lake locations. Although diving conditions are rather stable in these sites, they are still demanding, with 4°C water temperature all year round and an overhead environment. Over half (51%) of DCI cases in the technical diving group arose from dives performed in these mines.

CONTRIBUTING FACTORS

Assessment of potential predisposing factors was performed during the interview with the diver and the diving profile was evaluated when available (Figure 2). Contributing factors could be elucidated in 76% of the cases. Predisposing factors included: consecutive diving days (technical: 52% vs. non-technical: 54%, P = NS); multiple dives per day (technical: 21% vs. non-technical: 47%, $P < 0.001$); and flying after diving (technical: 14% vs. non-technical: 38%, $P < 0.001$). These are common features of diving vacations and diving safaris in the warm water environment. Fast ascent rates were

Figure 1

Diving location of the incident dive, for the whole group and separately for technical and non-technical dives. Cold water dives and warm water dives are presented under their own headings. 'Scandinavia' does not include mine/cave dives in Scandinavia, these are presented as a separate group. 'Other cold' includes cold dives in other locations, e.g., deep-sea dives and dives in northern countries outside Scandinavia. Information was available from tech: n = 193 and non-tech: n = 349. The percentages are based on these available data



reported in 50% of DCI cases in the non-technical patients (vs. technical: 21 %, $P < 0.001$). In the technical diving group the deeper and longer dives *per se* may have contributed to the risk of DCI. Other risk factors in the technical group were: consecutive diving days (52%); dehydration (technical: 27% vs. non-technical: 13 %, $P = 0.001$) during these long dives; and cold water (technical: 10% vs. non-technical 5%, P = NS), which causes reduced peripheral tissue perfusion, reducing inert gas elimination in these tissues.

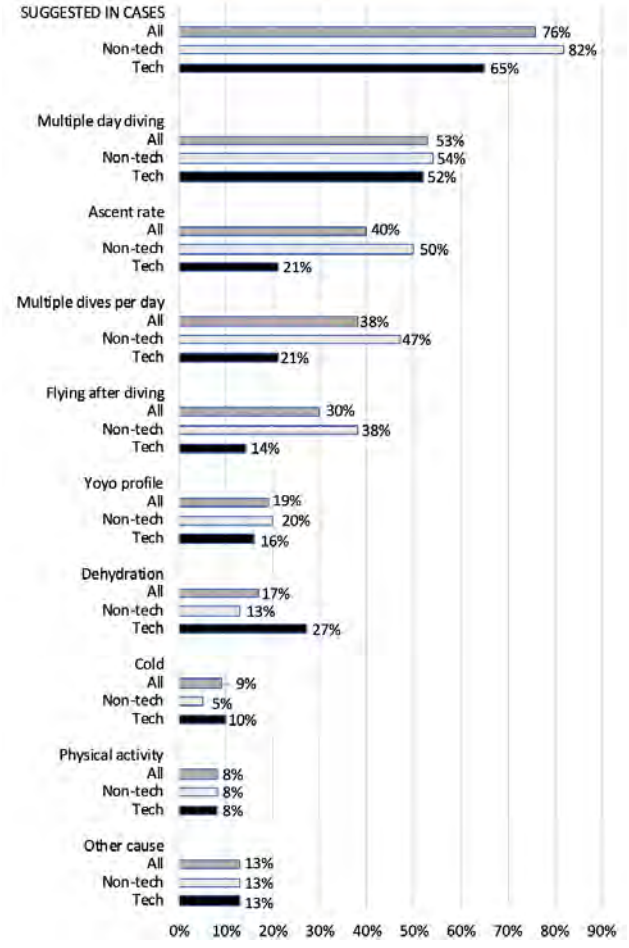
SYMPTOMS AND TREATMENT OF DCI

Presenting symptoms are shown in Figure 3. Tingling/itching was the most common symptom (66.2% of cases) followed by musculoskeletal pain (60.2%), constitutional symptoms (tiredness, light-headedness, excessive fatigue and malaise, 45.5%), numbness (36.3%) and dizziness/vertigo (21%). More serious manifestations included pulmonary symptoms (18.4%) and neurological symptoms (17.7%), subdivided into motor weakness (9.8%), visual disturbances (4%), coordination disturbances (1.9%), bladder symptoms (1.1%), abnormal reflexes (0.5%) and verbal disturbances (0.4%).

To determine possible differences in DCI symptoms in technical versus non-technical divers, we compared the symptom data of the last three years, when the data was more comprehensive (2016 to 2018, all treated in Turku University Hospital). Significant differences were seen in the prevalence of tingling/itching (technical: 49% vs. non-technical: 69%, $P = 0.05$), skin rash or cutis marmorata (technical: 40% vs. non-technical: 19%, $P < 0.05$) and headache (technical: 4% vs. non-technical: 17%, $P < 0.05$).

Figure 2

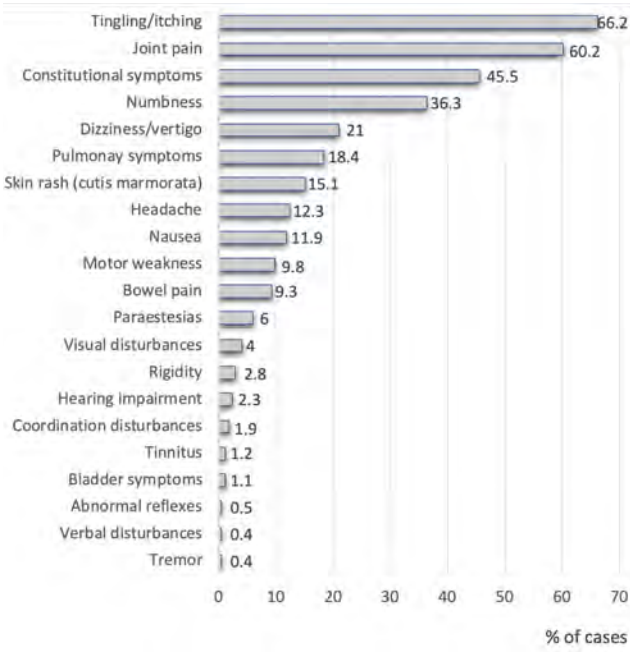
Suggested contributing factors for DCI. The first three bars 'suggested in cases' show the percentages of divers to whom one or more contributing factors were suggested. The other columns show this information for different possible factors separately. 'Other causes' include travelling by road over high mountains (which is quite usual for Finnish divers on diving trips in Norway), technical problems during diving, problems with the breathing gas and acute medical conditions. Data are presented for all divers, and for subgroups technical and non-technical dives separately. Information was available from all divers in this study: n = 571



First aid oxygen (FAO_2) was utilized on-site before admission to the hyperbaric chamber in 31% of all patients. However, 52% of technical divers had used FAO_2 compared to only 19% of non-technical divers ($P < 0.001$). This most likely reflects the availability of the oxygen on-site and the level of diving education. Median delay to recompression was 24 h (range: 1–510) in technical divers compared to 48 h (range: 1–1008) in non-technical divers ($P < 0.001$).

Primary treatment protocols were similar; most of the divers (79%) were treated with USN TT6 with or without extensions. Divers received more than one HBOT session in 55% of cases but there was no difference between the groups. Mean number of additional recompressions was 1.36 (range: 0–15). Additional recompressions followed different protocols over the years. Previously, the most commonly

Figure 3
Percentage of cases experiencing particular symptoms prior to the first recompression treatment. Constitutional symptoms include tiredness, light-headedness, inappropriate fatigue and malaise. Information was available from all divers in this study: $n = 571$



used protocol was 90–104 minutes at 243–253 kPa. Lately, the most common protocol has been either the USN TT6 or USN TT5 when patients had residual symptoms after the primary treatment.

Clinical outcomes were generally good. After HBOT, 82% of the patients were completely asymptomatic in both groups. Mild residual symptoms were present in 14% and the rate of unfit-to-dive was 4%. The latter group included the divers that had decided voluntarily themselves, especially for psychological reasons, not to return to diving. Additional reasons were clinical, and included, for example, permanent hearing impairment or vestibular residua.

Discussion

To our knowledge, this is the first study describing DCI in Finnish divers, with the majority of dives performed in an arctic diving environment. Throughout the year diving occurs in a very cold environment, which provides additional challenges to the divers. This study suggests a likely increase in number of divers using mixed breathing gases and/or closed-circuit rebreather diving in these arctic conditions. However, the annual number of DCI cases treated with recompression has remained at a constant level over the years. The increment of technical dives corresponds to deeper and longer dives, which translates to an increased risk of DCI in the well-educated divers.

Compared to a similar large study from Denmark,[10] this study reports a higher number of DCI cases per year (mean: 29 in Finland vs. 14 in Denmark[10]), even though the population of these two countries is similar. However, there are no statistics on the numbers of divers or diving activity in Denmark or Finland, and without an accurate denominator of this nature it is difficult to interpret the different numbers of DCI cases recompressed in the two countries. In addition, many Finns receive their certification abroad, and hence are not recorded at all in the Finnish statistics.

In this study, the recompressed divers were similar to those in the Danish study[10] and another large study from New Zealand.[11] The majority of the divers were males, with 78% vs. 79%[10] vs. 81%[11] and the mean age was 36 years vs. 35.5 years[10] vs. 33.6 years.[11] The special feature of this study of DCI patients requiring recompression therapy was the significant number of technical divers. In the New Zealand study, only 3.4% of the divers were using mixed gases in comparison to our study. Similarly, only 1% of New Zealand patients were using closed-circuit rebreathers compared to 6.8% of Finnish patients. The depth of the incident dive was similar in our non-technical group (25 msw/mfw) to that of the New Zealand cohort (25.8 msw/mfw), whereas the technical divers went deeper in the present study. Combining this with the effects of cold, it can be concluded that Finnish divers developing DCI tend to perform very demanding dives which may provide an explanation why we have not witnessed the decrease in the number of the DCI cases demonstrated in New Zealand or Denmark. The Danish study provided no details of the incident dive nor the breathing gases used. Interestingly, 37% of Finnish DCI patients in this study had previously been recompressed for DCI, indicating that these divers were strongly committed to diving or have a tendency to risky diving procedures.

The most common symptoms of DCI in this study were tingling/itching, musculoskeletal pain, constitutional symptoms, numbness and dizziness/vertigo. This finding is similar to previous reports, although the prevalence of the symptoms varies.[1,10,11] When analysing the subgroups (technical vs. non-technical) over the last three years of the study, the prevalence of most symptoms was similar in both groups. Only tingling/itching, skin rash/cutis marmorata and headache were demonstrated to have significantly different prevalence between the groups. The similarity of symptoms in both groups was an unexpected finding, as it could have been anticipated that in the long and deep dives (i.e., technical dives) the slow tissues would have absorbed more inert gas and when ascending in arctic diving conditions, due to decreased blood flow in peripheral tissues, could have exaggerated bubble formation in supersaturated tissues.

Usage of FAO_2 is still relatively uncommon, even though oxygen provider courses have been available for several years and many training organizations are requiring this certification when progressing through training levels.

In this study, only 31% of the divers had received FAO_2. However, the proportion was significantly higher in technical divers. This was most likely due to better availability of breathing grade oxygen on the dive site. It is also possible that many mild DCI cases never encounter medical facilities as the divers treat the symptoms with normobaric oxygen or in-water recompression. The use of FAO_2 in this study corresponds with earlier studies, which illustrated that 23–47% of divers were provided with FAO_2 prior to HBOT.[12,13] USN TT6 with or without extension was the most commonly used treatment in all three studies (79% vs. 69%[10] vs. 65%[11]). The rate of required additional recompressions was also comparable (1.36 vs. 1.27[11]).

In this study, HBOT was effective, evidenced by cases reaching complete (82%) or near complete (96%) recovery. This differs from previous reports, which have demonstrated an elevated rate of residual symptoms at hospital discharge (22–55%).[10,14–17] One explanation for this could be the difference in the re-treatment protocols. Furthermore, if the hospital discharge occurs within 12 hours after treatment, mild re-occurring DCI symptoms might still be absent, as symptoms often re-occur 12–24 hours after HBOT.[18] Most patients in this study were asymptomatic after only one or two treatments. If required, patients with residual or recurring symptoms were treated up to 15 times until symptoms had disappeared or a plateau in symptom improvement was reached. For the repetitive HBOT protocol there is no gold standard, although HBOT *per se* is recommended.[1]

An interesting finding is the high number of divers previously treated for DCI in both groups. It is possible that this could partly be explained with a good treatment outcome. A diver that recovers completely from DCI is more likely to continue diving compared to one that has residual symptoms. It is also plausible that the Finnish diving population contains a high proportion of motivated and focused enthusiasts who dive a lot and are therefore more likely to suffer problems. Highly motivated divers tend to continue diving after an adverse event. The high proportion of technical divers lends credibility to this theory.

During the 20-year observation period the HBOT re-treatment protocol has varied. The majority of the patients in this study received a shorter secondary treatment of 90 minutes at 243 kPa similar to other studies.[11,19] Recently, the preferred protocol for re-treatment in this population has been the USN TT6, with or without an extension, or USN TT5. Although not statistically significant, there have been observations that the USN TT6 confers better clinical outcomes than 90 minutes HBOT at 200 kPa irrespective of the severity of symptoms,[20] but this was a comparison of the protocols as a primary treatment rather than in re-treatment. Another comparison of primary treatment with shorter treatment tables (e.g., USN TT5) compared to longer tables (e.g., USN TT6) demonstrated better outcomes for the longer tables,[21] but again, it must be emphasized that this comparison was in primary treatment. When considering repetitive treatments, however, the cumulative and toxic effects of oxygen (i.e., UPTD, Unit Pulmonary Toxic Dose) should also be taken into account.[22,23]

LIMITATIONS

There are some limitations in this retrospective study. The long observation time was associated with many changes in data collection and treatment protocols. Previously, data collection was unstructured, resulting in a number of missing data points in the early cases. Also, the treatment protocols, particularly for re-treatments, were changing over the study period. Additionally, no systematic long-term follow-up of DCI patients to evaluate the final outcome is available. Some divers with residual symptoms after the HBOT may have completely recovered.

Conclusions

Although this study indicates an increasing popularity of technical diving in the Finnish diving community and a shift towards more demanding dives, the annual number of DCI cases has been constant. A marked observation is that DCI occurs in well-trained Finnish divers, who are performing challenging dives in all-year-around arctic conditions. Recently, half of the DCI cases requiring recompression therapy among technical divers occurred after dives in water-filled caves or quarries. Most divers recover well after treated DCI and a high rate of previously treated DCI in both technical and non-technical divers suggests that motivated divers continue diving after successful treatment of DCI. There is a need for improvement in the education of divers regarding the use of FAO_2 in treatment of DCI symptoms. Availability of FAO_2 on the dive site and by the dive operators should be mandatory.

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Evaluating the thermal protection provided by a 2–3 mm wet suit during fin diving in shallow water with a temperature of 16–20°C

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Cold; Immersion; Military diving; Rebreathers; Closed circuit; Thermodynamics; Vasoconstriction

Abstract
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Introduction: The purpose of the study was to evaluate the thermal protection provided by a 2–3 mm surfing wet suit during at least two hours of fin diving in shallow water with a temperature of 16–20°C. We examined the effect of wearing the suit while diving in cold water on cognitive performance, muscle strength, and hand motor function.
Methods: Subjects were six male well-trained rebreather divers, 19–23 years old, acclimatised to cold. They attended the laboratory on three separate occasions, when we conducted the experiment at one of three temperatures, 16, 18, and 20°C. Core temperature (gastrointestinal system), skin temperature, oxygen consumption, and cold perception were evaluated during the test. Before and immediately after the dives, subjects performed a series of cognitive, manual dexterity, and muscle strength tests.
Results: Core temperature decreased by 0.35–0.81°C over the two hours at all three water temperatures. No subject reached a core temperature below 35°C. The decrease in upper body skin temperature during the two hour dive ranged between 5.97 and 8.41°C ($P < 0.05$). Two hours diving in 16–20°C water resulted in a significant increase in the time taken to perform the task of unlinking and reassembling four shackles (~30% longer, $P < 0.05$). No effect was found on the cognitive or muscle strength tests.
Conclusions: A 2–3 mm wet suit provides adequate thermal protection in trained and cold-acclimatised young males engaged in active diving in shallow water with a temperature of 16°C and above.

Introduction

Thermal protection of combat divers is critical for their safety, as well as for their physical and mental function. However, a conflict always arises between the need for optimal thermal protection by a thicker diving suit and the need for optimal motor performance both in and out of the water, which of necessity implies a thinner suit. The traditional requirement for diving in water with a temperature of 18–29°C is a 5.5 mm wet suit made of neoprene, a synthetic rubber containing small gas bubbles. On the basis of presently available scientific knowledge, a diver may rest assured that a 5.5 mm neoprene suit will be sufficient for an active or passive dive lasting more than three hours at a shallow depth.[1]

For a number of years, sportswear manufacturers have been promoting thin (2–3 mm) neoprene wetsuits for a variety of water sports, such as surfing, swimming, and even diving. The high flexibility of these thinner suits may allow the diver better movement both in and out of the water,[2] which is of the greatest importance for combat divers. However, less is known about the thermal protection they provide.

Without optimal thermal protection, the diver may reach a level of thermal stress that can affect both mental and physical function.[3,4] A decrease in core temperature, even if not considered hypothermic, has been shown to affect different functional abilities that may become critical for combat divers. This may involve muscle,[3] cognitive[4] or motor function. Motor function, as well as muscle strength, may also be affected by a mild decrease in skin or core temperature.[5,6] In addition, reduced thermal protection in combat divers will lead to an increase in metabolic rate, which may in turn result in elevated CO_2 levels in the blood and thus expose them to an increased risk of central nervous system oxygen toxicity.[7]

To date, there has been little or no investigation of the thermal protection afforded by a 2–3 mm wetsuit and the concomitant effects on muscle strength, motor function or cognitive performance, with or without changes in core temperature, when diving in water to depths of less than 10 m. The purpose of the present study was therefore to

evaluate the thermal protection of a 2–3 mm surfing wetsuit during at least 2 h of fin diving in shallow water with a temperature of 16–20°C. Adequate protection was defined as maintenance of core temperature at ≥ 35°C under the stated conditions. We also evaluated the effect of these conditions on cognitive performance, muscle strength, and hand motor function while wearing the suit.

Methods

SUBJECTS

Subjects were six well-trained male rebreather divers, 22 (SD 1) years old, with no history of smoking. The number of subjects required for the study was determined using a formula for sample size calculation, based on the differences we hypothesised would be found on exposure to 16°C (see statistical analysis), and the expected homogeneity of the study population. All subjects were engaged in water activities in the Mediterranean Sea throughout the year and were therefore acclimatised to cold. All gave their written, informed consent to participate in the study, which was approved by the Israel Defense Forces Medical Corps Committee for Human Experimentation.

PREPARATION

Banjo type Telethermometer YSI 400A surface thermistors (YSI Inc., Yellow Springs OH, USA) were validated against a mercury thermometer, and differences between the two were noted for future readings. Upper body skin temperatures were measured, on the forearm and the chest. Due to the technical limitations of the available equipment, we measured upper body (arm and chest) skin temperature only. It was demonstrated in the past that arm skin temperature is slightly higher than calf temperature both at baseline and during a dive, and that the trend of the change was similar.[4] We assume that the two measurements we performed were to a large degree representative of the general change in skin temperature.

For core temperature measurement, we used a CorTemp™ ingestible core body temperature sensor which transmits core body temperature from the gastrointestinal system (HQ Inc. Wireless Sensing Systems & Design, Palmetto FL, USA). Each of the temperature sensors was validated against a mercury thermometer over the expected range for core temperatures between 35–39°C. Differences between the ingestible sensor and mercury thermometer readings were noted for future corrections.

We used a SwimEx Deepwater aquatic therapy pool – SX170T swimming flume (SwimEx® Systems, Warren RI, USA) which had undergone modification to allow deeper front water flow, thus making it more a simulator of underwater diving than just surface swimming.

EXPERIMENTAL PROCEDURE

Subjects attended the laboratory on three separate occasions, when we conducted the experiment at one of three temperatures: 16, 18, and 20°C. One subject failed to attend for the 18°C session. On the first day, subjects were examined by the physician to authorise their participation in the study, after which they signed the consent form and swallowed the ingestible sensors. Height and weight were recorded for each subject. A Lange skinfold caliper (Cambridge Scientific Industries, Cambridge MD, USA) was used to measure skin fold thickness at four sites: two on the arm, on the triceps and biceps, and on the subscapular and supra-iliac skin.[8]

MANUAL TASKS

Manual handling of a light weight

Subjects were evaluated for manual handling of a light weight. They were asked to unlink and reassemble a chain composed of four identical European-type large bow shackles with a screw pin, each measuring 61 by 78 mm and weighing 185 g, in the shortest time possible. This requires good hand motor function, as well as the involvement of several arm muscle groups responsible for stabilising the humerus and elbow joints. The manual handling test was performed before and after each of the three two-hour dives. Before the first dive, subjects performed the task three to five times for training purposes, until the time they took was stable. On subsequent occasions, however, there was no training. Subjects were strongly encouraged to complete the task as fast as possible.

Handgrip strength

Handgrip strength was measured for both the dominant and non-dominant hand using a recording hand dynamometer (Stoelting Co., Wood Dale IL, USA). In this test, the base of the dynamometer rests on the first metacarpal (on the heel of the palm), while the handle lies along the middle of the remaining four fingers. When the subject is ready, he squeezes the dynamometer with maximum isometric effort, maintaining this for about 5 s. Subjects were strongly encouraged to give this exercise their maximum effort. Muscle strength was measured before and after each of the three 2-h dives.

COGNITIVE TASKS

A series of three pencil-and-paper cognitive tests was performed before and after each dive. These user-friendly tests evaluate cognitive performance related in part to prefrontal cortex function, such as speed of information processing, the ability to focus attention, executive function, and short-term memory. Participants were given detailed instructions for each test. The three tests are simple to

perform, and are widely used in the field of cognitive and reasoning psychomotor testing.[9,10] On the first day, subjects had a practice session of 3–5 training trials until there was no further improvement in the results. Because the time interval between the three exposures was 24 hours, no further practice session was given.

Mathematics test

In this task, subjects were asked to perform addition and subtraction in a mixed arithmetic exercise using four single-digit numbers, for example: 4 - 3 + 8 - 6 = . Scores were assessed by recording the number of correct answers and the total number of errors over a 1 min period.

Number comparison test

In this test, multi-digit pairs of numbers were displayed to the subject, who had to decide whether the numbers in each pair were the same or different. For example, 41987 vs. 49671: Yes (numbers the same) or No (numbers different). Scores were assessed by recording the number of problems attempted, the number of correct answers, and the total number of errors over a 1 min period.

Number cancellation test (modified Stroop test)

The word "*red*" or "*blue*" appeared in black type at the beginning of each line, followed by 11 digits. The colour word was underlined randomly in either red or blue ink. If the colour word was underlined in the same coloured ink, the digits between 0–4 were to be cancelled; otherwise the instruction was to cancel the digits between 5–9. A digit could appear more than once in the line. For example, blue (red or blue underline) 89120172640. Scores were assessed by recording the number of problems attempted, the number of correct answers, and the total number of errors over a 1 min period.

EXPERIMENTAL PROTOCOL

Each subject wore a full-body 2–3 mm surfing suit (Psycho® series, O'Neill, Australia), individually fitted in accordance with the manufacturer's instructions. The legs were protected by swimming shoes and fins. Apart from the shoes, no additional protection, such as gloves or a hood, was used in the experiment.

The subject donned the closed-circuit oxygen underwater breathing apparatus (UBA), which consists of an oxygen cylinder, rebreathing bag, and soda-lime canister. Oxygen breathed from the bag is replenished automatically from the cylinder. The UBA was furnished with a pressure gauge for monitoring the oxygen pressure in the cylinder. Diving depth was 1–1.5 m. Subjects were instructed to propel themselves continuously through the water, with swimming speed controlled by the researcher and remaining constant throughout the exposure (~0.55 $m \cdot s^{-1}$). The divers remained connected to the diving gear at the sampling stops.

A series of measurements was taken at the beginning of the dive, at intervals of about 15 min during the dive, and at the end of the dive. Each sampling stop lasted about 1 min. Subjects were asked to pull themselves over to the edge of the swimming flume, lifting only their torso out of the water.

Measurements consisted of:
1. Completion of a cold score questionnaire shown to the diver on a board: 1 – comfortable; 2 – cool; 3 – cold; 4 – cold and shivering; 5 – very cold; 6 – request termination of the dive.
2. Recording of the oxygen pressure in the cylinder.
3. Skin temperature [arm (T_{arm}), and chest (T_{ch})].
4. Core temperature (T_{core}).

On day one, six subjects (three trials, two divers in each) dove continuously using a fin-diving technique at an average speed of ~0.55 $m \cdot s^{-1}$ in the swimming flume at a depth of 1–1.5 m for 2 h and at a water temperature of 20°C. On day two, five subjects dove on exactly the same protocol at a water temperature of 18°C. On day three, six subjects dove at a water temperature of 16°C. There was no possibility of changing the temperature of the large volume of water in the flume by more than 2°C in the 24-h interval between the experimental days. For this reason, among others, the experiment was not conducted in a randomised fashion with regard to temperature. Starting on day two, each of the divers was checked for the presence of the sensor in his stomach using the HQ receiver.

CALCULATIONS

Mean subcutaneous fat thickness was calculated as the arithmetic mean of measurements at the four sites according to a well-known formula:[11]

SKT = (Σsft – 16)/4, where SKT is subcutaneous fat thickness and sft is skin fold thickness.

In the closed-circuit diving system, oxygen is consumed only from the dry compressed oxygen in the cylinder, and due to rebreathing there is no loss of gas. Oxygen consumption was therefore calculated from the reduction in cylinder pressure in atmospheres absolute (atm abs), cylinder volume in litres corrected to STPD, water temperature, and the time between measurements in min:

$VO_2 = [\Delta P \times V \times 273 / (273 + T_w)] / \Delta t$, where VO_2 is oxygen consumption, ΔP is the reduction in cylinder pressure, V is cylinder volume, T_w is water temperature, and Δt is the time between measurements.

Mean upper body skin temperature was calculated as the average of chest and arm skin temperatures:
$T_{sk} = 0.5\ T_{ch} + 0.5\ T_{arm}$, where T_{sk} is mean skin temperature, T_{ch} is chest skin temperature, and T_{arm} is arm skin temperature.

Table 1
Subjects' characteristics (BSA = body surface area; BMI = body mass index)

Subject	Age (years)	Weight (kg)	Height (cm)	BSA (m^2)	BMI ($kg \cdot m^2$)	Fat (%)	Mean fat (mm)
1	23	76.5	183	1.98	22.8	12.3	6.7
2	22	70.0	177	1.86	22.3	16.6	9.4
3	22	91.5	180	2.11	28.2	21.0	13.7
4	22	70.0	180	1.89	21.6	13.5	7.5
5	21	76.0	183	1.98	22.7	13.1	7.2
6	23	72.0	176	1.88	23.2	20.8	13.5
Mean (SD)	22 (1)	76.0 (8.1)	180 (3)	1.95 (0.10)	23.6 (2.4)	16.2 (3.9)	9.7 (3.2)

Figure 1
Core temperature measured for each of the three water temperatures (16, 18, and 20°C). Values are presented as mean (SD)

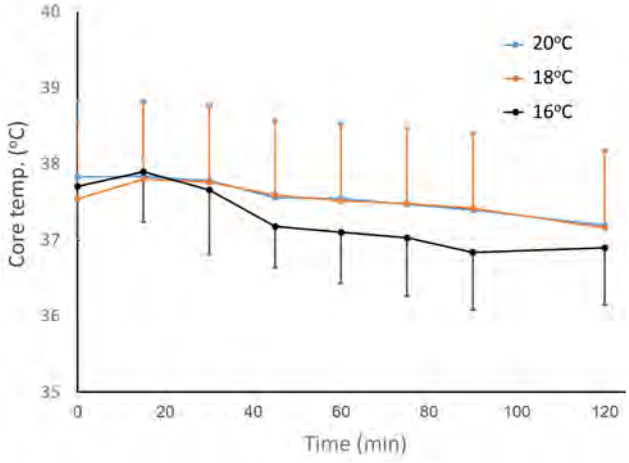
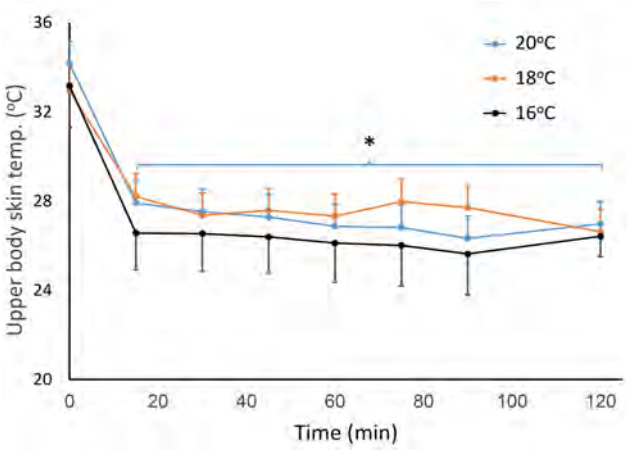


Figure 2
Upper body skin temperature measured for each of the three water temperatures (16, 18, and 20°C). Values are presented as mean (SD). * = significantly different from baseline during immersion at 16° and 20°C ($P < 0.05$)



Mean body temperature was calculated from core temperature and mean upper body skin temperature according to a well-known formula[12] as:
$T_b = 0.67\,T_{core} + 0.33\,T_{sk}$, where T_b is mean body temperature, T_{core} is core temperature, and T_{sk} is mean upper body skin temperature.

Body surface area (m^2) was calculated as:
$SA = 0.20247 \times \text{height (m)}^{0.725} \times \text{weight (kg)}^{0.425}$ according to a well-known method,[13] where SA is body surface area.

Total insulation was calculated from the total heat loss from the diver's body surface and the core-to-water temperature difference, as described in detail previously:[1]
$T_{tot} = (T_{core} - T_w) \times SA/[(0.87 \times VO_2 \times 4.83) + (0.83\Delta T_{core} \times BM \times 0.6)]$,[14] where T_{tot} is total insulation, T_{core} is core temperature, T_w is water temperature, SA is body surface area in m^2, 0.87 (E) is the fraction of oxygen converted to heat for fin divers, VO_2 is oxygen consumption ($L \cdot h^{-1}$), ΔT_{core} is the mean core temperature over the period of time T_{core} was measured, BM is body mass (kg), 0.6 is the portion of core from the body weight. Suit insulation and body insulation were calculated by replacing the core-to-water temperature gradient in the above equation by skin-to-water and core-to-skin gradients, respectively.

STATISTICAL ANALYSIS

A test for sample size was performed using an online calculator (Statistical Solutions LLC, WI, USA), based on an expected difference of 1°C after two hours exposure and a standard difference of 0.5 between subjects. Based on these conditions, for an α of 0.05 and a power of 0.95, a sample of four subjects was found to meet the objectives of the study. Results are expressed as mean (SD). Two-way ANOVA with repeated measures (time and water temperature) was performed on core, body, and skin temperature for water temperatures of 16 and 20°C. One-way ANOVA for time was performed for a water temperature of 18°C. Values for the three water temperatures were compared with baseline, and with every measurement carried out during the experiment (at min 15, 30, 45, 60, 75, 90, 105 and 120). When ANOVA reached statistical significance, a Tukey HSD post hoc analysis was performed on the different time points for each of the water temperatures.

Two-way ANOVA (time and water temperature) was performed for hand motor function and cognitive tests at 16 and 20°C, while 1-way ANOVA for time was performed on the values obtained at 18°C for the comparison between pre- and post-exposure.

Figure 3
Mean body temperature measured for each of the three water temperatures (16, 18, and 20°C). Values are presented as mean (SD). * = significantly different from baseline during immersion at 16 and 20°C ($P < 0.05$)

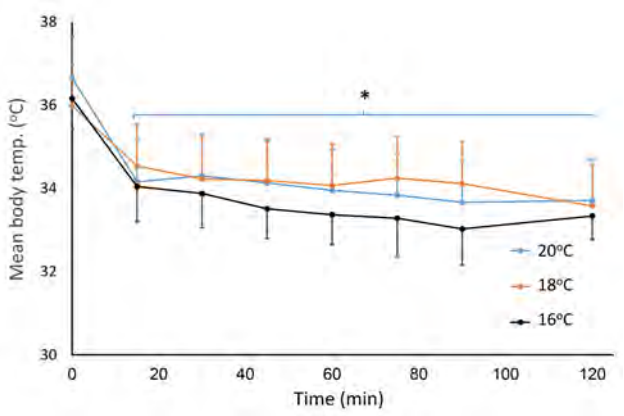


Figure 4
Cold sensation measured over the course of exposure to each of the three water temperatures (16, 18, and 20°C). Values are presented as mean (SD)

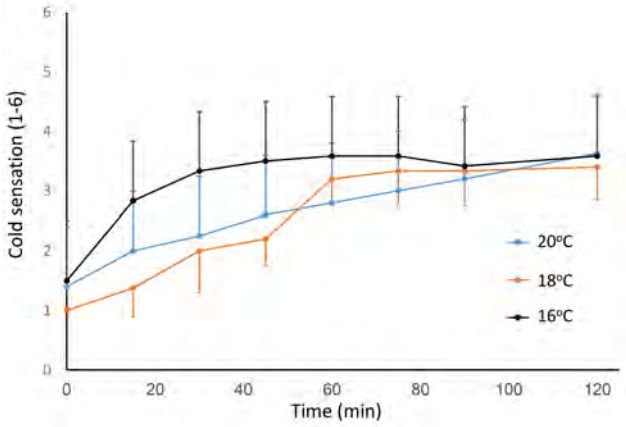
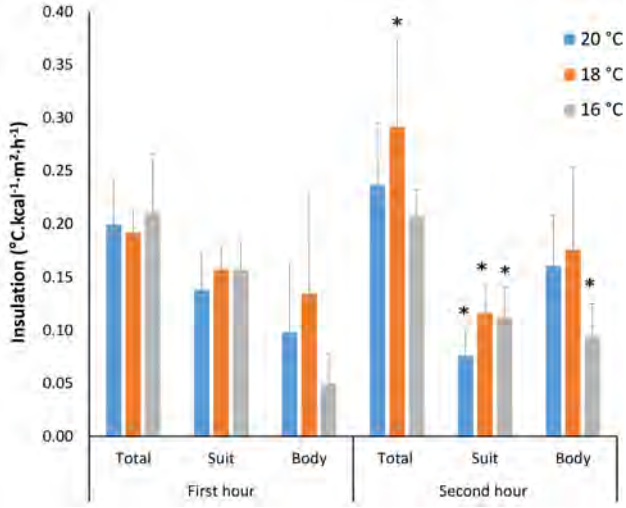


Figure 5
Total, suit, and body insulation for each of the three water temperatures (16, 18, and 20°C) during the first and second hours of cold water exposure. Values are presented as mean (SD). * = significantly different from the first hour ($P < 0.05$)



$P < 0.05$ was taken as the level of statistical significance for all analyses. A trend analysis was performed for the cognitive and motor function measurements.

Hand cold sensation was compared with baseline for each of the three water temperatures using the Friedman test for repeated measurements.

Results

MORPHOMETRIC CHARACTERISTICS

Subjects' characteristics are shown in Table 1. Subjects were young (22 (1) years of age), with a body mass index (BMI) of 23.6 (2.4) kg·m^2. Percent body fat was 16.2 (3.9)%, and the average sum of four skin folds was 38.8 (12.7) mm.

TEMPERATURE

Core temperature

The effect of water temperature on core temperature can be seen in Figure 1. Core temperature decreased over the two hours at all three water temperatures. At 20°C it had decreased by 0.29°C at 60 min, and by a further 0.35°C at 120 min. At 16°C it had dropped by 0.60°C at 60 min, and by a further 0.21°C at 120 min. Due to technical problems with the receiver on the 18°C day, we can only report a change in core temperature after 60 min in four subjects (+0.03°C), and a decrease of 0.38°C in only three subjects after 120 min. No subject reached a core temperature below 35°C. No statistical difference was found between core temperature measured at baseline and at any of the water temperatures. A comparison between the water temperatures of 16 and 20°C showed no significant difference ($P = 0.196$).

Upper body skin temperature

The effect of water temperature on upper body skin temperature is presented in Figure 2. Upper body skin temperature dropped by ~6°C during the first 15 min of all three exposures, after which the changes were very small. When subjects dove in 16, 18 and 20°C water, the decrease in upper body skin temperature during the first hour was 6.0, 5.8 and 7.3°C, with a subsequent increase during the second hour of 0.3, 0.1 and 0.1°C, respectively. There was no statistically significant difference between upper body skin temperature measurements for water temperatures of 16 and 20°C ($P = 0.231$). All of the upper body skin temperature measurements performed at 16°C were significantly lower than baseline ($P < 0.05$). There was no statistically significant difference between any of the measurements and baseline for exposure to 18°C ($P > 0.075$). For the upper body skin

Table 2
Motor function before and after the dive (values are presented as mean (SD))

Temp.	Pre-dive time (s)	Post-dive time (s)	Delta (%)	F-value	*P*-value
20°C	44.0 (4.4)	57.8 (4.7)	33 (20)	27.618	0.001
18°C	43.8 (2.5)	56.2 (4.6)	28 (4)	22.474	0.003
16°C	42.5 (3.4)	58.3 (4.8)	38 (14)	43.515	0.001

Table 3
Handgrip strength for right and left hands before and after the dive (values are presented as mean (SD); RH = right hand; LH = left hand; MH = mean hand)

Water temperature	Pre-dive			Post-dive			*P*-value
	RH strength (kg)	LH strength (kg)	MH strength (kg)	RH strength (kg)	LH strength (kg)	MH strength (kg)	
20°C	45.4 (6.0)	43.7 (7.2)	44.6 (6.3)	45.4 (5.2)	47.2 (5.9)	46.3 (5.1)	0.61
18°C	48.5 (8.0)	49.5 (8.6)	49.0 (8.2)	46.1 (6.8)	45.0 (5.2)	45.6 (5.7)	0.52
16°C	46.1 (3.0)	47.3 (6.0)	46.7 (3.9)	45.6 (4.6)	44.0 (5.4)	44.8 (4.8)	0.48

Table 4
Summary of cognitive test results (values are presented as mean (SD))

Test	Score based on:	Water temperature					
		20°C		18°C		16°C	
		Pre-dive	Post-dive	Pre-dive	Post-dive	Pre-dive	Post-dive
Number cancellation	Problems attempted	13.5 (2.4)	12.7 (2.3)	15.2 (2.3)	14.4 (1.1)	15.7 (3.8)	14.8 (2.0)
	Correct answers	12.7 (1.9)	12.3 (2.1)	13.4 (1.9)	13.0 (1.6)	14.8 (3.8)	13.7 (2.5)
	Errors	0.8 (1.0)	0.3 (0.5)	1.8 (0.8)	1.4 (1.1)	0.8 (0.8)	1.2 (0.8)
Mathematics	Correct answers	14.8 (4.5)	14.8 (4.6)	16.2 (4.1)	15.4 (6.9)	16.3 (6.8)	15.8 (5.2)
	Errors	0.7 (0.8)	0.7 (0.8)	1.4 (1.1)	0.6 (0.5)	1.2 (0.8)	0.8 (0.4)
Number comparison	Problems attempted	18.5 (6.4)	17.7 (6.2)	20.6 (6.8)	18.6 (6.5)	20.5 (6.6)	18.2 (6.9)
	Correct answers	18.3 (6.5)	17.5 (6.2)	20.0 (6.7)	18.0 (6.2)	20.2 (6.4)	17.5 (7.2)
	Errors	0.2 (0.4)	0.2 (0.4)	0.6 (0.9)	0.6 (0.9)	0.3 (0.5)	0.7 (0.8)

temperature measurements performed at 20°C, statistically significant lower skin temperatures were found at min 15, 30, 45, 60, and 90 compared with baseline ($P < 0.05$).

Mean body temperature

The effect of water temperature on mean body temperature is presented in Figure 3. When subjects dove in 16, 18 and 20°C water, the decrease in mean body temperature during the first hour was 2.5, 1.9 and 2.6°C, with a further decrease of 0.3, 0.5 and 0.4°C during the second hour, respectively. There was no statistically significant difference between the measurements for water temperatures of 16 and 20°C at any given time. A statistically significant difference from baseline was found for measurements performed at 20°C ($P < 0.05$) and 16°C ($P < 0.005$), but not at 18°C.

Cold sensation

The effect of water temperature on cold sensation relative to time is presented in Figure 4. During immersion at 18 and 20°C, cold sensation intensity was significantly different from baseline from min 60 until the end of the exposure, whereas at 16°C this was the case from min 30 ($P < 0.05$).

Insulation

Total body and suit insulation was calculated for the first and second hour of immersion. Total insulation ranged from 0.21 to 0.24°C·kcal^{-1}·m^2·h^{-1} in the first hour and from 0.22 to 0.33°C·kcal^{-1}·m^2·h^{-1} in the second hour. Body insulation ranged from 0.11 to 0.14°C·kcal^{-1}·m^2·h^{-1} in the first hour and from 0.14 to 0.20°C·kcal^{-1}·m^2·h^{-1} in the second hour. Suit insulation ranged from 0.10 to 0.11°C·kcal^{-1}·m^2·h^{-1} in

the first hour and from 0.08 to 0.13°C·kcal^{-1}·m^2·h^{-1} in the second hour (Figure 5).

MANUAL TASKS

Manual handling of a light weight

A summary of the measurements of manual handling before and after the two hours of water activity is presented in Table 2. Two hours of diving at 16–20°C resulted in a significant increase in the time taken to perform the task of unlinking and reassembling the four shackles. The time taken to complete the task for all three water temperatures increased by ~30%. For 16°C the increase was 15.8 s (38 [14]%), for 18°C it was 12.4 s (28 [4]%), and for 20°C 13.7 s (33 [20]%).

Handgrip strength

The results of the handgrip strength measurements are summarised in Table 3. There was a small insignificant decrease in handgrip strength of 1.87 (4.36) kg for 16°C, and a small non-significant increase of 1.73 (4.55) kg ($P = 0.214$) for 20°C. There was no statistically significant difference between handgrip strength at 16 and 20°C. No significant difference in handgrip strength was found at 18°C.

COGNITIVE TESTS

The results of the three cognitive tests (mathematics, number comparison, and number cancellation) are summarised in Table 4. We found no significant effect of the three temperature conditions on any of the tests. However, we noted a consistent non-significant decrease in performance on the number comparison and cancellation tests, both in the number of problems attempted and the number of correct answers. For example, in the number cancellation test we found that after two hours there was a decrease of 0.8 in the number of problems attempted for a water temperature of 20°C, a decrease of 0.8 for 18°C, and of 0.9 for 16°C. There was no significant difference between 16°C and 20°C.

Discussion

The present study was conducted on well-trained, acclimatised subjects. Its main finding is that a full-length, 2–3 mm neoprene wet suit can protect fin divers from significant thermal stress for at least the first two hours of a dive in shallow water with a temperature of 16°C and above. Suit insulation as calculated in the present study was found to be ~80% of that of a 5.5 mm suit.[1] Immersion in 16°C water induced a significant decrease in upper body skin temperature (6.8°C), mean body temperature (2.9°C), and core temperature (0.8°C), although core temperature failed to reach the critical level required for a definition of hypothermia. These temperature changes were accompanied by significant cold sensation (a score of 4–5 out of 6) and a decrease in motor function (~30%; $P < 0.05$), but with no effect on muscle strength or on any of the cognitive performance parameters measured in the study.

Core temperature increased slightly during the first 15 min of the 2 h exposure, decreased during the subsequent 60 min, and stabilised over the final 30 min (Figure 1). The initial small elevation in core temperature observed in 16 and 20°C water may be related to overheating while wearing the suit before entering the swimming flume, an observation reported in previous studies.[15,16] The decrease in core temperature, particularly from min 15 to 90 in 16°C water, took place at a rate of 0.85°C per hour. This is comparable with the previous study from our laboratory, in which a decrease in core temperature of 0.3–1.2°C was found in fin divers wearing a 5.5 mm suit in 17–18°C water.[1] The high inter-subject variability in core temperature changes observed in the present investigation was also similar to the cited study.[1] Because subjects were well controlled for metabolic rate, both by supervision of their pre-exposure food intake and of their physical activity rate during the cold exposure (a uniform, paced swimming velocity), this variability may be explained by the wide range of percent body fat (12.3–21%) and body surface area (1.86–2.11 m^2), which have been shown to influence the rate of heat loss from the body.[17] Muscle shivering, although not monitored in the present study, was evident in some of the subjects. Related in part to the subject's body fat, muscle shivering increases heat production and delays the core temperature drop, and may thus also have contributed to the inter-subject variability found in the study.

A number of investigators found a correlation between reduction in core temperature and skin fat thickness.[1,17,18] We observed a stable core temperature over the last 30 min in 16°C water, when no change was found: 36.83, 36.85, and 36.90°C at 90, 105, 120 min, respectively. Stability of core temperature represents a balance between heat production and heat loss. Our results are in agreement with the suggestion of a previous investigation,[19] that core temperature may stabilise when wearing a slightly thicker suit (4 mm), and that during exercise slimmer subjects will reach a stable core temperature when exposed to ~13°C. Core temperature stabilised in the present study at all three water temperatures. The decrease in both 18 and 20°C water was very small during the entire experiment, whereas in 16°C water core temperature dropped until about min 60, after which it stabilised (Figure 1).

Exercise increases heat production from active muscles. However, the increase in heat loss during exercise in cold water is also partially due to vasodilatation in the working muscle tissue.[14] It was found that a work intensity of > 200 kcal·m^2·h^{-1}, which is 4–5 multiples of the resting metabolic rate (1 MET), is more advantageous than rest for maintaining a higher core temperature in cold water.[20] The subjects in the present study consumed 1.2–1.3 L O_2·min^{-1}, which is ~4 MET, suggesting that the stabilisation of core temperature may be explained in part by the fin activity performed by the divers. The fact that our subjects had been well trained

in swimming may have protected them from the muscle fatigue which could have resulted from the physical activity rate in the study. However, untrained individuals may not succeed in maintaining this level of physical activity, which can induce heat production due to work of the muscles, but also result in accelerated heat loss due to the convection of heat in the water.

Previously, it was reported that the thermal protection provided by a neoprene suit decreases with an increase in ambient pressure.[21] Based on the observations of that study, we calculated that for combat divers using a rebreather, who are usually limited to a depth of ~8 m to reduce the risk of developing central nervous system oxygen toxicity, the depth effect on the suit will be a reduction of no more than 25% in its thermal protection.

Hand motor function, as evaluated by the shackle test, decreased after two hours of fin diving at all three water temperatures (Table 2). A large body of literature exists on the correlation between the drop in skin temperature and the decrease in hand and finger dexterity.[5,6] It was found that finger dexterity decreased for a hand skin temperature of 13, but not 16°C.[5] In contrast, an earlier study found that finger skin temperature had to drop to 10–13°C for there to be a decrease in finger dexterity.[22] In addition, it was demonstrated that the performance of tasks involving significant movement of the joints is very sensitive to cooling of the fingers and the hand, similar to the task required of subjects in the present study.[23] It was even shown that cooling of the forearm on its own resulted in a decrement on a finger dexterity task. This decrease in hand motor function was explained in part by changes in neuromuscular function, as well as peripheral mechanisms in the limbs.[24,25] In the present study, forearm skin temperature was measured at 15-min intervals throughout the exposure, and the lowest temperature measured close to the end of the two hours was ~24°C (Figure 3). However, whereas the forearm skin area was covered by the suit, the fingers were unprotected, predicting a much larger decrease in skin temperature there. This may explain the ~30% increase in the time taken to complete the task after two hours immersion in cold water.

A number of studies have suggested that finger dexterity and task performance are more dependent on finger blood flow than on finger temperature,[5,26] implying that as long as blood flow to the fingers is sufficient for the task, the temperature will be of less consequence. In contrast, a later study demonstrated that finger dexterity can be maintained with direct heating even if finger blood flow decreases.[27] In the present study, the 2-h long exposure of subjects' hands to mildly cold water was shown to have a greater effect on manual performance than the fast cooling induced by exposure to extreme cold.[5] Although the implication of the current results, especially for combat divers, may be the need to wear gloves, this may not always be the right solution. When Korean women divers wore a wet suit, the addition of gloves failed to provide any extra protection against heat loss at 17°C, and even caused deterioration of finger motor function.[28]

Handgrip strength is important in many areas of manual activity. This test has frequently been used to evaluate the effect of intramuscular temperature on muscle strength. A number of studies showed that the immediate effect of cold application was a reduction in muscle strength,[29,30] whereas others failed to do so.[31] For example, in twelve female college students who placed their forearm in a 10°C cold bath for 30 min, handgrip strength was reduced by 6 kg (-19%) compared with baseline.[30] In contrast, in another study[31] no effect of cold exposure was found on forearm muscle strength, agreeing with the present investigation in which no consistent change was observed (Table 3). The small decrease we found in forearm skin temperature also implies that forearm muscle temperature was maintained throughout the exposure, which may explain why there was no significant drop in muscle strength.

None of the cognitive function tests showed a significant effect of the three water temperatures on simple cognitive function. A number of investigators have evaluated the effect of a decrease in core temperature on cognitive performance. Cognitive performance was not affected by a moderate reduction in core temperature (a decrease of 0.3–1°C in rectal temperature and a mean skin temperature of 26°C).[32] Different protocols used to evaluate the effect of cold exposure on cognitive performance resulted in vastly differing conclusions. Among other theories regarding the relationship between cognitive tasks and cold, it was suggested that cold may cause distraction,[33] resulting in impaired performance of different tasks, whereas it was also speculated that cold exposure may result in improved performance due to increased attention on the part of the subject.[34] The amount of training prior to cold stress may play a critical role in the measured effect of cold on certain aspects of performance.[34] However, the cognitive tests used in the present study were sufficiently simple for subjects to achieve stable performance over 2–3 trials. It would be very difficult to speculate as to the effect of training prior to cold water exposure when in the present study no significant effect was measured.

LIMITATIONS

One limitation of the present study may be its design. A counterbalanced design, which can account for any accumulated fatigue or acclimatisation to cold water, may have been more appropriate. However, because our subjects were considered to be well trained and acclimatised to cold water, this may not have had a significant effect on our findings.

A further limitation may be that the skin temperature measurements, which were performed only on the upper body (chest and arm), cannot be considered whole body skin temperature. However, it has been demonstrated that

upper body skin temperature is slightly higher than leg skin temperature both at baseline and during a full body dive.[4] The change found in the study may therefore represent the actual change that would have been found in lower limb skin temperature.

Conclusions

In summary, the present study demonstrated that a 2–3 mm wet suit provided adequate thermal protection in trained and cold-acclimatised young males, engaged in active diving in shallow water with a temperature of 16°C and above. Stability of core temperature proved that a balance had been achieved between heat production and heat loss. No reduction in cognitive or hand muscle function was found, other than a decrease in hand/finger motor function.

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Inhibition of NR2B-containing NMDA receptors during nitrogen narcosis

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Key words
Brain; Hippocampus; Hyperbaric medicine; Neuron; NMDA receptor

Abstract
(Peng B, Hao D-D, Li X, Wang G-H, Guan Z-Y, Jiang Z-L. Inhibition of NR2B-containing NMDA receptors during nitrogen narcosis. Diving and Hyperbaric Medicine. 2019 December 20;49(4):276–282. doi: 10.28920/dhm49.4.276-282. PMID: 31828746.)
Introduction: When humans breathe compressed air or N_2-O_2 mixtures at three to four atmospheres pressure, they will experience nitrogen narcosis that may possibly lead to a diving accident, but the underlying mechanisms remain unclear.
Methods: Mice were exposed to 1.6 MPa breathing a N_2-O_2 mixture adjusted to deliver an inspired PO_2 of 32–42 kPa. The electroencephalogram (EEG) and forced swimming test were used to evaluate the narcotic effect of nitrogen. Neuronal activity was observed via c-Fos expression in cortex and hippocampus tissue after decompressing to the surface. To further investigate underlying molecular mechanisms, we incubated cultured hippocampal neurons with various NMDA concentrations, and measured expression of NMDA receptors and its down-stream signal with or without 1.6 MPa N_2-O_2 exposure.
Results: Both the frequency of the EEG and the drowning time using the forced swimming test were significantly decreased during exposure to 1.6 MPa N_2-O_2 ($P < 0.001$). Additionally, in cultured hippocampal neurons, the increased levels of phosphorylated NR2B and cAMP-response element binding protein (CREB) induced by NMDA stimulation were significantly inhibited by exposure to 1.6 MPa N_2-O_2.
Conclusions: Our findings indicated that NR2B-containing NMDA receptors were inhibited during nitrogen narcosis.

Introduction

When human beings are exposed to hyperbaric inert gases e.g., nitrogen, argon and xenon, the central nervous system (CNS) will be inhibited due to their narcotic potency. Nitrogen narcosis has been recognized since the earliest studies of human and animal physiological responses to diving conditions, and includes disturbances in motor and locomotor coordination, hallucinations, sedation, and cognitive disruptions, often leading to diving accidents.[1,2]

Franks and Lieb have proved that the inhibition of the N-methyl-D-aspartate receptor (NMDAR) is likely the critical mechanism in the anaesthetic and analgesic effects of xenon gas.[3] Thus, we supposed that nitrogen, as another inert gas, may also act on NMDARs leading to narcosis. Glutamate plays a major role in the neurotransmission of excitatory signals via long axonal projections of neurons in the CNS and acts on diverse receptors including amino-3-hydroxy-5-methyl-4-isoxazole propionic acid receptors (AMPAR), NMDAR, and kainate receptors. Some studies have revealed that selective blockade of excitatory glutamatergic neurotransmission in the CNS can induce general anaesthesia with unconsciousness, analgesia, and immobility.[4] NMDARs are an important subtype of glutamate receptors and may be targets of anaesthetics.[5] NMDARs, composed of GluN1, GluN2 (GluN2A-D), and GluN3 (GluN3A-B) subunits, are expressed ubiquitously and abundantly throughout the human CNS and play a key role in regulating glutamatergic synaptic transmission. NMDAR channels require two GluN1 subunits and two GluN2 subunits or GluN3, and their functional properties are determined by the constitutive GluN2 subunits (GluN2A–D) and/or GluN3 (GluN3A-B).[6] Among these subunits, NR2B is the most abundant in the CNS and it seems a molecular target of anaesthesia, thus we hypothesized that hyperbaric nitrogen might also (at least partly) act on this site.

Inhaled anaesthetics such as xenon and nitrous oxide have been shown to inhibit NMDAR. In electrophysiological studies, ketamine, nitrous oxide, and xenon are potent inhibitors of NMDA-activated currents.[7] Ligand-gated ion channels on neurons have been all cited as target proteins for inert gas including nitrogen in animal models.[8–12] It remains unclear whether they share a similar mechanism between general anaesthesia and nitrogen narcosis, therefore the present study was designed to investigate the changes in NMDAR in the development of nitrogen narcosis.[3,7]

Methods

ANIMALS

Male adult (6–9 weeks of age) and pregnant C57BL/6j mice were provided by the Experimental Animal Center of Nantong University (Institutional license: SYXK(SU)-2012-0030). All animal use protocols were approved by the Institutional Animal Care and Use Committee of Nantong University (approval number 20140901-001). All efforts were made to minimize the number of animals used and their suffering. Behaviors relating to food and water intake, fecal character, hair color, mobility, and body weight were monitored daily. At the end of the experimental period, the mice were anaesthetized using isoflurane and killed by cervical dislocation under general anaesthesia. In total, fifty-five adult mice were randomly divided into two groups: a control group ($n = 24$) and a 1.6 MPa N_2-O_2 mixture exposure group ($n = 31$). Mice were housed in group cages with 4–6 animals per cage at 23°C with food and water available *ad libitum* and maintained in a room with a 12/12 h light/dark cycle.

HYPERBARIC EXPOSURE

Hyperbaric exposure was performed as described in our previous experiment.[13] Briefly, compressed air was introduced to the chamber (Wuhu Diving Equipment Factory, Anhui, China) at a rate of 100 kPa·min^{-1} up to 200 kPa (additional pressure), then pressure was further increased to 1.6 MPa by addition of pure nitrogen (Nantong Tianyuan Gas Co. Ltd, Jiangsu, China) at 200 kPa·min^{-1}. Mice were maintained at 1.6 MPa for an hour, followed by five hours decompressing to atmospheric pressure. The concentrations of oxygen and carbon dioxide were monitored in real time by SDA monitors (Analox, North Yorkshire, England). Oxygen was added to maintain the inspired PO_2 between 32–42 kPa and this was increased to 50 kPa during decompression. Carbon dioxide levels were not allowed to exceed 1 kPa and CO_2 was removed using soda lime absorbent. To avoid the stress-induced changes involved in the hyperbaric exposure, mice in the control group were placed in the chamber at normobaric pressure only breathing air.

RECORDING OF EEG

Fifteen mice were anaesthetized with isoflurane and placed on a heating pad, and then two bipolar stainless steel electrodes were planted into the forehead (2 mm posterior to the bregma, 2 mm lateral from the midline, and 1 mm deep beneath the skull). The ground electrode was attached to prefrontal skin as described by Wisor.[14] After surgery, mice were housed alone with free access to food and water. Digital EEG monitoring (RM6240BD, Chengdu Instruments, Chengdu, China) to evaluate the narcotic potency of nitrogen was performed when the electrodes were completely fixed at one week after the operation. During EEG recording, the acquisition frequency was 1 kHz, the scan speed was 200 ms·div^{-1}, and the sensitivity was 1 μV. Band width of the EEG signal recording was set as 0.5–30 Hz. Finally, the mean frequency of the EEG was analyzed using RM6240 3.0 software: alpha rhythm 8–12 Hz and beta rhythm 13–30 Hz were defined as fast waves; delta rhythm 1-3 Hz and theta waves 4–7 Hz were defined as slow waves.

FORCED SWIMMING TEST

A cylinder (30 cm height × 20 cm diameter) filled with 15 cm height of water (23 ± 2°C) was placed in the hyperbaric chamber, and the mouse was put in the cylinder before compression. The drowning time, defined as losing the ability to keep the head above the water, was scored during the hyperbaric N_2-O_2 mixture exposure. A total of 30 mice were measured in this test.

PRIMARY NEURON CULTURE AND NMDA STIMULATION

Briefly, the hippocampus of an embryonic (E17–18) mouse was isolated, cut into pieces, and digested with 0.125% trypsin at 37°C for 12 min. The digested brain tissues were mildly triturated to a single-cell suspension, and plated at a density of 70,000 cells·cm^2 on to coverslips or dishes coated with poly-L-lysine. The day of plating was counted as day-in-vitro (DIV) 0. The feeding medium containing neurobasal media (Thermo Fisher Scientific, Waltham, USA), B-27 neural culture reagent (Thermo Fisher Scientific, Waltham, USA), 0.5 mM L-glutamine (Thermo Fisher Scientific, Waltham, USA), 100 units·ml^{-1} penicillin and 0.1 mg·ml^{-1} streptomycin (Thermo Fisher Scientific, Waltham, USA), was changed by one-half every three days. Cultures were maintained in humidified air containing 5% CO_2 at 37°C. On DIV 11-12, the culture media was changed to the buffer solution containing 110 mM NaCl, 5.4 mM KCl, 1.8 mM $CaCl_2$, 10 mM 4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid (pH 7.42), 10 mM D-Glucose, 0.8 mM $MgCl_2$, and the cells were exposed to 1.6 MPa N_2-O_2 for an hour and decompressed to the surface as quickly as possible. To achieve global activation of NMDAR, neurons were stimulated with NMDA (Sigma-Aldrich, St. Louis, Missouri, USA) at different concentrations when the pressure reached 1.6 MPa.

CELL VIABILITY ASSAY

After decompression to atmospheric pressure, 3-(4,5-dimethyl-2-thiazolyl)-2,5-diphenyl-2-H-tetrazolium bromide (5 mg·ml^{-1} in phosphate-buffered saline, PBS) was added to each culture well. After incubating at 37°C for four hours, the medium was removed, dimethylsulfoxide was added to each well, and the cells were incubated for another thirty minutes at 37°C. Finally, the absorbance was read at 570 nm using SN209941 multi-mode microplate readers (Bio-Tek, Winooski, USA). Data were normalized to 100% control values.

WESTERN BLOT ANALYSIS

After decompressing to the surface, mice were immediately killed by decapitation under isoflurane anaesthesia, their brain tissues were quickly harvested, and carefully dissected into hippocampus and cortex on ice, and then cold tissue lysis buffer was added in. In cultured cells, cell lysis buffer was added into cultures at the end of the hyperbaric exposure, and then the chamber pressure was rapidly decreased at a rate of 0.1 MPa·s^{-1}. The homogenate was ultrasonicated in an ice bath and then centrifuged for 10 min at 12,000 g at 4°C. The concentration of supernatant protein was tested using the BCA protein assay kit (Thermo Fisher Scientific, Waltham, USA). An equal amount of protein (10–40 μg as optimal for each antibody) for each sample was loaded into 8–12% Bis-Tris gel for electrophoresis. Polyvinylidene fluoride membranes with transferred proteins were blocked with 5% milk in tris buffered saline plus 0.1% Tween-20 for one hour and then with the following primary antibodies overnight at 4°C: glyceraldehyde-3-phosphate dehydrogenase (GAPDH) (Millipore, Darmstadt, Germany); rabbit anti-cleaved caspase-3 polyclonal antibody 1:1000 (Cell Signaling Technology (CST), Danvers, USA); mouse anti-β-actin 1:8000 (Sigma-Aldrich Co., St. Louis, USA); rabbit anti-AMPA Receptor 1 (GluA1) (CST, Danvers, USA); and rabbit anti-Phospho-AGluA1 (Ser845) (CST, Danvers, USA), phospho-NR2B (CST, Danvers, USA), and total NR2B (CST, Danvers, USA). After several washes in Tris-buffered saline, secondary IRDye 800 CW goat anti-mouse or rabbit 1:10000 (Li-COR, Lincoln, USA) was incubated for two hours at room temperature, and the immunoreactivities were captured using a fluorescence scanner (Odyssey Lix, Li-COR, Lincoln, USA). Semi-quantitative evaluation of protein levels was performed by densitometric scanning using Image-Pro® Plus 5.1 software (Media Cybernetics, Bethesda, USA).

IMMUNOFLUORESCENT STAINING

Cultured hippocampal neurons were washed three times with 0.01 M PBS, fixed with 4% paraformaldehyde, antigen-repaired in 0.1 M glycine for 10 minutes, permeabilized in pre-cooling methanol at -20°C for eight minutes, blocked in 10% bovine serum albumin for one hour at room temperature, and then incubated at 4°C overnight with anti-rabbit phospho-CREB (cAMP-response element binding protein) (CST, Danvers, USA). This was followed by incubation with Goat anti-Rabbit 1:200 (Sigma-Aldrich Co., St. Louis, USA) for one hour. After washing with PBS, cultured cells were captured under the same laser intensity settings using confocal microscopy (TCS SP8, Leica, Wetzlar, Germany).

STATISTICAL ANALYSIS

All the variables were tested for normal distribution using Shapiro-Wilk test with SPSS 17.0 software (IBM, USA). Normally distributed data were presented as the mean (SD) and analysed with an independent sample *t*-test or one-way analysis of variance (ANOVA) with the LSD post hoc test. Non-normal data were analysed with the Mann-Whitney U test or Kruskal-Wallis test.

Results

HYPERBARIC N_2-O_2 EXPOSURE EFFECTS ON THE EEG AND MOTOR FUNCTION

The frequency of the EEG in the control group was 10.17 (1.6 SD) Hz while it was significantly decreased to 4.56 (1.01) Hz during the hyperbaric exposure (Figure 1A–B, $P < 0.001$ vs control group). Additionally, mice breathing N_2-O_2 at 1.6 MPa drowned more quickly than those at atmospheric pressure (Figure 1C, $P < 0.001$ vs. control group).

HYPERBARIC N_2-O_2 EXPOSURE AND C-FOS EXPRESSION

Neuronal activity assessed via cortical and hippocampal c-Fos expression was not significantly altered after hyperbaric N_2-O_2 exposure (Figure 2A–B, $P > 0.05$ vs. control group).

EFFECT OF NMDA INCUBATION ON CELL VIABILITY AND CLEAVED CASPASE-3 EXPRESSION IN CULTURED HIPPOCAMPAL NEURONS WITH OR WITHOUT N_2-O_2 EXPOSURE

In vivo, time is required for decompression to atmospheric pressure and changes in the behavioral performance and the physiological and metabolic functions of mice induced by hyperbaric N_2-O_2 exposure will recover gradually. Cultured hippocampal neurons were thus chosen for further investigation of the potential influences of hyperbaric exposure because only a short decompression time is needed. To find the suitable NMDA concentration that could stimulate NMDAR moderately but not cause cell damage, we observed the cell viability and cleaved caspase-3 expression in cultured hippocampal neurons incubated with various NMDA concentrations with or without 1.6 MPa N_2-O_2 exposure. We found that neither 10 μM nor 20 μM NMDA incubation caused a decrease in cell viability (0.87 (SD 0.14) in 10 μM, and 0.83 (0.10) in 20 μM) and an up-regulation in cleaved caspase-3 both in control- and in the hyperbaric group, which suggested that the 10 μM or 20 μM NMDA was suitable to stimulate NMDA (Figure 3A–C). In addition, hyperbaric N_2-O_2 exposure significantly prevented the up-regulation of cleaved-caspase-3 induced by 50 μM NMDA incubation (0.71 (SD 0.04) vs. 0.59 (0.06)) (Figure 3B–C, $P = 0.021$ vs. 0 μM or 50 μM control group)), which indicated that hyperbaric exposure may partly inhibit NMDAR.

Figure 1

Changes in EEG and swim test performance of mice exposed to 1.6 MPa N_2-O_2 mixture. (A) Representative EEG in control and 1.6 MPa N_2-O_2 groups. (B) The frequency of EEG in each group, n = 6 in control group and n = 9 in the hyperbaric group (C) Drowning time in the forced swimming test, control vs. hyperbaric exposure, n = 15 in each group. The data were analyzed using independent sample t-test

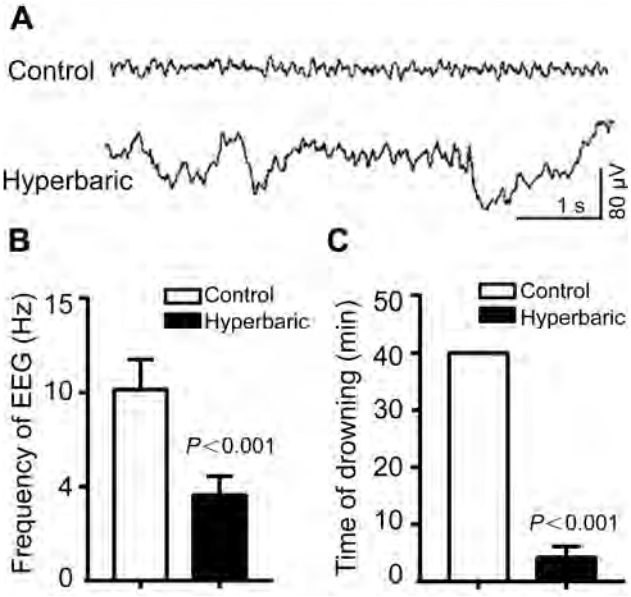
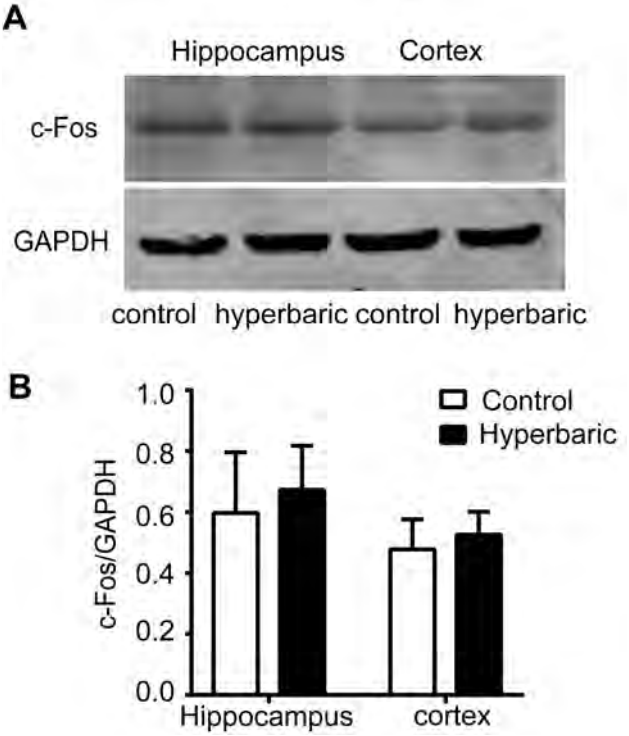


Figure 2

c-Fos expression in the hippocampus and cortex of mice exposed to 1.6 MPa N_2-O_2. (A) Representative immunoblotting image of c-Fos and GAPDH. (B) The gray intensity of c-Fos /GAPDH, n = 5 in each group. The data were analyzed using the Mann-Whitney U test



HYPERBARIC N_2-O_2 MIXTURE EXPOSURE INHIBITED NR2B PHOSPHORYLATION AND REDUCED DOWNSTREAM P-CREB LEVEL AFTER NMDA STIMULATION IN CULTURED HIPPOCAMPAL NEURONS

To explore the potential mechanism of changes in the EEG and behavior performance during 1.6 MPa N_2-O_2 exposure, we determined the expression and phosphorylation levels of GluA1 and NR2B, the subunits of AMPAR and NMDAR respectively. No significant change was seen in the GluA1 and pGluA1 expression after hyperbaric exposure (Figure 4A–B, $P > 0.05$ vs. control group). However, the increased NR2B phosphorylation levels induced by NMDA incubations were significantly inhibited by 1.6 MPa N_2-O_2 exposure (Figure 4C–D, $P < 0.001$ vs. control group) (10 μM group, 0.61 (SD 0.03) vs. 0.43 (0.01) and 50 μM group, 0.62 vs. 0.41 (0.02)). Additionally, the phosphorylation levels of CREB in the cell nucleus, a downstream target of NR2B were also reduced by 1.6 MPa N_2-O_2 exposure (Figure 4E).

Discussion

The Meyer-Overton hypothesis suggests that a narcotic gas causes disruption of membrane geometry, leading to dysfunction in cell surface proteins and ion channels. Although this theory has been disproven in favor of other mechanisms such as interactions with neurotransmitter-gated ion channels or other hydrophobic sites on neurons, it still holds that the more lipid soluble an inert gas is, the more narcotic it is.[15] Xenon has been shown to inhibit not only NMDAR but also AMPAR and kainate receptors. We hypothesized that hyperbaric nitrogen will also act on these kinds of proteins.[3,16] The present study established a mouse model of nitrogen narcosis and investigated the influence of hyperbaric nitrogen on the NMDAR in cultured mouse neurons.

During hyperbaric exposure the EEG showed a reduction in rapid wave activity (alpha and beta waves) and an increase in slow wave activity (theta and delta waves). Furthermore, we found that mice exposed to 1.6 MPa N_2-O_2 exhibited a drowning time shorter than under normal pressure. These results suggested that exposure to 1.6 MPa N_2-O_2 could induce CNS inhibition and motor function reduction, two important characteristics of nitrogen narcosis. It is acknowledged that the drowning time result must be interpreted cautiously because increased respired gas density, increased work of breathing, and consequent earlier exhaustion at 1.6 MPa may have contributed to the result independently of a narcotic effect.

Figure 3

Cell viability and cleaved caspase-3 expression in cultured hippocampal neurons after NMDA incubation with or without 1.6 MPa N_2-O_2. (A) Cell viability (normalized to 100% of control). (B) Representative immunoblotting of cleaved caspase-3 and β-actin, $n = 4$ in each group. (C) Fold changes in the gray intensity of cleaved caspase-3/β-actin. The data were analyzed using the Kruskal-Wallis test, and Mann-Whitney U test for multiple comparisons

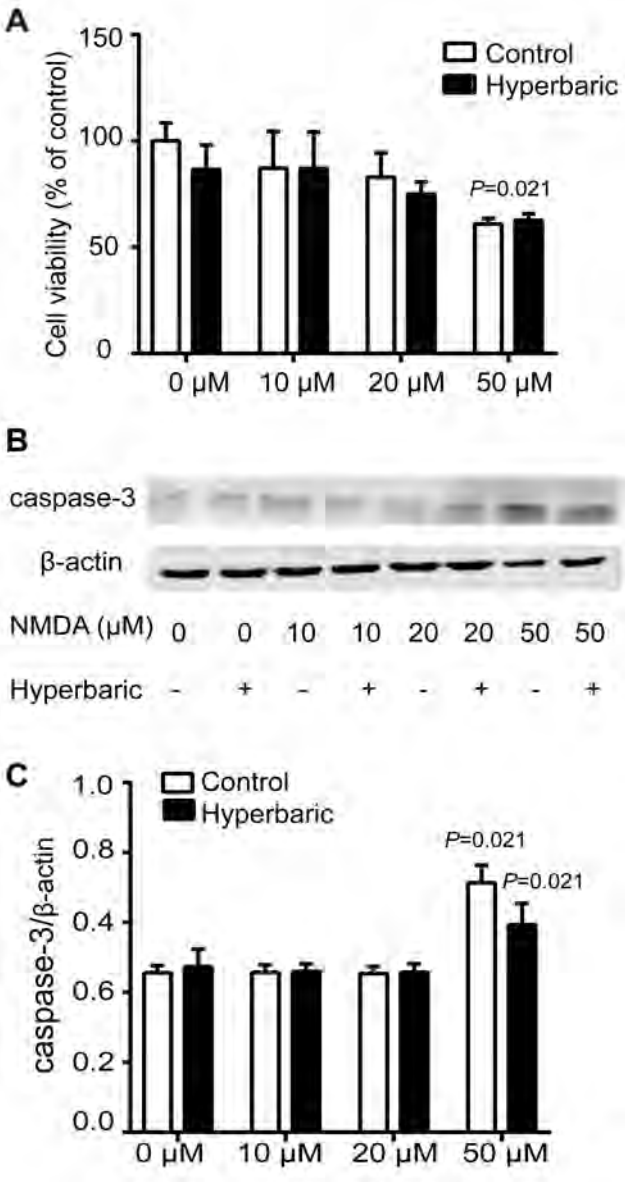
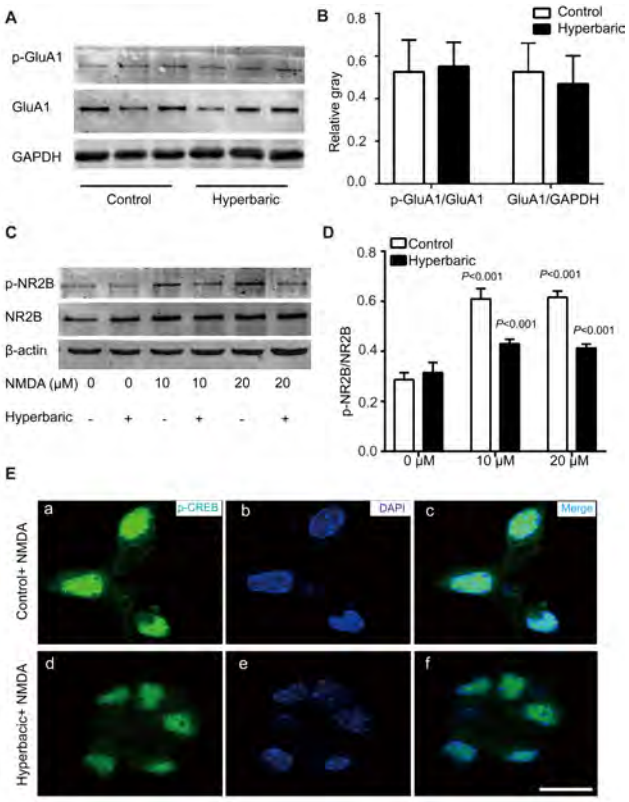


Figure 4

The increases in the phosphorylated levels of NR2B and CREB in cultured hippocampal neurons after NMDA incubation were inhibited by 1.6 MPa N_2-O_2 exposure. (A) Representative expression of p-GluA1 measured using western blot analysis. (B) Fold changes in the gray intensity of p-GluA1/GluA1 and GluA1/GAPDH, $n = 3$ in each group, the data were analyzed using the Mann-Whitney U test. (C) Representative expression of p-NR2B measured using western blot analysis. (D) Fold changes in the gray intensity of p-NR2B/NR2B, $n = 3$ in each group, one-way analysis of variance and LSD for post hoc test were used. (E) Immunofluorescent images showing the pCREB expression (green in a and d) in the nucleus (blue, DAPI staining b and e), scale bar 25 μm, $n = 4$ in each group



Humans breathing compressed air at pressures exceeding 0.4 MPa (30 metres' sea water (msw), partial pressure of N_2 ~ 0.32 MPa) will experience symptoms resembling those after the use of alcohol, marijuana, and some benzodiazepine drugs, which tend to develop insidiously with depth. Onset of more severe symptoms can render an individual incapable of self-control.[17] In rats, a pressure of 4 MPa of nitrogen was necessary to produce anaesthesia indicated by 100% loss of the righting reflex, and deep nitrogen narcosis was obtained at 75% of the anaesthetic pressure threshold (3 MPa).[18] More subtle cognitive and motor changes have been reported in humans at 0.3 MPa and 0.8–1.0 MPa in laboratory animals.[11,19] The present findings on the effect of nitrogen on the EEG and (possibly) motor function in mice exposed to 1.6 MPa N_2-O_2 were consistent with these reports.

A number of experimentally supported mechanisms of inert gas narcosis have been reported at the CNS level and to involve both pre- and post-synaptic effects, many of which are potentially shared by nitrogen and other anaesthetics.[20,21] NMDAR, the major mediators of glutamatergic neurotransmission, have been recognized as an important target in the induction of anaesthesia. Previous research has shown that 3 MPa nitrogen exposure significantly prevented the increase of extracellular glutamine levels by NMDAR stimulation.[22] Additionally, repeated nitrogen exposure disrupted NMDAR function.[12] Consistent with these reports, 1.6 MPa N_2-O_2 exposure in

the present study reduced the phosphorylation levels of NR2B and CREB in cultured hippocampal neurons, which may prevent the lateral redistribution and internalization of NMDA receptors.[22] Thus, besides directly affecting the fluidity and structure of the cell membrane, 1.6 MPa N_2-O_2 exposure might inhibit the trafficking as well as the surface distribution of NMDAR. This may thus become a critical mechanism for inhibiting excitatory synaptic function and plasticity.[23]

In addition, the present study suggests that hyperbaric nitrogen may act on both synaptic and extra-synaptic NR2B receptors without selectivity because we also found that hyperbaric N_2-O_2 exposure significantly prevented the up-regulation of cleaved-caspase-3 induced by 50 μM NMDA incubation. In previous studies, nitrogen was described to have a pro-GABA activity, to decrease glutamate release, and to have a very poor anti-NMDA activity.[1,2,11] Vallée et al. found that NMDA receptors remained functional under nitrogen narcosis, as NMDA exposure significantly reversed the decrease of dopamine release induced by nitrogen narcosis.[22] In contrast Lavoute et al. reported that the administration of 0.5 nM NMDA produced a significant increase of dopamine at atmospheric pressure, but not during 3 MPa nitrogen exposure; suggesting that the NMDA receptor was inhibited (but perhaps incompletely) during nitrogen narcosis.[12] In the present study, 50 μM NMDA administration caused a decrease in cell viability or up-regulation in caspase-3 expression both in normobaric and hyperbaric conditions, suggesting that the NMDA receptor remained functional, but weak inhibition may exist.

Unfortunately, a number of responses to hyperbaric exposure in neurons including dynamic ion influx and bioelectric activity could not be observed due to technical limitation. An alternative way to detect changes in the expression and phosphorylation of downstream signals for many membrane receptors or channels could help us evaluate their functions. NR2B-containing NMDAR are highly permeable to calcium ions that can trigger numerous intracellular signaling pathways including Ca^{2+}/calmodulin-dependent protein kinase II/IV (CaMKII/IV) and CREB, which then will prominently affect neuronal activity.[24,25] Actually, activation of CaMKII by Ca^{2+} influx through NMDAR could potentiate synaptic efficacy by inducing synaptic insertion and increased single-channel conductance of AMPAR, NR2B anchoring and synapse density.[26–28] A recent report revealed that CREB-brain derived neurotrophic factor (BDNF) signaling exerted both rapid and slower homeostatic regulation of AMPAR expression.[29] Therefore, the present results may indicate that hyperbaric nitrogen exposure is likely to affect the phosphorylation of NR2B and its downstream signaling pathway, and consequently inhibit excitatory transmission in the CNS.

The present study suggests that inhibition of NR2B-containing NMDA receptors during hyperbaric nitrogen exposure may contribute to nitrogen narcosis and resultant CNS inhibition. However, there are some limitations in this study. More evidence is needed to prove that the hippocampus is the sensitive region. Secondly, whether a similar effect can be observed in cortical neurons or other regions is not known. Moreover, it is unknown if pretreatment with a NR2B blocker can influence the EEG and forced swimming tests, the threshold pressure of nitrogen narcosis in mice, or even the actual NMDA-mediated ion channel slow current of a cultured neuron during hyperbaric exposure.

Conclusion

The present findings indicated that NR2B-containing NMDA receptors were inhibited during nitrogen narcosis.

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Longitudinal screening of hearing threshold in navy divers: is diving really a hazard?

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Key words
Fitness to dive; Health surveillance; Hearing loss; Audiology; Military diving

Abstract
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Introduction: Hearing loss (HL) is common in the adult working population. It is widely assumed that diving is a risk factor for HL. However, studies with sufficient follow-up comparing HL in divers to non-divers are limited. This study aimed to assess the hearing threshold (HT) of Royal Netherlands Navy divers who had been diving for more than 15 years and to compare it to the ISO standard 7029:2017 reference table.
Methods: In this 25-year retrospective cohort study the Royal Netherlands Navy Diving Medical Centre audited the medical records of 1,117 Navy divers. Yearly dive medical assessments were performed according to professional standards, including audiometry. HTs were compared to the ISO 7029:2017 reference table, including Z-distribution, using paired *t*-tests.
Results: Thirty-five divers were included who had been diving for 15 years or longer. The HT increased significantly in nine of the 16 measured frequencies, while the Z-score decreased significantly in nine of the 16 tested frequencies (eight in both ears). In the 25-year follow-up the pattern was more obvious, with one significantly increased HT, and 10 significantly decreased Z-scores.
Discussion: The absolute HT increases after 15 years of military diving, but less than would be expected from normal age-related deterioration. Moreover, when comparing Z-scores, this sample of divers actually hear better than non-divers. We conclude that military diving is not an increased risk for HL compared to regular occupational hazards and suggest withdrawing the requirement for routine yearly audiometric evaluation as part of a dive medical examination.

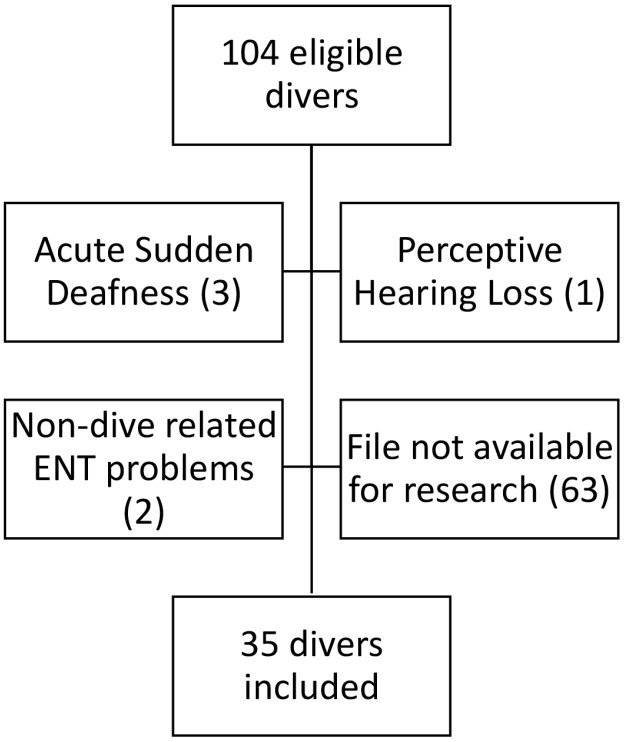
Introduction

"*Divers have always been deaf, so the story goes*".[1] It is a common belief that divers suffer from hearing loss (HL). However, HL is common in the general population. Aside from a physiological age-related reduction in hearing threshold (HT), occupational exposure to noise is the largest cause for HL in the developed world.[2,3]

It has been hypothesized that diving, particularly changes in atmospheric pressure (and as a consequence the risks of ear barotrauma) and decompression sickness, affects hearing and thus increases divers' risk for HL.[4] Many studies have reported that hearing thresholds are reduced in occupational and military divers.[5–12] In contrast, studies in sports divers have found no HL.[13,14] Exposure to loud noises, such as airflow or communication systems inside a diving helmet could also contribute to HL.[4,15] Most studies are cross-sectional and lack comparison to baseline data. Incidence varies from as high as 50% in self-reported questionnaires to 5% in patient-controlled trials. In some studies, the HL was more predominant in the left ear, while other studies have found the opposite.[7,16] A few longitudinal studies have been conducted, with follow up periods varying from two to twelve years. Results vary from no significant HL to a severe rise in HT.[9,17,18]

Additional factors affecting HL are smoking and ear, nose and throat (ENT) problems. Compared to the general population, divers experience more ENT problems, such as middle-ear barotrauma.[19–21] The literature is inconclusive on the matter of whether these ENT problems affect HT. With regard to smoking there is a little more evidence, however, it is unclear if smoking induces HL by itself or accentuates

Figure 1
Flowchart to illustrate subject selection



HL after noise exposure. Sung et al. found a possible dose-response relationship between smoking and HL in the low-frequencies.[22,23] Even though the HL was statistically significant in this study, the clinical relevance of an increase of HT of 1 or 2 dB is debatable.

As the HT increases with age, it is often difficult to assess whether HL has been the result of noise exposure or physiological ageing. To better compare HL to a reference group, the ISO 7029:2017 standard provides equations to describe HL as a variance of a normal distribution (Z-score).[3] This is increasingly common in other fields of medicine, such as pulmonary medicine.[24] Recently, a study by Sames et al. used these equations and found no significant difference in HL between longitudinally assessed occupational divers and expected age-related changes.[25]

In this 25-year retrospective cohort study we assessed the HL in military divers and compared this to the HL in the common working population using the ISO standard 7029:2017, both as absolute dB-values and as Z-scores. We hypothesized that HL in divers is equal to the general working population.

Methods

The Medical Ethics Committee affiliated with the Amsterdam University Medical Centre approved our methods for handling personal details and privacy and concluded that they were concordant with the guidelines of the Association of Universities in the Netherlands and the Declaration of Helsinki (document reference: W19-033).

DATA COLLECTION

The Royal Netherlands Navy Diving Medical Centre performs yearly medical assessments of military divers in compliance with international professional standards.[26] When entering the service as a navy diver, the candidate should have no significant hearing loss and no history of severe ENT problems, such as Meniere's disease or surgical procedures.

Since the introduction of an electronic file system in 1993 up to 31 December 2018, 1,117 Navy divers had been assessed on more than one occasion. From this database audiometric data from divers who had dived for more than 15 years were selected. Audiometric data of divers that started diving before the introduction of the electronic file system were extracted from the paper archives.

The audiometric data of all Navy divers up to the age of 50 with a diving career of 15 years or longer were entered in an electronic database. Using the calculations provided in the ISO 7029:2017 standard, we computed the age-adjusted Z-scores. Cases with missing audiometric data or divers with non-diving related ENT problems, such as sudden deafness or perceptive hearing loss, were excluded. Also, divers who had already left military service at the time of the study could not be included, since their medical file was off-site for long term storage and not available for research. In contrast to many other studies, we chose not to exclude middle-ear barotrauma or successfully treated vestibular decompression sickness, since it is related to diving and possibly can induce hearing loss.

ANALYSIS

Audiometric data acquired when starting a career as a diver were considered as baseline. Data from fifteen (or 20 or 25 if applicable) years later were recorded. Data was registered both as hearing threshold (i.e., the level at which a subject hears a certain frequency) as well as standardized as deviation from the mean (Z-score). Statistical analyses were performed with SPSS Statistics for Windows (IBM Corp; Armonk, NY: 2015, version 23.0), using paired-samples t-tests for hypothesis testing. The alpha value was set at 0.05 and therefore statistical significance was assumed when $P < 0.05$.

Results

The 1,117 identified Navy divers had been diving for 7.8 years on average (median: 6, IQR: 3–11); 104 of them had been diving for 15 years or longer. Six cases were excluded due to acute sudden deafness, perceptive hearing loss or non-dive ENT related problems. More than half of the eligible divers had already left military service and their file was not available for research purposes. After exclusion (see Figure 1) 35 divers were included.

Figure 2
Hearing thresholds (with 95% CI) vs. ISO 7029:1017 reference values (with SD): baseline values

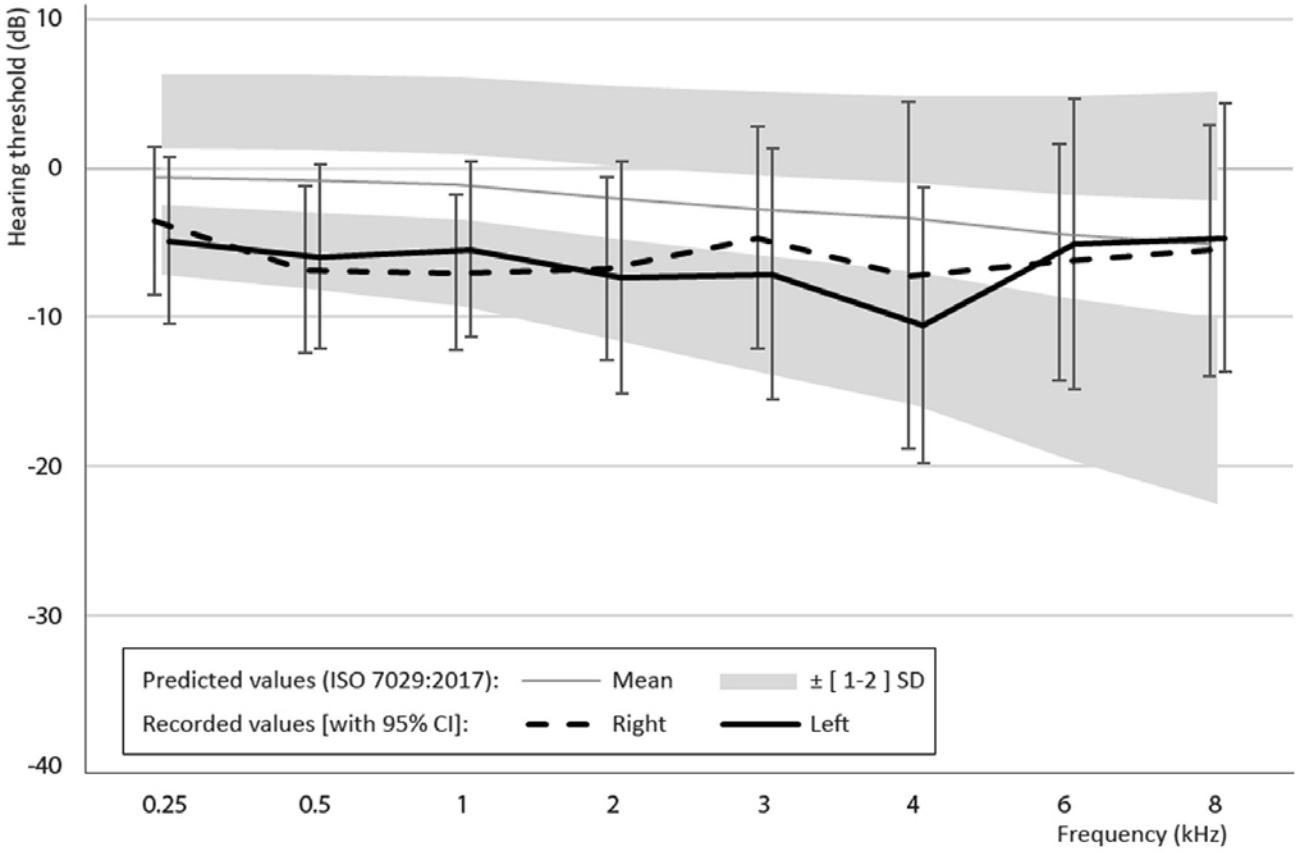


Figure 3
Hearing thresholds (with 95% CI) vs. ISO 7029:1017 reference values (with SD): 15 year follow up

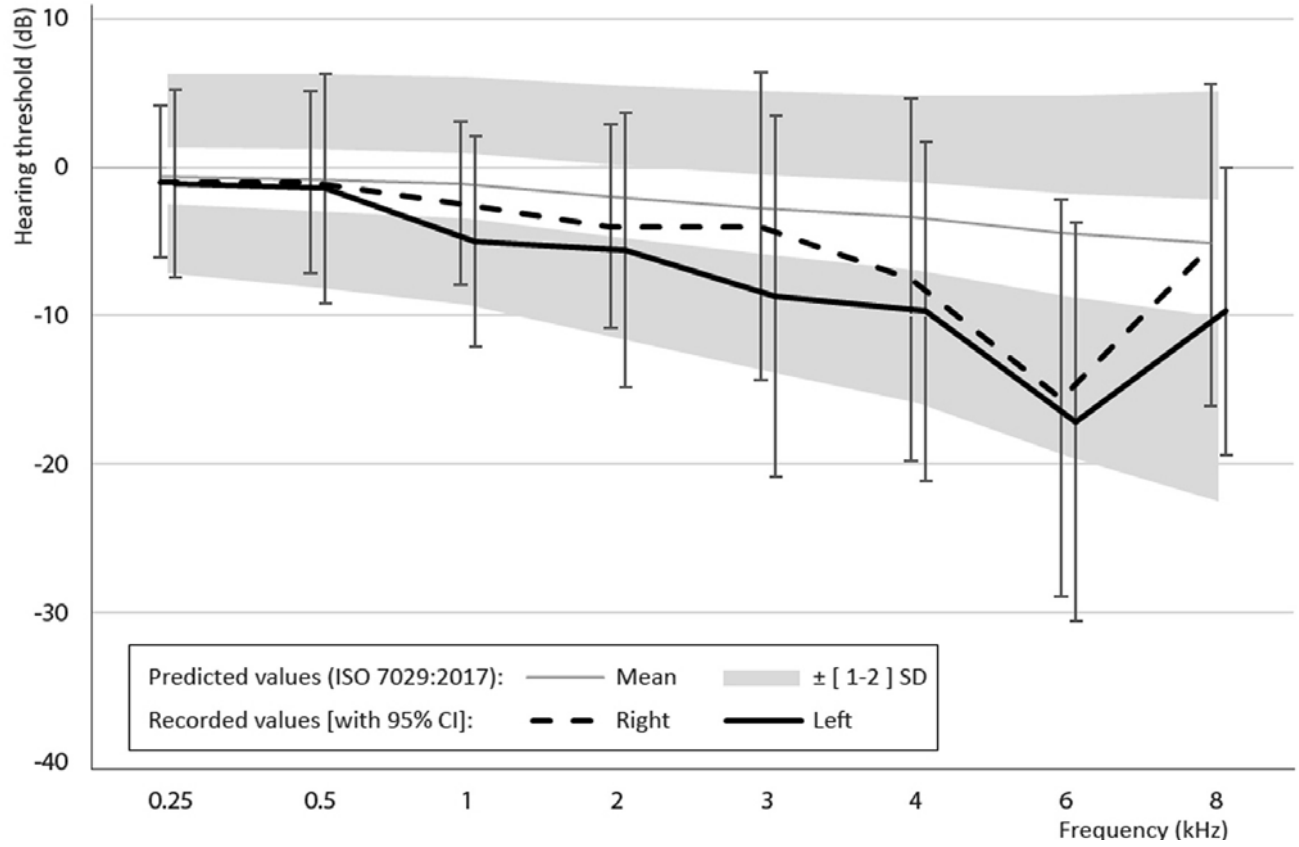


Figure 4
Hearing thresholds (with 95% CI) vs. ISO 7029:1017 reference values (with SD): 20 year follow up

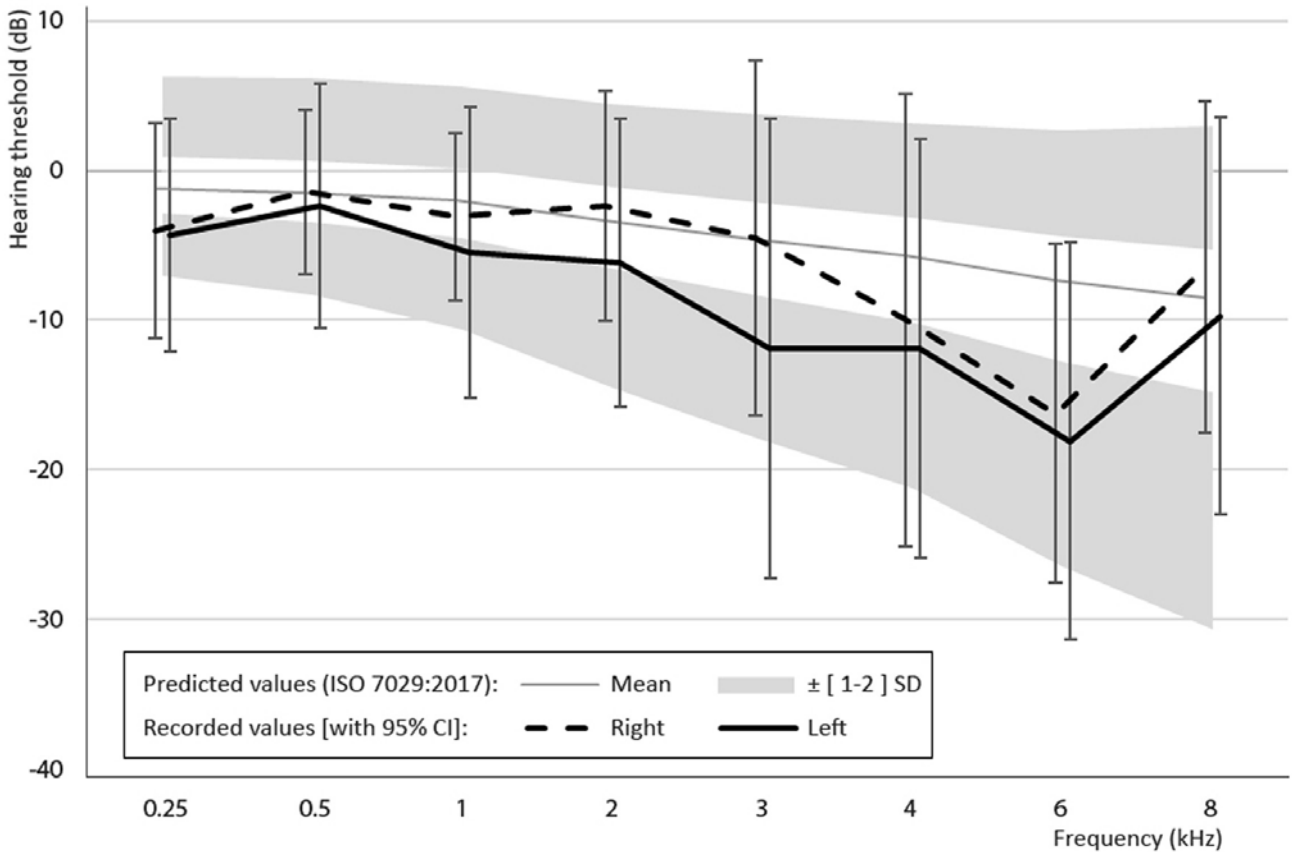


Figure 5
Hearing thresholds (with 95% CI) vs. ISO 7029:1017 reference values (with SD): 25 year follow up

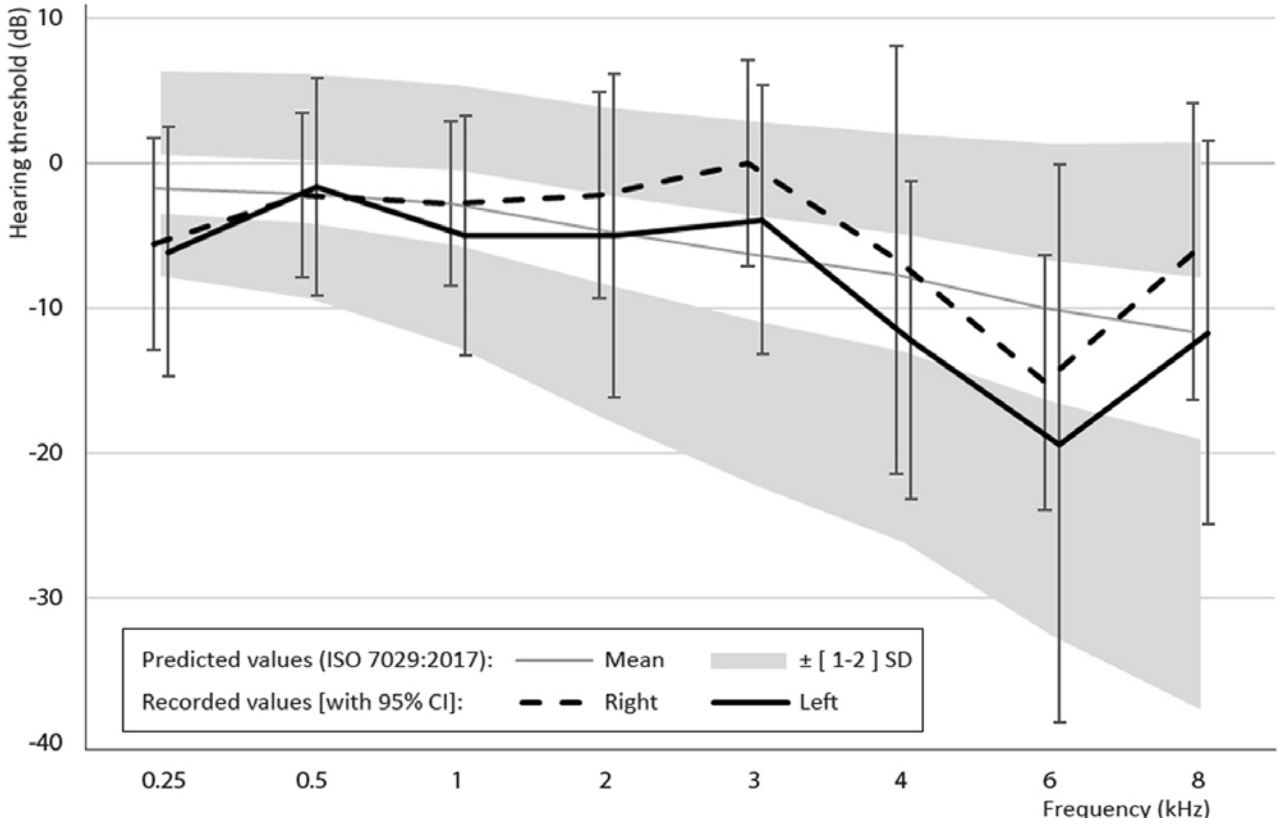


Table 1
Hearing thresholds as absolute values and Z-scores (with 95% CI): baseline values

Frequency	Left		Right	
	dB (95% CI)	Z-score (95% CI)	dB (95% CI)	Z-score (95% CI)
250 Hz	4.9 (-0.7–10.5)	0.62 (-0.38–1.62)	3.6 (-1.4–8.6)	0.48 (-0.4–1.36)
500 Hz	5.9 (-0.2–12)	0.86 (-0.21–1.93)	6.8 (1.2–12.4)	1.09 (0.09–2.09)
1 kHz	5.5 (-0.4–11.4)	0.88 (-0.19–1.95)	7 (1.9–12.1)	1.16 (0.19–2.13)
2 kHz	7.3 (-0.7–15.3)	1.34 (-0.14–2.82)	6.7 (0.6–12.8)	1.21 (0.05–2.37)
3 kHz	7.1 (-1.3–15.5)	1.24 (-0.29–2.77)	4.7 (-2.7–12.1)	0.77 (-0.6–2.14)
4 kHz	10.6 (1.4–19.8)	1.82 (0.21–3.43)	7.2 (-4.4–18.8)	1.2 (-0.83–3.23)
6 kHz	5.1 (-4.6–14.8)	0.67 (-0.98–2.32)	6.3 (-1.6–14.2)	0.9 (-0.58–2.38)
8 kHz	4.7 (-4.2–13.6)	0.51 (-0.89–1.91)	5.5 (-2.9–13.9)	0.73 (-0.63–2.09)

Table 2
Hearing thresholds as absolute values and Z-scores (with 95% CI): 15 year follow up ($n = 35$, mean age 37.5, SD 3.2 years). Statistically significant values have been marked with an asterisk. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Frequency	Left		Right	
	dB (95% CI) delta	Z-score (95% CI) delta	dB (95% CI) delta	Z-score (95% CI) delta
250 Hz	1.2 (-5.1–7.5) -3.7 **	0.15 (-1.39–0.15) -0.47	1 (-4.1–6.1) -2.6*	0.05 (-1.19–1.29) -0.43
500 Hz	1.4 (-6.3–9.1) - 4.5 **	0.11 (-1.66–0.11) -0.75*	1 (-5.2–7.2) -5.8***	0.02 (-1.36–1.4) -1.07***
1 kHz	5 (-2.1–12.1) -0.5	0.68 (-0.77–0.68) -0.2	2.4 (-3.1–7.9) -4.6***	0.2 (-0.94–1.34) -0.96***
2 kHz	5.6 (-3.6–14.8) -1.7	0.48 (-1.24–0.48) -0.86**	4 (-2.8–10.8) -2.7**	0.25 (-1.03–1.53) - 0.96***
3 kHz	8.7 (-3.4–20.8) +1.6	0.78 (-1.19–0.78) -0.46	4 (-6.3–14.3) 0.7	-0.04 (-1.79–1.71) -0.82***
4 kHz	9.7 (-1.7–21.1) -0.9	0.71 (-0.92–0.71) -1.11***	7.6 (-4.6–19.8) +0.4	0.34 (-1.45–2.13) -0.86**
6 kHz	17.1 (3.7–30.5) +12 ***	1.33 (-0.31–1.33) +0.66	15.6 (2.2–29) +9.3***	1.11 (-0.52–2.74) +0.21
8 kHz	4.7 (-5–14.4) 0	-0.26 (-1.42–0.9) -0.77**	5.3 (-5.5–16.1) -0.2*	-0.22 (-1.45–1.01) -0.95**

Of these 35 subjects, 21 had been diving for more than 20 years and nine had been diving for more than 25 years. Baseline data on hearing threshold and associated Z-scores are displayed in Table 1. Tables 2–4 display the same data with delta values (compared to baseline) at 15, 20 and 25 year follow up respectively. Any statistically significant increase or decrease of hearing threshold or Z-score compared to baseline have been marked with an asterisk (*). Please note that due to decreasing numbers of subjects in the 20 and 25-year follow-up groups, delta values are slightly different than when manually calculated from the displayed data in the tables.

Visual representations of the data are given in Figures 2–5. These figures combine the 7029:1017 reference values with the collected data.

Discussion

Hearing thresholds increased after 15 years of military diving, but not by more than the general working population. Increased hearing thresholds were more common at 6kHz, the typical frequency for noise-induced hearing loss, however, in comparison with age-adjusted norms, divers' hearing was better than that of the general population. At the lower frequencies (500, 1000 and 2000 Hz) hearing thresholds decreased or remained almost unchanged. This effect is more profound after 20 or 25 years' diving.

In some previous studies a longitudinal decrease in hearing thresholds has been described at the lower frequencies.[18] This has been attributed to the learning effect of frequently performing pure tone audiometry.[27] Also similar to other studies is the greater HL at 4 to 8 kHz,[7,8,11] but our absolute increase of HT is less than most previous studies. In line with the findings of Sames et al., we conclude that HL after 15–25 years of diving is less than might be expected from age-related decrease.[25]

In comparison to previous studies of divers, our different results could perhaps be attributed to increased awareness and usage of protective measures to prevent hearing loss. Many of the previous studies were conducted as long as 30 years ago. Technology to reduce noise generated from airflow and communication systems has been improved significantly over the years. Given the fact that underwater

Table 3

Hearing thresholds as absolute values and Z-scores (with 95% CI): 20 year follow up (n = 21, mean age 41.9, SD 2.6 years). Statistically significant values have been marked with an asterisk. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Frequency	Left		Right	
	dB (95% CI) delta	Z-score (95% CI) delta	dB (95% CI) delta	Z-score (95% CI) delta
250 Hz	4.3 (-3.5–12.1) -1.9	0.88 (-0.99–0.88) -0.04	4.1 (-3.1–11.3) +0.2	0.87 (-0.99–2.73) +0.32
500 Hz	2.4 (-5.8–10.6) -4*	0.28 (-1.59–0.28) -0.65	1.4 (-4.1–6.9) -5.3***	0.03 (-1.22–1.28) -1.07***
1 kHz	5.5 (-4.2–15.2) -0.9	0.64 (-1.35–0.64) -0.43	3.1 (-2.5–8.7) -4.0*	0.15 (-1–1.3) -1.02
2 kHz	6.2 (-3.4–15.8) -1.2	0.22 (-1.47–0.22) -1.11**	2.4 (-5.3–10.1) -3.8**	-0.34 (-1.79–1.11) -1.44***
3 kHz	11.9 (-3.5–27.3) +4.8*	0.95 (-1.37–0.95) -0.3	4.5 (-7.3–16.3) +1.7	-0.19 (-2.07–1.69) -0.63
4 kHz	11.9 (-2.1–25.9) +1.3	0.43 (-1.51–0.43) -1.4**	10 (-5.1–25.1) +3.1	0.16 (-1.94–2.26) -1.01 *
6 kHz	18.1 (4.8–31.4) +12.2**	0.80 (- 0.73–0.8) -0.05	16.2 (4.9–27.5) +8.8**	0.64 (-0.68–1.96) -0.49
8 kHz	9.8 (-3.5–23.1) +4.1	-0.10 (-1.54–1.34) -0.73*	6.4 (-4.7–17.5) +1.6	-0.54 (-1.85–0.77) -1.13**

Table 4

Hearing thresholds as absolute values and Z-scores (with 95% CI): 25 year follow up (n = 9, mean age 46.1, SD 2.3 years). Statistically significant values have been marked with an asterisk. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Frequency	Left		Right	
	dB (95% CI) delta	Z-score (95% CI) delta	dB (95% CI) delta	Z-score (95% CI) delta
250 Hz	6.1 (-2.5–14.7) +2.4	0.88 (-0.99–0.88) +0.65	5.6 (-1.7–12.9) +1.2	0.87 (-0.99–2.73) +0.43
500 Hz	1.7 (-5.8–9.2) -5.3	0.28 (-1.59–0.28) -1.16	2.2 (-3.5–7.9) -3.40	0.03 (-1.22–1.28) -0.96*
1 kHz	5 (-3.2–13.2) -0.1	0.64 (-1.35–0.64) -0.6	2.8 (- 2.9–8.5) -3.70	0.15 (-1–1.3) -1.13*
2 kHz	5 (-6.2–16.2) -1.8	0.22 (-1.47–0.22) -1.52**	2.2 (- 4.9–9.3) -4.40	-0.34 (-1.79–1.11) -1.82***
3 kHz	3.9 (-5.3–13.1) -0.7	0.95 (-1.37–0.95) -1.45**	0 (-7.1–7.1) -1.3	-0.19 (-2.07–1.69) -1.32*
4 kHz	12.2 (1.3–23.1) +1.9	0.43 (-1.51–0.43) -1.75**	6.7 (-8.1–21.5) -0.6	0.16 (-1.94–2.26) -1.83**
6 kHz	19.4 (7.3–31.5) +11.0 *	0.8 (-0.73–0.8) -0.68	15.1 (6.3–23.9) +4.60	0.64 (-0.68–1.96) -1.6**
8 kHz	11.7 (-1.6–25) +4.4	-0.1 (-1.54–1.34) -1.11	6.1 (-4.1–16.3) -0.9	-0.54 (-1.85–0.77) -1.79**

noise has more effect when ears are directly exposed in-water, the increased usage of helmet diving could also reduce HL.[15,28] An alternative explanation could be that military divers are relatively less exposed to underwater noise than commercial divers. Indeed, the tasks of military divers included relatively noise-free activities such as clearance diving and ship inspections. However, this explanation is unlikely because our population included Navy divers with a history of exposure to explosions, construction work or handling firearms.[10,16]

This study incorporated evaluation of HL as an age-corrected normal distribution. While an absolute increase of hearing threshold is easier to interpret, the Z-score ranks the individual patient against peers of the same age. Although natural deterioration due to ageing leads to increased hearing thresholds even in healthy individuals, we would like to emphasize that clinicians should still encourage their patients to wear hearing protection when they are exposed to noisy working environments. It is important to keep in mind that high incidences of self-reported HL could possibly be the result of awareness in patients due to successful preventive medicine, and not audiometric abnormalities.[10,12]

Many professional standards recommend yearly audiometric evaluation in divers. Our data suggest military diving is not an additional risk factor for HL. Some other studies suggest only very small increases of HT.[22,23] The clinical relevance of these very small changes in HT is doubtful. Also, the value of routine annual medical examinations has been questioned.[25,29] We feel our data support the policy in some countries to reduce the frequency of dive medical examinations, or at least perform audiometry 'on indication', for instance after noise exposure or barotrauma, and not as a routine investigation. Our data cannot give an evidence-based suggestion for the optimal frequency of audiometric

investigation. The Royal Netherlands Navy considers that once every five years, or earlier when indicated, is frequent enough to monitor long term health effects of military divers. This is in line with current policy in New Zealand and the UK for occupational divers.[25,26]

STRENGTHS AND LIMITATIONS

To our knowledge the present study is the first to evaluate hearing loss after 25 years of military diving. With increasing age of occupational divers these data are relevant for both clinicians and divers. Additionally, approaching HL as a normal distribution allows a more contextually accurate evaluation of hearing change compared with absolute changes in hearing thresholds.

Some limitations also need to be addressed. Firstly, this study did not include data describing depth and number of dives. Our population typically dives up to a depth of 80 metres' sea water with helium-oxygen gas mixtures, but additional research is required to evaluate whether our results can be translated to saturation divers or alternative breathing gases. Secondly, the small sample in the 20 and 25 year follow up group (21 and 9 respectively) could possibly leave our study unable to detect small changes compared to the reference group. However, the clinical relevance of very small statistically significant differences is doubtful. Lastly, small samples could make this study susceptible to selection bias as a result of the 'healthy worker effect', where individuals with health issues, hearing loss being one of them, are more likely to discontinue diving than their healthy colleagues. And while our electronic file system is not able to screen for the individuals excluded for ENT-problems, our general experience is that ENT-problems are seldom a reason to be discharged from diving.

Conclusions

The present study is the longest longitudinal analysis of HL in navy divers. While the absolute HT increases at 6 kHz after 15 to 25 years of military diving, this is well within the range of physiological hearing deterioration. While our sample is small, the results agree with the study by Sames et al. We conclude that military diving does not seem to be an additional hazard for developing HL compared to general occupational hazards. At longer follow-up periods, this effect becomes more pronounced, with divers age-adjusted hearing being better than 20 or 25 years earlier. This could be the result of effective awareness and usage of hearing protection. We encourage clinicians to adopt the normal distribution as given in the ISO-7029 standards to evaluate changes in HL in divers more accurately, and to reduce the frequency of mandatory audiometric testing in healthy divers.

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Diving and mental health: the potential benefits and risks from a survey of recreational scuba divers

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Abstract
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Introduction: Scuba diving is physically and cognitively demanding. Medical guidance regarding physical and mental health (MH) issues and related prescribed medication is often based on limited evidence. There is a paucity of data concerning diving with MH issues. This survey aimed to investigate the prevalence of MH issues and use of prescription medications among United Kingdom (UK) sport divers, and the rate of non-compliance with current guidance among divers suffering depression and anxiety. The positive effects of scuba diving on MH were also considered.
Methods: An anonymous online survey was publicised through diving exhibitions and social media. Measures included diver and diving demographics; GAD-7 Anxiety and PHQ-9 depression questionnaires; diagnosed current and/or past MH conditions; medication usage; comorbid medical conditions/treatments; disclosure of past/current MH issues; and perceived MH benefits of diving.
Results: Data from 729 respondents revealed MH issues at rates comparable with the general population. Current and/or past MH issues were reported by 111/729, with 60 having active diagnoses, and 45/60 taking prescribed psychotropic medications; 21/45 did not declare their medication on diver self-certification medical forms. The activity of diving was thought to be beneficial to MH by 119/729 respondents.
Conclusions: Divers experienced expected levels of MH issues, but did not comply with current medical guidelines on modifying or abstaining from diving activity or reporting their MH condition. Changes may be needed to diver training to encourage more accurate reporting and aid development of evidence-based protocols. Guidelines could be reconsidered in light of current diver behaviour, risks and potential MH benefits.

Introduction

Scuba diving requires both physical and mental discipline, organization, and the ability to interact with other divers in an environment where initiative and dependency are crucial for the safety of those involved. These risks, combined with the specific physiological demands placed on divers, have led to the development of a regulatory culture in which divers are required to disclose relevant medical conditions to a qualified specialist, and to refrain from diving when medical conditions may affect their own safety and the safety of others.[1–5]

Medical recommendations for divers are usually based on sound understanding of basic physiological processes; for example, in relation to respiratory conditions which increase risks of pressure-related injuries to the lung.[1–5]

For some conditions, including the common mental health (MH) issues of depression and anxiety, few data exist to support evidence-based recommendations. The United Kingdom Diving Medical Committee (UKDMC) describes the relation between MH and fitness to dive as complex. Existing guidelines may be unclear to the ordinary diver, or not evidence based. Large datasets on which to base recommendations (e.g., clinical trials among divers) are unlikely to be forthcoming. Nonetheless UKDMC strives to produce pragmatic advice for divers and guidance for medical professionals involved in fitness to dive certification.[1]

In common with other medical conditions which may impact fitness to dive, UKDMC require diagnoses of MH conditions to be reported to an approved diving medicine referee for further assessment. For depression, the guidance

states that divers should only return to the water once depression has 'lifted', and that they should wait three months after initiating medication to allow side effects to resolve. Divers are only permitted to take newer selective serotonin reuptake inhibitor (SSRI) antidepressants, or some second line agents such as Mirtazepine (with additional depth restrictions). Divers should refrain from diving whilst using older antidepressant medications (ADM), or if taking multiple psychotropic medications concurrently. For anxiety, no specific recommendations are made by UKDMC, but the advice not to dive when taking multiple psychotropic medications still applies.[1]

It is difficult to estimate the proportion of sport divers who would be judged unfit to dive based on UKDMC criteria, but the number may be substantial. MH issues are a principle burden of disease globally with 25% of adults in the UK diagnosed with MH issues in any one year.[6–8] The disorders of anxiety and depression represent the majority of cases.[9] Despite the effectiveness of psychotherapy, the mainstay of treatment for mood disorders remains ADM.[10] A retrospective analysis of UK prescribing data reveals a steady increase in the use of ADM over the past 20 years.[11] For the 1.5 million patients observed between 1995 and 2011, growth in new prescriptions for SSRI antidepressants did not reduce usage of older tricyclic antidepressants (TCA). Across this 17-year period 23% of patients were prescribed ADM at least once. Extrapolating from these 2011 figures, and applying UKDMC guidance, as many as 6% of the general population might therefore be excluded from diving based solely on rates of TCA and other non-SSRI ADM usage.[12] Fully accounting for dual-prescriptions, changes in dose or the SSRI prescribed, and the relapsing/remitting nature of depression itself, would all serve to increase this estimate.

Medical regulations and medical authorities are sometimes perceived by divers as excessively risk averse, and a threat to continuing participation in the sport.[1,2,13] It is known that divers do not always disclose medical conditions, especially those relating to respiratory, cardiac or diabetes issues, that might affect their dive status either during the season, or when completing the annual medical self-certification form.[14,15] Thus, there is likely to be a small but important covert population of active divers with current MH problems, and prescribed ADM, which remains understudied.

Anecdotal evidence may suggest that divers with MH conditions are successfully diving outside the UKDMC guidelines, perhaps indicating an opportunity to consider the acceptable level of risk against the potential benefits of the activity of diving on MH.

For diving guidance to be pragmatic it must reflect both the risks and potential benefits of the activity. Diving involves physical activity and encourages social connectedness and cooperation, acknowledged to be beneficial for MH.[16,17] A growing literature indicates that green spaces (gardens, parks, fields, moors etc.), and more recently blue spaces (lakes, beaches, sea etc.) may have restorative effects, and provide benefits for mental health and wellbeing.[18–20] Specific effects of scuba diving on MH have not been studied but the restorative effects of exposure to nature have been found sensitive to differences in activity type, and divers frequently access blue spaces for extended periods of time and are active within them.[21–23] The role of positive emotional regulation is receiving increasing attention in the treatment of mood disorders, implying that greater scrutiny should be given to medical guidance that may disrupt a sociable, physically active, and positively-affective pursuit.[23]

The aim of this study was to collect data which might help place an upper bound on the potential harms caused by relaxing the current MH diving guidance, and the opportunity costs of the current restrictions. Specifically, we investigated the prevalence of MH issues and the use of prescription medications among sport divers, and the rate of non-compliance with current guidance among divers' suffering depression and anxiety. The benefits of scuba diving on improving mental well-being were considered, and perceived barriers to diving were elicited. Our study did not attempt to establish any association between MH issues and risk of decompression illness (DCI), or psychological stress as an influence in diving accidents.

Methods

An anonymous, observational, on-line questionnaire was compiled using diver and diving-demographic questions used in previous field data studies along with the Patient Health Questionnaire for Depression (PHQ-9) and the Generalized Anxiety Disorder (GAD-7) questionnaire (GAD-7 for regular or uncontrollable worries regarding everyday life).[14,15,24–27] Demographic questions included affiliations, year of first dive, year of most recent dive, total dives since learning, dives in the last 12 months, and maximum depth ever dived.[14,15,24,25] Technical divers were defined by maximum depth ever dived > 40 metres and affiliation to one or more technical diving organisations. Other questions involved current and/or past diagnoses for both MH and other conditions, and medications and treatments used. Additional questions probed the perceived benefits of diving on MH; diver understanding of transparency/openness with other divers, and awareness of the UKDMC recommendations concerning MH issues. Subjectively divers were also asked if they had experienced panic before or during a dive, and if so, how frequently. Finally, free text comments were encouraged.

The survey was available online for seven months from March 2015 and publicised through diving exhibitions and social media. Divers were free to participate and were not actively recruited. At the close of the survey, data were scrutinised for duplicate entries and completeness.

Table 1
Contingency table of PHQ-9 and GAD-7 scores by 729 respondents

PHQ-9	GAD-7				
	0–4	5–9	10–14	15–21	Total
0–4	531	40	2	1	574
5–9	54	38	6	0	98
10–14	6	20	9	1	36
15–27	2	3	8	8	21
Total	593	101	25	10	729

Descriptive statistics and tables are used to summarise the distribution of responses. Chi squared ($\chi 2$) was used to test for independence in 2 x 2 tabulations. Generalized linear models using a gaussian or negative-binomial link were used to estimate the effect of covariates on the PHQ-9 and GAD-7, and on the number of dives; these were fitted using the rstanarm R package using default, non-informative, priors. From these models we report mean differences in scores or proportions, along with 95% credible interval (CI) or Bayes factor (BF) as appropriate. All software and data required to reproduce the findings reported here are included in an online data supplement doi: 10.5281/zenodo.1421734. In the opinion of the National Health Service (NHS), Health Research Authority, NRES Committee South West, Cornwall and Plymouth, no ethical review is required for anonymous studies of this type.

Results

Analysis was performed on 729 records, of whom 29% were women. The median age was 48 (range 16 to 85, IQR 19). Men in our sample were typically older than women (mean difference = -4.6; 95% CI = -6.6 to -2.5). Diving demographics were representative of the UK sport diving population; the median years of diving experience was 14 (IQR = 15), and the median number of life-time dives was 465 (IQR 840). The median number of dives completed in the last 12 months was 40 (IQR = 50). Maximum depth ever dived ranged from 5 to 200 metres' sea water (msw) (median = 47, IQR = 21). As a group, the maximum depth ever dived by the technical divers (232) was a median of 63 msw (IQR = 32). Even accounting for age, women had less life-time diving experience than men but had not been less active in the past 12 months. The estimated difference in the lifetime number of dives since learning for women vs. men was -195 (95% CI = -351 to -31), and for dives in the previous 12 months this difference was immaterial (a single dive less, 95% CI = -12 to 9 dives).

GENERAL HEALTH

Of the 729 respondents, alcohol was regularly consumed on a weekly basis by 66% and 7% were current cigarette smokers. Of the 98% (716) respondents who reported their weight, 32% had a normal body mass index (BMI 18.5–24.9); 42% were overweight (BMI 25.0–29.9) and 25% were obese (> 30.0). Five women were underweight (BMI < 18.5).

Medications prescribed for non-MH health conditions were reported by 35% of divers with cardiac (9%), asthma (3%), and diabetes (2%) issues reported.

DEPRESSION (PHQ-9) AND ANXIETY (GAD-7)

All 729 respondents completed both PHQ-9 and GAD-7 questionnaires (Table 1). Depression and anxiety scores were comparable with national population norms, and selected items from both scales were compared with data from the UK Biobank.[28,29] Comparison of individual items from the PHQ-9 and GAD-7 also indicated our respondents endorsed items at similar rates to the large sample held at www.ukbiobank.ac.uk.[28,29]

Moderate to severe depression scores (PHQ-9 from 10 to 27) were reported by 8% (57/729) of respondents, with 77% (44/57) of this group undiagnosed. Moderate to severe anxiety scores (GAD-7 from 10 to 21) were reported by 5% (35/729), with 60% (21/35) of this group undiagnosed. Further analysis showed moderate and/or severe scores for both depression and anxiety (≥ 10) were reported by a small group (26/729), of whom 11/26 were diagnosed.

CURRENT OR PAST DIAGNOSED MENTAL HEALTH ISSUES

Of the 729 respondents, current or past MH issues were reported by 15% (111/729) of divers, with 8% (60/729) reporting a current MH issue. Women were more likely to report a current MH issue than men (28/183 vs. 32/486, $\chi 2[1] = 9.1$, $P = 0.003$). Separate to the PHQ-9 and GAD-7 questionnaire, physician diagnosed depression (7%) and anxiety (3%) were the most frequently self-reported issues, with other conditions including: bipolar disorder (0.5%), and single cases of schizophrenia, social/generalized anxiety disorder, post-traumatic stress disorder, eating disorder, personality disorder, and dysthymia. Due to the anonymity of the study further clarity of the mental health reports was not possible.

Regular use of physician-prescribed psychotropic medication was reported by 45 divers (Table 2). Significantly more women (25/28 $P < 0.016$) were prescribed medication than men (20/32). SSRIs were prescribed for 68% of these respondents, with five respondents prescribed more than one medication. Perceived daily side effects from medication were reported by two respondents, and three more were unsure; the remaining 40 reported no side effects from their drug regime.

Of the group prescribed MH medication (45/729), 51% continued diving immediately after diagnosis; 18% resumed diving after one month; and 27% resumed diving after two

Table 2
MH drug type, number and percentage reported by 45 respondents, five used more than drug

Drug type	Total reports from 45 respondents
Selective serotonin reuptake inhibitors	
Citalopram	15
Fluoxetine	8
Sertraline	6
Paroxetine	4
Escitalopram	1
Total	34 (68%)
Tricyclic antidepressants	
Amitriptyline	1
Total	1 (2%)
Other	
Bupropion/Wellbutrin	5
Venlafaxine	4
Mirtazapine	2
Lamotrigine	2
Clonazepam	1
Trazodone	1
Total	15 (30%)

months. Diving whilst on medication was not associated with perceived side effects by the majority 89%. One respondent thought he suffered from dry eyes whilst diving on the medication; the remaining four were unsure.

Non-pharmacological MH treatments were reported by 47% (28/60) of those reporting current MH issues and included cognitive behavioural therapy and other talking therapies including: counselling; psychodynamic therapy; stress anxiety and mood management courses; hypnotherapy; and eye movement desensitization and reprocessing.

DIVING WITH MH ISSUES

There was no difference in the lifetime number of dives between respondents with current MH issues (60) and those without MH issues (669) (difference = -94 dives, 95% CI = -324 to 198, BF10 = 0.09). However, respondents with current MH issues (60) reported substantially fewer dives in the previous 12 months compared with 669 respondents with no MH issues (33 vs. 59 dives, difference = -27 dives, 95% CI = -36 to -16, BF10 = 567).

Asked if the MH issue affected their perceived ability to dive safely, 93% (56/60) participants said it did not, three were unsure, and one thought the ability to dive safely was affected but did not specify in what way. The activity of diving was considered to subjectively improve MH issues by 90% (54/60) of respondents.

DISCLOSURE, TRANSPARENCY/OPENNESS AND UNDERSTANDING OF MH ISSUES

Of the 60 respondents currently diagnosed with MH issues 55% did not declare their MH health status on the annual medical self-certification forms. Of the 45% (27/60) who had declared their MH issue through self-certification using internationally-recognised diving industry medical screening standards, none had ever been refused fitness to dive. Many respondents failed to disclose MH issues to their diving companions or buddy, with 48% (29/60) unsure if others were aware of their MH issue.

Overall 31% (227/729) stated that their general practitioner was, to their knowledge, unaware of their diving activity. Only 21% of all respondents (152/729) were aware of the UKDMC recommendations and guidance on MH issues. Free text responses suggested there is a degree of stigma attached to admittance of MH issues and a fear of exclusion due to their MH, for example: "*Because of this stigma we have dived where other people in the group, or dive operator/ instructor does not know our medical history. We felt this was necessary in fear of being told we can't dive when we know we are ok*", and "*There is such stigma attached to mental health issues, not all mental health issues should stop people from being able to access the beauty of the underwater world*".

More than half of respondents (482/729), both with and without a declaration of MH, had experienced feelings of anxiousness before or during a dive, at some time during their diving career. Self-defined panic was reported by 19% of all divers before or during a dive. Women were more likely than men to report experiencing panic before or during a dive (32% vs. 14%). Respondents with current MH issues were more likely to report panic before or during a dive (37%; 22/60) than those without MH (17%; 117/669).

TECHNICAL DIVERS

There was no statistical difference in the proportion of technical divers vs. non-technical divers with a current MH diagnosis (20/232, vs 40/497; $\chi2[1] = 0.014$, $P = 0.907$) or a PHQ-9 or GAD-7 score > 10 ($\chi2[1] = < 0.001$, $P = 1$). Mean differences between technical and non-technical divers on the PHQ-9 and GAD-7 were 0.11 (95% CI = -0.57 to 0.81), and -0.35 (95% CI = -0.88 to 0.20) respectively. Amongst

divers with a current mental health issue, technical divers were no more or less likely than non-technical divers to have informed their buddy ($\chi2[1] = < 0.001$, $P = 1$), or to have self-declared any other medical condition ($\chi2[1] = 1.894$, $P = 0.169$).

Discussion

Our study group of UK sport divers were similar to the general population in terms of the number reporting MH issues, but with a lower prevalence of antidepressant prescriptions. The type of medication prescribed was broadly similar to the general population, the majority being prescribed an SSRI.[10–12] However, we found that substantial numbers of sport divers were either unaware of the current UKDMC guidance or failed to comply with guidance in relation to MH. Many divers failed to exclude themselves for a sufficient period when initiating or changing ADM, when taking a non-SSRI medication, or when taking more than one psychotropic medication. Five divers were currently prescribed more than one MH medication thus contravening guidelines.[1] A small number of divers had not informed their general practitioner that they were active scuba divers. Overall, the respondents were broadly representative of the UK sport-diving population and demonstrated similar diving demographics to those in other studies and reports.[13,14,24,25]

When completing the GAD-7 and PHQ-9 our respondents revealed rates and severity of depression and anxiety comparable to, or marginally lower than, large national surveys.[6,26–29] Women were at elevated risk for both depression and anxiety compared with men, and were more likely to be prescribed an ADM.[6,30] Of note was the number of divers who scored ≥ 10 on both the PHQ-9 and GAD-7, but who were not currently diagnosed by a physician for depression or anxiety. This indicated a substantial burden of symptoms which were not under medical management.

The data showed that the divers with MH issues were no less experienced than others without a diagnosis but had logged fewer dives over the previous 12-month period. Our data cannot explain why this is the case, but it may be that MH conditions affect the motivation to dive, or that divers recognise the need for caution when they are unwell and modify their behaviour accordingly. However, these data are drawn from a relatively small subset of respondents and inferences should be treated with caution. Few divers believed that their MH issues affected their ability to dive safely, or that any medications produced unwanted side-effects whilst diving.

We found that a relatively large number of divers had reported feelings of panic before or during a dive, and that women were much more likely than men to report these feelings. Due to the methodology of the study we were not able to explain in any detail how the respondents defined their panic. Anxiety and panic as risk factors for diving accidents have been reported, although for fatalities it often remains unknown whether panic was a contributing factor.[31–35] Nonetheless, these divers might benefit from a more open culture, in which vulnerability and subclinical MH issues can be disclosed without fear of prejudice.

As in a recent study of military veterans, divers in our study reported diving to have a positive impact on their mood and MH, and the majority of those reporting a MH issue thought the activity of diving improved their condition.[36] This belief is of interest given the attention in recent years regarding the benefits of green and blue spaces on mental health.[18–22] These findings are also consistent with observations from non-diving groups where exercise has been found to be beneficial to mental well-being.[16,17,37]

Responses to our survey indicate low levels of accountability and understanding in relation to mental health and fitness to dive. Divers did not routinely comply with UKDMC recommendations, and disclosure and openness of MH issues with other divers was not always observed. These findings are consistent with other studies on drug use, alcohol use, and cardiac health among divers, which show similar patterns of non-disclosure and relatively little knowledge of guidelines.[13,14,24,25]

Few respondents in the MH group were aware of the formal guidance from the UKDMC. Only 21% were aware of the recommendations, indicating both the need for continuing diver-education, and greater emphasis on fit-to-dive guidelines in dive training regimes. Divers are variously required to complete a medical statement form according to the guidelines of specific diving bodies but there is little uniformity of questions nor a central body for data collection.[1,2] Data suggest there may be the case for more rigorous health screening of the technical diver subgroup, due to the more extreme physiological conditions to which they are exposed.[13,15]

Free text responses in this study clearly showed a stigma attached to MH issues as well as a fear of being prevented from diving through transparency/openness; this may in part account for the general overall lack of openness.

LIMITATIONS

Anonymous online surveys suffer from potential response bias. Divers who have left the sport may not be included in this study, and divers who feel they have something to report may be more likely to respond. Issues may be exaggerated or under-reported, and reluctance to admit MH issues may preclude participation. Mental health issues themselves may influence participation rates.

Conclusions

For diving health guidance to be pragmatic it must reflect both the risks and potential benefits of the activity. Divers resemble the UK population in their level of MH morbidity,

but are not always compliant with current medical guidance relating to antidepressant medication and mood disturbance. Failure to disclose in some respondents may reflect a stigma associated with MH issues, whilst some divers may be poorly informed. Divers may be deliberate in their non-disclosure, seeking to avoid exclusion from the sport. The vast majority of respondents reported that diving improved their mental health and wellbeing. With no consistent evidence and only field data relating to specific risks for ADM medication and mood disturbance when diving, perhaps future guidance to divers should consider the level of risk in light of the potential benefits of continuing to dive recreationally.

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Technical report

Performance of cartridge and granular carbon dioxide absorbents in a closed-circuit diving rebreather

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Abstract
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Introduction: Scrubbers in closed-circuit rebreather systems remove carbon dioxide (CO_2) from the exhaled gas. In an attempt to be more user-friendly and efficient, the ExtendAir® non-granular, pre-formed scrubber cartridge has been developed. The cartridge manufacturer claims twice the absorptive capacity of granular CO_2 absorbent, with less variability, lower work of breathing, and reduced exposure to caustic chemicals after a flood. To our knowledge there are no published data that support these claims.

Methods: Cartridge (ExtendAir®) and granular (Sofnolime® 797) scrubbers of equal volume and mass were tested five times in an immersed and mechanically ventilated O_2ptima rebreather. Exercise protocols involving staged (90 minutes 6 MET, followed by 2 MET) and continuous (6 MET) activity were simulated. We compared: duration until breakthrough, and variability in duration, to endpoints of 1.0 kPa and 0.5 kPa inspired partial pressure of CO_2; inspiratory–expiratory pressure difference in the breathing loop; and pH of eluted water after a 5 minute flood.

Results: Mean difference in scrubber endurance was 0–20 % in favour of the ExtendAir® cartridge, depending on exercise protocol and chosen CO_2 endpoint. There were no meaningful differences in endpoint variability, inspiratory–expiratory pressure in the loop, or pH in the eluted water after a flood.

Conclusions: Cartridge and granular scrubbers were very similar in duration, variability, ventilation pressures, and causticity after a flood. Our findings were not consistent with claims of substantial superiority for the ExtendAir® cartridge.

Introduction

In closed-circuit rebreather (CCR) diving, divers rebreathe recycled expired gas. Since humans consume oxygen and produce carbon dioxide (CO_2), these gases need to be added to and removed from the breathing 'loop' respectively. CO_2 is removed by a chemical reaction with a 'scrubber' material; typically 'soda lime', which is a granular compound mix of sodium hydroxide (NaOH), calcium hydroxide ($Ca(OH)_2$) and water. This reaction produces calcium carbonate ($CaCO_3$) and water. When there is reduced $Ca(OH)_2$ remaining in the scrubber material, expired CO_2 can 'break through' and be rebreathed by the diver. Breakthrough can also occur if soda lime is improperly packed in the scrubber canister such that CO_2 can pass through without reacting (often referred to as 'channelling'), or if the canister is improperly installed thus allowing 'bypass'. Rebreathing CO_2 reduces the efficacy of ventilation in elimination of CO_2 from the body and can lead to hypercapnia. This may produce hazardous symptoms such as dyspnoea and anxiety and can ultimately result in the diver losing consciousness.[1]

With the above in mind, there is a strong focus among rebreather divers on not exceeding effective scrubber absorptive capacity, and on proper packing and installation of scrubber canisters. An alternative to packing scrubbers with loose granular soda lime preparations are so-called scrubber cartridges (ExtendAir® 801C, Micropore, Newark DE, USA). These single-use products are intended to optimise absorptive capacity, eliminate packing and simplify installation. The cartridge is manufactured by wrapping sheets of absorbent compound around a core in a spiral arrangement, with pre-formed linear channels allowing axial gas flow through the cartridge (Figure 1). ExtendAir® cartridges are putatively claimed to: 1) Out last a granular system (presumably of similar mass or volume) by two times

Figure 1
Micropore ExtendAir® 801C CO_2 scrubber cartridges

or more; 2) Exhibit less variation in duration at any test condition (± 5% versus ± 30% using granules); 3) Exhibit 8.5% lower work of breathing; 4) Produce 70% less caustic contamination after a 5 minute flood of a rebreather.[2–5] This latter claim relates to the known propensity for soda lime to produce an extremely alkaline liquid when in contact with water. If a soda lime scrubber canister becomes partially flooded and if the contaminated water reaches the diver in the breathing loop, it can cause chemical burns to the mouth and airway.

There are no publicly available data to support these claims. Therefore, we undertook a laboratory study in which we compared ExtendAir® cartridges to a matched canister volume of granular soda lime preparation in respect of scrubber duration; variability in duration; resistance to ventilation; and caustic potential. Our primary aim was to establish whether (or not) there was indicative support for the various claims of superiority for ExtendAir® cartridges in relation to these parameters when compared under a limited set of conditions.

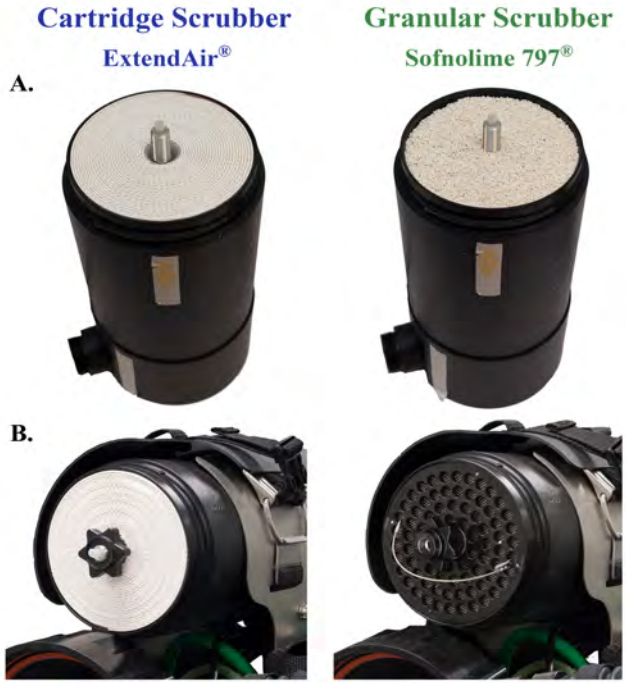
Methods

SCRUBBERS

In this bench test we compared ExtendAir® 801C CO_2 absorbent cartridges (Micropore, Newark, USA) to canisters containing Sofnolime® 797 granular soda lime (Molecular Products, Harlow, UK). The ExtendAir® cartridge absorbent material contains $Ca(OH)_2$ (> 85%), NaOH (3%) and potassium hydroxide (KOH, 2%),[5] whereas the Sofnolime® 797 granules contain $Ca(OH)_2$ (> 75%), NaOH (< 4%).[6]

To ensure a meaningful comparison, we utilised an O_2ptima closed-circuit rebreather (Dive Rite, Lake City, USA) which is designed to accept either an ExtendAir® cartridge or equivalent volume of granular soda lime in the same scrubber canister (Figure 2). All scrubber products

Figure 2
A) Scrubber canisters shown with ExtendAir® cartridge installed (left) and packed with Sofnolime® 797 granular absorbent (right). B) Assembled scrubbers installed in the Dive Rite O_2ptima closed-circuit rebreather. Granular absorbent is retained with a stainless-steel scrim (right)



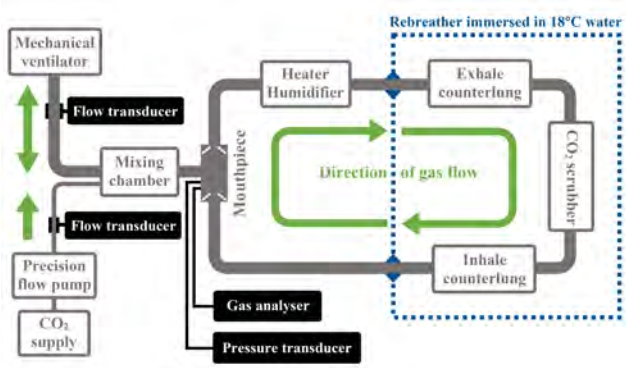
had been recently purchased, were in date and had been appropriately stored within the supplied sealed packaging prior to use. The ExtendAir® cartridges weighed 2.15 kg and Sofnolime® 797 granular scrubbers, packed by an experienced rebreather instructor, weighed 2.08 kg for all trials. Granular absorbent was measured by mass (GM-11 laboratory balance, Wedderburn Scales, Auckland, New Zealand) and packed to equivalent volume, then assembled within 5 minutes, and trials commenced within 15 minutes. The timings for cartridge scrubber assembly were aligned with the granular scrubber packing.

EXPERIMENTAL SET-UP

The study was conducted in the Exercise Physiology Laboratory at the University of Auckland. All experiments were conducted with the rebreather submerged in an upright position at surface pressure (approximately 1 atmosphere or 101.3 kPa). The air and water temperature were maintained throughout the experiment at 18°C.

Details of the bench test apparatus have been published previously.[7] Briefly, the inspiratory and expiratory hoses of the submerged O_2ptima rebreather were attached to a test circuit (Figure 3) using tubing adaptors (MLA304, AD Instruments, Dunedin, New Zealand). The test circuit conduit was composed of 35 mm diameter smooth bore respiratory tubing (MLA1015, AD Instruments, Dunedin, New Zealand) connected to a one-way respiratory valve (5710, Hans Rudolf, Shawnee, KS, USA). The mouthpiece

Figure 3
A schematic layout of the experimental test circuit (grey) and monitoring equipment (black). See text for explanation



included a port for sampling deadspace gas for analysis of CO_2 during inspiration and a port for measuring pressure in the mouthpiece throughout the respiratory cycle. A clinical heater humidifier (Fisher and Paykel Medical, Auckland, New Zealand) reproduced heating (set to 34°C) and humidification of expired gas that would occur with a human breathing on the loop.

Breathing was simulated using a sinusoidal mechanical ventilator (17050-2 Lung Simulator, VacuMed, Ventura, USA) with an inspiratory/expiratory ratio of 1:1. Mixing of gases within the lungs was simulated using a 4 L chamber where CO_2 was added from a Douglas bag reservoir using a precision flow pump (R-2 Flow Controller, AEI Technologies, Pittsburgh, USA) to the inspired gas from the rebreather loop.

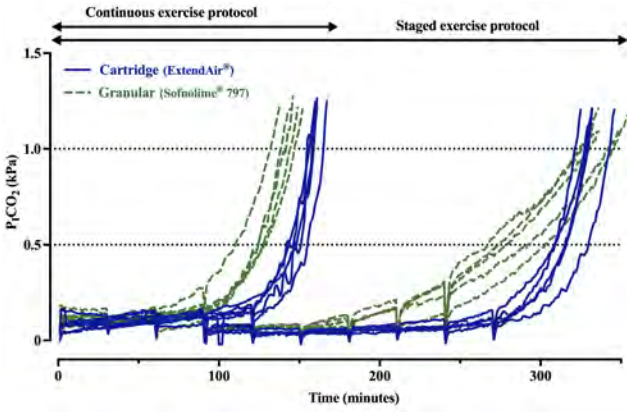
Every 30 minutes the trial (and endurance time) was paused, to remove condensation from the loop and to recalibrate gas flow and gas analysers. This recalibration ensured accurate CO_2 addition, for consistent trials. All data were sampled at 1 kHz using Powerlab 16/35 and LabChart 7 data acquisition and analysis system (AD Instruments, Dunedin, New Zealand).

The diluent gas was air, and the rebreather oxygen set point was 0.7 atmospheres (71 kPa), representing a circuit oxygen fraction of ~70 % at atmospheric pressure).

EXERCISE PROTOCOLS

Each scrubber type was subjected to ventilation and CO_2 addition parameters simulating two exercise protocols: 1) staged exercise; 2) continuous moderate exercise. The staged exercise protocol was intended to resemble a typical dive, with a 90 minute period notionally representing the descent and bottom phase with moderate exercise intensity (6 MET ~ oxygen uptake 21 ml·kg^{-1}·min^{-1}), followed by a lower intensity period (2 MET ~ oxygen uptake 7 ml·kg^{-1}·min^{-1}) notionally representing the resting decompression phase. This low intensity phase continued until the inspired partial pressure of CO_2 (P_ICO_2) rose to 1.0 kPa (breakthrough).

Figure 4
Breakthrough curves for granular (green dashed lines; Sofnolime® 797) and cartridge (blue lines; ExtendAir®) scrubbers. Inspired partial pressure of CO_2 (P_ICO_2) is plotted for two exercise protocols; continuous exercise (6 MET, left side); and staged exercise (6 MET for 90 minutes followed by 2 MET until breakthrough, right side). Horizontal dotted lines highlight CO_2 breakthrough endpoints of P_ICO_2 0.5 and 1.0 kPa



The continuous exercise protocol has been used previously,[7] and utilises ventilation and CO_2 addition parameters simulating continuous 6 MET exercise from the beginning of the experiment until breakthrough. During the 6 MET exercise the minute ventilation was set to 45 L·min^{-1}, with a tidal volume of 1.5 L and a respiratory rate of 30 breaths per minute; CO_2 was added at a rate of 2 L·min^{-1}. During the 2 MET exercise minute ventilation was reduced to 17 L·min^{-1} (tidal volume of 1.0 L and 17 breaths per minute), and CO_2 was added at a rate of 0.67 L·min^{-1}. The respiratory volumes and CO_2 flows were independently verified using a pneumotachograph (800 L, Hans Rudolf, Shawnee, USA) and an independent flow transducer (MLTJOL, AD Instruments, Dunedin, New Zealand) respectively.

SCRUBBER FLOODING

We exposed five unused scrubber canisters packed with both types of scrubber material to a simulated flood by completely flooding the rebreather scrubber compartment with fresh water with the scrubber canister in situ. After 5 minutes of immersion, the scrubber cartridge or granules were removed and the pH of residual water within in the scrubber canister was measured (pH meter 9532000, Hach, Loveland, USA).

OUTCOME MEASURES

1) Scrubber duration. We compared the mean time to breakthrough of 1.0 kPa P_ICO_2 in the two scrubber types for both the staged and continuous exercise protocols. A secondary endpoint of breakthrough to P_ICO_2 0.5 kPa was retrospectively analysed.
2) Duration variability. We compared variability within scrubber types by calculating a coefficient of variation (%) for both exercise protocols.
3) Ventilation pressures. The mean peak-to-nadir expiratory/

Table 1

Scrubber duration (minutes) to breakthrough, variation in duration (%), peak-to-nadir expiratory/inspiratory loop pressures (kPa) during ventilation, and pH of water eluted from flooded granular (Sofnolime® 797) and cartridge (ExtendAir®) scrubbers. Breakthrough endpoints of 0.5 and 1.0 kPa inspired partial pressure of CO_2 (P_ICO_2) are shown for staged exercise (6 MET for 90 minutes followed by 2 MET to breakthrough) and continuous exercise (6 MET) protocols; standard deviation (SD); coefficient of variation (CV); mean difference (MD) with 95% confidence interval [95% CI]

	P_ICO_2	**Cartridge** (ExtendAir®)		**Granular** (Sofnolime®)		**Cartridge** (ExtendAir®) **versus Granular** (Sofnolime®)	
		Mean (SD)	CV	Mean (SD)	CV	MD [95% CI]	*P*-value
Scrubber duration (min)							
Staged exercise	**1 kPa**	329 (8)	2.4%	330 (10)	3.1%	-1 [-14 to 12]	0.89
	0.5 kPa	314 (9)	2.9%	278 (14)	5.2%	36 [19 to 54]	0.001
Continuous exercise	**1 kPa**	158 (4)	2.5%	139 (6)	4.2%	19 [11 to 26]	< 0.001
	0.5 kPa	144 (6)	5.8%	120 (7)	5.9%	24 [14 to 33]	< 0.001
Ventilation pressures (kPa)							
Staged exercise		0.57 (0.04)		0.63 (0.04)		-0.06 [-0.11 to 0.00]	0.053
Continuous exercise		1.23 (0.27)		1.18 (0.11)		0.04 [-0.25 to 0.34]	0.75
Causticity							
pH (flooded scrubber)		12.8 (0.0)		12.7 (0.1)		0.2 [0.1 to 0.3]	0.009

inspiratory pressure difference measured at the mouthpiece was taken as a surrogate index of breathing performance. This measure was calculated for both scrubber types during the two exercise protocols.

4) Causticity. We compared the mean pH of water eluted from the five flooded scrubbers of each type in order to estimate the causticity of a contaminated solution that might be inhaled or ingested by the diver.

SAMPLE SIZE AND STATISTICAL ANALYSES

In accordance with testing protocols recommended by the Navy Experimental Diving Unit (NEDU)[8] we used a sample size of 5 for each scrubber type and exercise protocol. Therefore, in total twenty trials were conducted in no specific order; five ExtendAir® cartridges, and five Sofnolime® granule scrubber canisters in both exercise protocols.

Mean and standard deviation (SD) are provided for scrubber duration, ventilation pressures and pH. Independent samples *t*-tests, with α set at 5%, were used to compare the mean differences in scrubber duration, ventilation pressures and pH alongside 95% confidence intervals (CI).

Results

In the staged exercise protocol, cartridge and granular scrubbers exhibited equal duration (0% difference) at the P_ICO_2 endpoint of 1.0 kPa P_ICO_2. The gradient of breakthrough was steeper for cartridges compared to granular absorbent, as highlighted by the mean difference of 36 minutes (13%) at the P_ICO_2 endpoint of 0.5 kPa (Table 1 and Figure 4). Not surprisingly, the continuous exercise protocol resulted in much shorter breakthrough times compared to the staged exercise protocol. In this protocol the cartridges outperformed the granules by 14% (mean difference of 19 minutes) and 20% (mean difference of 24 minutes) at the P_ICO_2 endpoints of 1.0 kPa and 0.5 kPa, respectively (Table 1 and Figure 4).

The between-trial variability in scrubber duration was similar for both types of scrubbers in all conditions (Table 1), with granular scrubbers exhibiting slightly more variability than cartridges in every condition. The absolute deviation for both scrubber types was low, being always less than 6 % of total duration.

There was no difference between the cartridge and granular scrubbers in mean peak-to-nadir expiratory/inspiratory pressure difference measured at the mouthpiece in either the 6 MET or 6 then 2 MET simulated exercise conditions (Table 1).

After flooding both scrubbers for 5 minutes, the eluted water became extremely alkaline; slightly more so for the cartridge (ExtendAir® cartridge pH = 12.85 (SD 0.04) vs. pH = 12.66 (0.12) for the Sofnolime® granules, Table 1).

Discussion

This comparison of a cartridge and a granular scrubber of identical volume and similar mass in the O_2ptima closed-circuit rebreather revealed few practically important differences.

DURATION

Scrubber duration is similar between the two types, though there are differences depending on the exercise protocol and chosen endpoint.

We tested two exercise protocols; a staged exercise protocol and a continuous exercise protocol. Because of the reduced exercise intensity (with proportionally decreased CO_2

addition and minute volumes), endurance time (for either scrubber type) was more than twice as long in the staged compared to the continuous exercise protocol. Although continuous moderate exercise is commonly simulated in endurance testing, staged exercise arguably has a higher relevance to actual diving, with a higher intensity for 90 minutes simulating the descent and bottom phase, followed by a lower intensity period simulating the decompression phase.

The European standard EN 14143 for rebreather testing,[9] recommends that manufactures should report their CO_2 scrubber endurance time at the lower breakthrough threshold of 0.5 kPa. We report both 0.5 kPa and 1.0 kPa but chose 1.0 kPa as our primary breakthrough endpoint as this level of inspired CO_2 is an indisputable physiological hazard.

During the staged exercise protocol both scrubber types had virtually identical CO_2 breakthrough duration at the 1.0 kPa endpoint. The striking difference was that breakthrough in the granular scrubbers was more gradual (Figure 4) meaning that the P_ICO_2 for Sofnolime® reached the 0.5 kPa secondary breakthrough endpoint on average 36 minutes earlier than the ExtendAir® cartridges (Table 1). It is possible to speculate that either pattern of breakthrough is an advantage or disadvantage. For example, if a diver is symptomatically sensitive to an increase in CO_2, the more gradual breakthrough in the granular scrubber could provide an earlier warning signal. However, it has been shown that divers are particularly bad in detecting high CO_2 levels, and can retain CO_2, sometimes even without obvious symptoms or major adjustments in ventilation.[10] On that basis, the longer period with lower inspired CO_2 (and less danger of CO_2 retention) associated with the ExtendAir® cartridge could therefore be considered advantageous. During the continuous exercise protocol both canisters exhibited a similar exponentially increasing pattern of CO_2 accumulation (Figure 4), and the ExtendAir® canister exhibited a longer duration to breakthrough using either endpoint criteria (Table 1). However, longer durations for cartridges in our study (24 minutes for 0.5 kPa breakthrough and 19 minutes for 1.0 kPa breakthrough) were considerably less than the claimed doubling of duration published in the ExtendAir® cartridge manufacturer's promotional material,[2] despite the fact that the comparison was made with a granular canister of equal volume and almost identical weight.

In the latter regard, the ExtendAir® scrubbers were slightly heavier (3%) than those packed with granular scrubber material. In theory more scrubber material could account for higher endurance times. However, the ExtendAir® canister also included structural plastic material that does not contribute to the chemical reaction which suggests that it is more efficient. This higher efficiency could be explained by a different amount of catalyst in the ExtendAir® canister (5%) versus the granular soda lime (< 4%) and/or the type of catalyst (respectively, KOH + NaOH versus only NaOH). The cartridge also potentially has a higher amount of active absorbent $Ca(OH)_2$, although the datasheets of both scrubbers are ambiguous on the exact amount in both (respectively, > 85% and > 75%). One related point which is obvious but needs to be made, is that the present comparison was made between cartridge and granular absorbents of near identical volume and weight in a rebreather canister designed to take both types. This seemed a pragmatic and ecologically valid approach to the comparison. However, most rebreathers utilising granular soda lime incorporate canisters of greater volume which contain a greater mass of soda lime. These higher capacity systems will last longer. For example, in a recent study in which a different rebreather with a scrubber canister containing 2.64 kg of soda lime (Sofnolime® 797) was operated in the identical continuous exercise protocol as used in the present study, the mean duration to breakthrough at P_ICO_2 of 1.0 kPa was 202 min.[7] There is no equivalent option of increasing the size of ExtendAir® cartridges.

VARIABILITY IN DURATION

Both canister types exhibited similar between-trial variation in breakthrough endpoint (less than 6% in either exercise protocol). This casts some doubt on the ExtendAir® cartridge manufacturer's marketing claim that granular scrubbers have a much higher variability. Also, we must acknowledge that our test granular canisters were packed by an experienced operator using precisely weighed masses of soda lime, and thus with a superior degree of consistency that is unlikely to be replicated in the real world. To properly pack a granular scrubber, some training and practice is necessary, whereas ExtendAir® canisters require no packing prior to assembly. The evidential basis for the claim that granular canisters exhibit much greater variability in duration is not specified,[2] but the possibility that variability is greater during real world use than found in the present study cannot be excluded.

CIRCUIT PRESSURES

Though an imperfect surrogate, the peak-to-nadir expiratory/inspiratory pressure difference in the loop can be regarded as an index of breathing performance. The present tests demonstrated no difference between the two scrubber types tested. However, as with the variability in duration, this result must also be interpreted with some caution. The experiments were conducted at atmospheric pressure, and we cannot exclude the possibility that a relevant advantage or disadvantage for the ExtendAir® cartridges might become apparent when they are operated at greater depth and gas densities.

CAUSTICITY

After a five minute flood, both scrubber canisters eluted water with a pH of almost 13 that would be extremely caustic and result in serious injuries if inhaled or ingested. This result appears to contrast with the manufacturer's claim that the ExtendAir® cartridge would be 70% less caustic than granular absorbent.

We did not evaluate the possibility of caustic inhalation of soda lime dust during the packing phase of a granular scrubber canister. The manufacturers of Sofnolime® expect that the risk of caustic powder inhalation is negligible since the caustic chemicals are contained in a pellet.[6] In contrast to inhalations of caustic water during use of a rebreather, the authors are unaware of clinically significant inhalations of dust during granular scrubber canister packing, so it is probably an extremely rare event. Nevertheless, it is acknowledged that the lack of a requirement to pack loose material containing fine particles is a theoretical advantage of the ExtendAir® cartridge.

LIMITATIONS

This study has some limitations that must be acknowledged.

First, the scrubber canisters were operated at surface pressure and in temperate water. Operation of scrubbers at greater pressures (and with denser gases) and at lower temperatures is known to affect duration (typically adversely). It must therefore be explicitly understood that the purpose of the study was not to define expected durations, but rather to compare two different scrubber types under a set of standardised conditions. These data cannot be used to formulate usage guidelines for either of the scrubber materials tested. Similarly, other granular products (8–12 mesh) may be used in this rebreather and produce differing outcomes.

Second, and in a related vein, these experiments were undertaken in a narrow range of pressure, temperature, and simulated exercise conditions that are limited compared to the myriad of possible combinations encountered in diving. Our experiments examined scrubber endurance under sub-maximal exercise conditions and did not include a maximal capacity breakthrough challenge, such as introducing 3 $L \cdot min^{-1}$ CO_2 with ventilation set to 75 $L \cdot min^{-1}$ at 6 MFW, as required for European Standard EN 14143.[9] Extrapolation of the comparisons to scenarios with other combinations of these variables must therefore be made with caution. Nevertheless, with the possible exception of the effects of gas density on work of breathing (acknowledged earlier), there is no obvious reason to believe that varying conditions would preferentially advantage or disadvantage one scrubber type over another.

A strength of the bench test design was a rigorously standardised comparison. The use of a rebreather canister explicitly designed to accept either type of scrubber resulted in a comparison that seemed equitable.

Conclusions

In a comparison of CO_2 absorbent cartridges and granular soda lime canisters occupying identical volumes and of comparable mass, no evidence was found to support claims that the cartridge scrubber (ExtendAir®) would exhibit double the duration, less variability in duration, lower work of breathing, or produce a less caustic solution when flooded, than a granular product (Sofnolime®). During submaximal testing, both types of CO_2 scrubbers operated effectively in a closed-circuit rebreather and the preferred scrubber material may depend on other factors such as availability, costs and preference of the diver.

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Case reports

Fatal air embolism in a breath-hold diver

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Key words
Diving deaths; Barotrauma; Breath-hold diving; Scuba; Cerebral arterial gas embolism (CAGE); Pulmonary barotrauma; Case reports

Abstract

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Cerebral arterial gas embolism (CAGE) from breath-holding or inadequate exhalation during ascent is a well-recognised complication of scuba diving. It does not usually occur with breath-hold (BH) diving in those with normal lungs, as the volume of gas in the lungs on surfacing cannot exceed what it was on leaving the surface. However, a BH diver who breathes from a compressed gas supply at depth essentially becomes a scuba diver and is at risk of pulmonary barotrauma (PBt) and CAGE on ascent. In this case, a 26-year-old male experienced BH diver breathed from a scuba set at approximately 10 metres' sea water depth and ascended, sustaining massive PBt and CAGE with a fatal outcome. BH and scuba divers, especially those with less experience, need to be well-informed about this potential risk.

Introduction

Breath-hold (BH) diving has increased in popularity over the past decade, with some participants being certified scuba divers and others not. Scuba training includes an explanation and reinforcement of the effect of Boyle's Law in the context of scuba diving. A scuba regulator delivers breathing gas to the diver at ambient pressure and, unless vented sufficiently during ascent, gas inspired at depth will expand and can over-distend the lungs. This can cause pulmonary barotrauma (PBt) which may lead to cerebral arterial gas embolism (CAGE) as a result of gas passing from ruptured alveoli into the pulmonary veins and distributing in the systemic circulation. CAGE can and has occurred from a depth as shallow as one metre.[1,2]

Similarly, BH divers who breathe from a scuba diver's breathing gas supply at depth are at risk of PBt and CAGE unless sufficient gas is exhaled during their ascent. For the unaware and untrained, this practice can be precarious.

There appear to be few published cases of PBt and/or CAGE in BH divers who have breathed from a scuba supply so the frequency of it occurring is unknown.[3,4] A recent report did describe PBt and CAGE in an unconscious BH diver who was rescued from 24 metres' sea water (msw) and sustained arterial gas embolism when given ventilations via air purged from a rescuer's alternate air supply during ascent.[5]

Case report

A physically fit 26 year-old experienced BH diver was 'free diving' with a buddy who was diving with scuba in sheltered waters at a popular shore dive site. While the buddy was at a depth of approximately 10 msw, the victim dived down and breathed from the scuba regulator before ascending. He became unconscious upon reaching the surface and was noted by the buddy to have blood coming from his mouth. Resuscitation at the scene and subsequently in a nearby hospital was unsuccessful.

A CT scan performed immediately post cessation of resuscitation attempts showed evidence of massive pulmonary barotrauma, with bilateral pneumothoraces, pneumopericardium, pneumomediastinum, subcutaneous emphysema and intravascular gas in the brain (CAGE), liver, spleen and kidneys. Extensive alveolar-interstitial pulmonary opacification was also evident, radiating from central to peripherally along the broncho-vascular structures likely as a result of aspiration of seawater but possibly also from pulmonary haemorrhage (Figures 1,2).

Discussion

Pulmonary barotrauma with subsequent CAGE is a well-recognised complication of compressed gas diving and of submarine escape training.[6] It does not occur in recreational BH divers with normal lungs unless the diver has breathed compressed gas from a scuba regulator as in this case, or

Figure 1
Coronal chest CT scan image performed immediately after cessation of resuscitation attempts showing evidence of massive barotrauma, with bilateral pneumothoraces, pneumopericardium, pneumomediastinum, subcutaneous emphysema and intravascular gas in the liver. Extensive alveolar-interstitial pulmonary opacification is also evident, likely as a result of aspiration of seawater but possibly also from pulmonary haemorrhage. An endo-tracheal tube is in situ

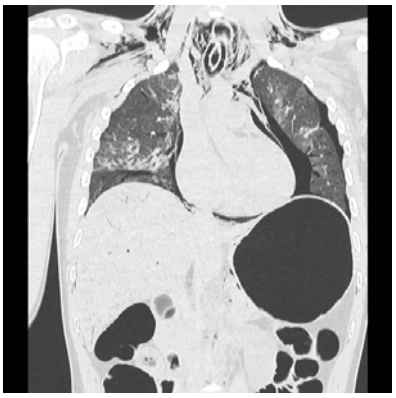
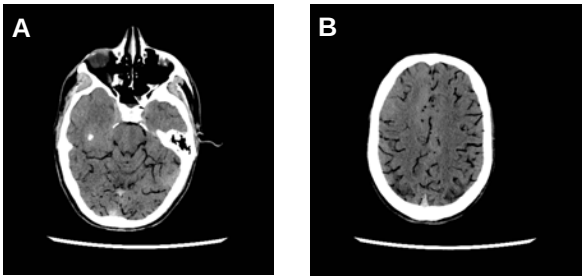


Figure 2
Axial brain CT images showing extensive intracerebral intravascular gas (CAGE)



from a compressed air-pocket underwater, such as in a wreck or cave. During escape training, submariners enter the water column at a given depth via an air lock and free ascend to the surface, usually in a specially-designed submarine escape immersion suit.[7] In Australia, this typically occurs from depths of nine and 20 msw, but such free ascent training has recently been discontinued. CAGE as a complication of submarine escape training has been reported in 0.01–1.9% of practice ascents,[6] which mandated the presence of an operational recompression chamber adjacent to the tower.

Breathing from scuba at 10 msw, the BH diver in this case would have inhaled air at a pressure of two atmospheres absolute. Unless some of this air was exhaled during ascent to the surface, the combination of increasing lung gas volume and rising transmural pressure would have combined to cause pulmonary tissue damage (barotrauma). It may have been that he held much of his breath during ascent, which would have been his usual and generally safe practice with normal BH diving. However, failure to adequately exhale during this ascent after breathing compressed air resulted in massive barotrauma.

During scuba diving training and certification, "*entry level divers are taught that the most important rule in scuba diving is to breathe normally at all times and never hold your breath*".[7] This rule applies especially during ascent. Some certification programs include training in an emergency ascent without an on-going breathing gas supply to specifically reduce the likelihood of breath-holding.[8] This needs to be strictly controlled to minimise the risk. However, the risk to a BH diver taking a breath from a regulator at depth may not be expressly taught in scuba courses. Likewise, although there are now specific BH diving courses, some of these may also not highlight the risk of taking a breath of compressed air at depth.

Conclusions

Breath-hold divers are at risk of PBt and CAGE should they take a breath of compressed air at depth during a dive. Education of both scuba divers and BH divers is needed to avoid similar cases occurring in the future.

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A case of Löfgren's syndrome confused with decompression sickness

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Key words
Hyperbaric oxygen; Differential diagnosis; Mycobacterium marinum infection; Pulmonary sarcoidosis

Abstract

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A broad differential diagnosis is important to provide appropriate care. This may be challenging for conditions like decompression sickness (DCS) which can be easily confused with other conditions. In suspected DCS, treatment may be an important part of the diagnosis. An improvement in symptoms after hyperbaric oxygen treatment (HBOT) is consistent with a DCS event. However, HBOT may also impact symptoms in other conditions, including Löfgren's syndrome (LS). LS, a poorly understood, clinically distinct phenotype of sarcoidosis, is a complex, multi-system granulomatous inflammatory condition. Like DCS, LS symptoms are heterogeneous and idiosyncratic. We report on a patient initially diagnosed with DCS who presented new symptoms suggestive of LS after HBOT.

Introduction

Decompression sickness (DCS) is a syndrome associated with a reduction in ambient pressure that produces a supersaturation of dissolved inert gas. Excessive supersaturation may provoke bubble formation and lead to DCS. While the mechanisms are not fully elucidated, hyperbaric oxygen therapy (HBOT) is established as the definitive treatment. HBOT promotes inert gas elimination, increases tissue PO_2, reduces inflammation, and promotes tissue healing.

Consideration of a broad differential diagnosis is important in determining appropriate treatment where DCS is suspected. Confirming DCS can be challenging due to idiosyncratic presentation and nonspecific manifestations. Clear understanding of patient history, signs and symptoms, and the level of decompression stress experienced are crucial in establishing the index of suspicion. Case management can be difficult when clinical suspicion is low.

Löfgren's syndrome (LS) is thought to be a clinically distinct phenotype of sarcoidosis; a complex, multi-system granulomatous inflammatory disease of unknown aetiology. Any organ may be affected, but most commonly the lungs.[1] LS may initially present with ambiguous constitutive symptoms and is often identified by acute presentation of the classic triad symptoms: bilateral arthritis/periarticular inflammation; erythema nodosum; and/or bilateral hilar lymphadenopathy. Diagnosis is one of exclusion since it is easily confused with other infectious diseases. While the diagnosis is typically established with complementary clinical, radiological, and histological findings, the classic presentation of LS may be sufficient to make a presumptive diagnosis based on clinical manifestations.[2]

The following case describes a diver initially treated for DCS but later diagnosed with LS and stage II pulmonary sarcoidosis following acute symptom presentation post-HBOT. Challenges in differential diagnosis, unique clinical presentation, and the potential impact of HBOT on LS are discussed.

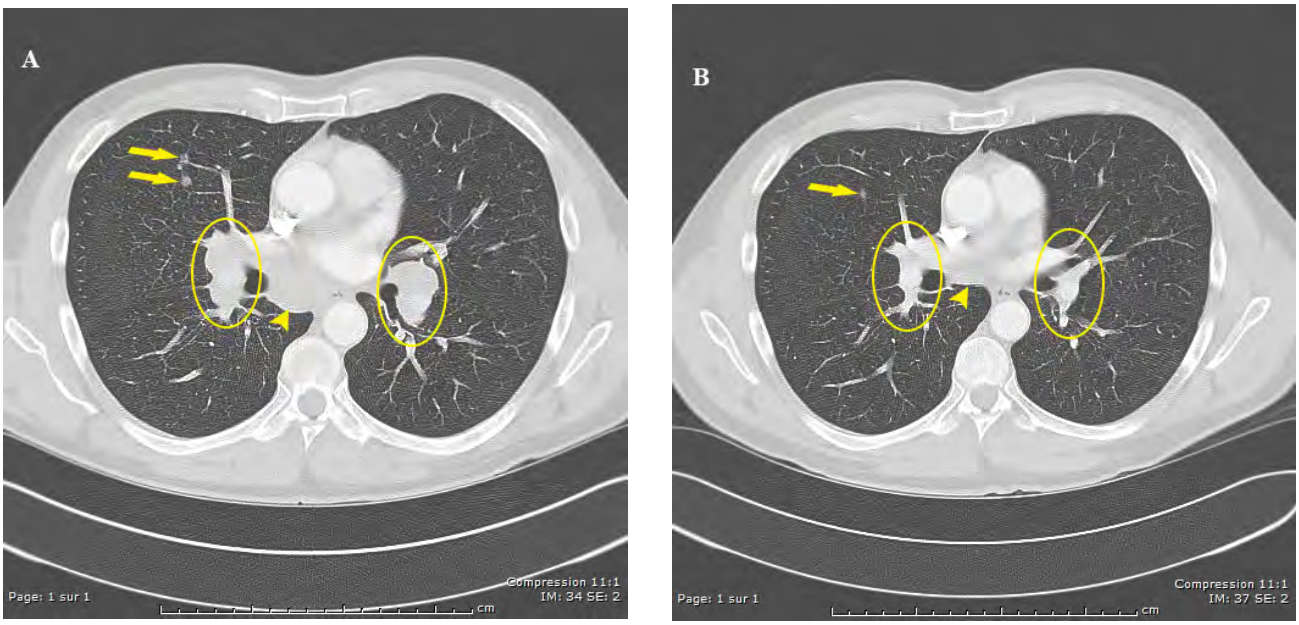
Case presentation

The patient was a 53 year-old male diver, a relatively healthy non-smoking teetotaller, with a history of performing approximately 200 working dives in a public aquarium annually, generally to a maximum depth around 6 metres' sea water (msw) for 1 h. Equipment and supplies at the surface necessitated that dives typically followed a saw-tooth profile, however, only entry and exit times were recorded. He had not exceeded a depth of 7 msw in the three weeks prior to this event.

He first reported feeling unusual, unwell, fatigued, and cold over a three-week period prior to medical consultation. Symptoms progressed to include periodic shivering and

Figure 1

Axial computerized tomography scans of the chest (mediastinal window). Image (a) taken 19 days post-HBOT shows two nodules visible in the pulmonary parenchyma of the left lobe (marked by arrows), enlarged mediastinal lymphadenopathy (marked by arrow head), and bilateral hilar lymphadenopathy (marked by ovals). Image (b) was taken five months post-HBOT and demonstrates the regression of pulmonary nodules, mediastinal lymphadenopathy, and bilateral hilar lymphadenopathy



diffuse muscle aches. Pain reportedly began in the shoulders and migrated to the heels and ankles in the two weeks pre-consultation. Approximately one-week pre-consultation he experienced intense and piercing bilateral ankle pain. He continued to dive throughout and reported that the pain was reduced or almost eliminated at depth but returned approximately 90 min after surfacing.

His last dive pre-consultation was performed two days earlier, to a maximum depth of 7 msw for 65 min. Symptoms returned approximately 4–5 h later; bilateral pain primarily in the heels and ankles, but also in the wrists, elbows, hips, and in the dorsal region of the back. Pain continued to intensify until the morning of consultation (7/10 maximum), expressed bilaterally with marked difficulty walking. The patient contacted the provincial diving emergency medical hotline and was advised to seek further evaluation. After an initial emergency room evaluation, the patient was directed to the on-call hyperbaric physician. No indications of diminished neurological function were found upon examination.

No supplemental oxygen was administered prior to HBOT. Physical exam found normal vital signs and the possibility of minor bilateral wrist swelling. DCS was suspected and an United States Navy HBOT Table 6 (USN TT6) recompression was performed.[3] After 10 min at maximal pressure (284 kPa, 2.8 atmospheres absolute), the patient reported relief of pain. Paraesthesia in the right heel was eliminated. All pain was resolved following the USN TT6. Diving was prohibited for two weeks and 500 mg naproxen BID prescribed.

Three hours following the USN TT6 the patient experienced feeling cold with marked continuous shaking for approximately 20 min. A self-measured oral temperature of 37.8°C was later reported. He fell asleep and awoke 2 h later feeling tired but otherwise stable. Three days post-HBOT he noticed painful bilateral nodules on the anterior ankle and shin. Blood work assayed eight days post-HBOT indicated signs of inflammation and/or infection (Table 1). Nine days post-HBOT he reported feeling less pain but had acquired a dry cough.

Medical follow-up 11 days post-HBOT uncovered signs of acute arthritis in the ankles and appearance of painful anterior ankle and shin nodules. Rheumatology evaluation the following day was unremarkable for neck, cardiopulmonary, and abdominal exams, with bilateral periarticular ankle inflammation and erythema nodosum in the crural region. A pre-recompression chest X-ray showed a 15 mm nodular opacity in the inferior lobe of the right lung. The rheumatologist suspected LS and prescribed 50 mg indomethacin to be taken every 8 h.

The patient was evaluated by a lung specialist 19 days post-HBOT. Findings included a SpO_2 of 94%, mild dry cough, but no lymphatic swelling, shortness of breath, or visual disturbances. Synovitis in ankles and erythema nodosum remained. Thoraco-abdominal CT scan showed multiple pulmonary nodules and mediastinal and bilateral hilar lymphadenopathy (Figure 1a). There was no abdominal lymphadenopathy. Spirometric and carbon monoxide diffusion capacity were above predicted values.[4] Inflammatory markers returned to the normal range four

Table 1

Blood work results post-HBOT. Normal ranges are presented in parentheses in column one.[19,20] High (H) and low (L) identify measures that are considered outside of the normal range. NA identifies factors that were not measured

Measure (normal values)	Result	
	8 d	26 d
Erythrocytes (4.18–5.62 $x10^{12}\cdot L^{-1}$)[19]	4.56	4.56
Hemoglobin (134–173 $g\cdot L^{-1}$)[19]	136	138
Hematocrit (0.39–0.50)[19]	0.400	0.401
Leukocytes (4.0–12.0 $x10^{9}\cdot L^{-1}$)[19]	9.2	7.4
Neutrophils absolute (4.3–7.5 $x10^{9}\cdot L^{-1}$)[19]	7.9 (H)	6.0
Lymphocytes absolute (1.6–4.4 x $10^{9}\cdot L^{-1}$)[19]	0.6 (L)	0.7 (L)
Monocytes absolute (0.4–1.0 $x10^{9}\cdot L^{-1}$)[19]	0.6	0.6
Eosinophils absolute (0.06–0.8 $x10^{9}\cdot L^{-1}$)[19]	0.1	0.2
Basophils absolute (0.0–2.7 $x10^{9}\cdot L^{-1}$)[19]	0.0	0.0
Erythrocyte sedimentation rate (1-10 $mm\cdot h^{-1}$)[20]	32 (H)	17 (H)
C-reactive protein (0.0–3.0 $mg\cdot L^{-1}$)[20]	69.1 (H)	10.6 (H)
Albumin (59.1–70.1 $g\cdot L^{-1}$)	60.7	NA
Alpha-1 globulins (1.6–3.2 $g\cdot L^{-1}$)	4.0 (H)	NA
Alpha-2 globulins (8.0–12.6 $g\cdot L^{-1}$)	10.8	NA
Calcium ($mmol\cdot L^{-1}$)	NA	2.3
RA test (fixation latex)	Negative	NA

weeks after HBOT (Table 1). An ophthalmologic exam was unremarkable.

Eight weeks following HBOT the patient reported no symptoms and a chest X-ray showed signs of nodule regression. He was cleared for and resumed diving. He had no symptoms at the five-month follow up and a CT scan showed regression of mediastinal and hilar lymphadenopathies and a 50% volume reduction in many pulmonary nodules (Figure 1b). He remained symptom free at one-year post-HBOT, with normal size mediastinal lymph nodes, and lung tissue with only three small nodules, all with diameters less than 5 mm.

Discussion

Delayed reporting of DCS symptoms is not unusual. There is also no diagnostic test to confirm DCS. The decision to treat with HBOT was possibly influenced by multiple factors: recent diving activity, presentation of symptoms consistent with DCS, lack of contraindications, and availability of HBOT. Nonspecific symptoms such as fatigue, malaise, and transient periarticular discomfort have been associated with DCS in approximately 40% of cases.[5] The pattern of symptom reduction during diving and return post-dive was consistent with DCS. There were, however, inconsistencies that make it unlikely that this was a DCS event.

Spinal cord DCS may present with bilateral motor deficits, and back pain, but it predominantly manifests immediately after surfacing and indicates severe DCS.[6] Patient and physician reports suggest that the difficulty walking was more likely due to intense pain and fatigue than neurological decrement. Additionally, the patient's dive profiles were not provocative. The USN no-decompression limit for 8 msw is 1,102 min[3], far greater than the patient's dive times, making DCS highly improbable.

Involvement of multiple joints bilaterally and migrating pain are also not common in DCS, although it is a notably unusual feature in LS. The 15 mm lung nodule documented pre-recompression by X-ray was characteristic of stage II sarcoidosis but its clinical relevance was not identified during the initial review. It was reported by the radiologist days after HBOT. Pulmonary nodules less than 30 mm are not uncommon and are typically benign,[7] thus not providing strong evidence for differential diagnosis. Skin lesion biopsies can help to verify LS,[8] but this patient did not initially present with erythema nodosum. The differential possibilities are broad and include infectious, toxic, and inflammatory agents. Acute presentation of the classic triad signs/symptoms after recompression and HBOT resulted in a new diagnosis of LS, stage II sarcoidosis.

The peak of immunological response in LS is often characterized by erythema nodosum at about three weeks after a precipitating stimulus (e.g., infection) and is associated with peak neutrophil counts.[9] Spontaneous recovery generally begins approximately six weeks after inoculation, with full recovery within two years. This typical disease course roughly paralleled the patient's experience in this case.

LS is associated with heightened abnormal immune responses to antigenic triggers in genetically susceptible individuals. While the cause was not confirmed in this case, mycobacterium, and particularly non-tuberculosis mycobacteria (NTM), has been associated with sarcoidosis.[10,11] NTM, such as *Mycobacterium marinum*, is found in both fresh and saltwater environments, and skin and pulmonary infections have been reported.[12] Human infection is possible with small cuts, abrasions, or following trauma. The site of infection is characteristically marked by a lesion. The risk of skin contact was possible in this case since the dive gear did not provide complete isolation. The patient also reported that *M. marinum* levels were higher than normal in the facility during the period when he became ill, although facility records were not made available.

No primary traumatic skin lesion was reported. However, aspiration of antigens has been suggested with pulmonary sarcoidosis-like infections. Certain occupations exposed to airborne antigens (e.g., healthcare and agriculture workers) are at increased risk.[13] It is possible that the lungs were the primary site of infection following aspiration of a waterborne bacterial antigen such as *M. marinum*. Potassium peroxymonosulfate (Virkon™ S), the disinfectant used to sterilize the diving equipment, may also have been a respiratory irritant. The impact of repeated exposure to Virkon™ S residue is unclear.

Limited information is available on the interaction between HBOT and LS. Pain attenuation following HBOT has been reported in chronic pain syndromes[14] and site specific oedema,[15] and may be associated with improvement in localized inflammation seen in conditions like rheumatoid arthritis.[16] Pain reduction in this patient may have been associated with attenuation of inflammation, localized oedema, and reduction in proinflammatory cytokines. Although pre-HBOT inflammatory measures were not collected, post-HBOT markers were elevated. While diving, pain relief may be associated with some combination of reduced joint load, compression from the diving wetsuit, increased hydrostatic pressure, and regional cooling.

HBOT for infections generally involves exposure to 243 kPa (2.4 atmospheres absolute) with the understanding that the increased PO_2 will lead to bactericidal effects.[17] HBOT reportedly promotes host defences such as improved bacterial targeting by leukocytes,[18] which were slightly elevated in this case post-HBOT (Table 1). It is possible that a combination of elevated oxygen partial pressure and high bacterial counts led to bacterial destruction and subsequent increased release of toxins into systemic circulation. This may have resulted in acute onset of constitutive and classic triad manifestations, and the report of marked shaking.

The case information had several limitations. Blood work was not performed prior to HBOT. Therefore, no measures were available for inflammatory or infectious factors pre-HBOT, making it difficult to evaluate the impact of LS versus the possible effects of HBOT. Biopsies were not conducted, making it impossible to confirm the diagnosis of LS or to establish the presence of specific infectious agents. Documentation of *M. marinum* levels were not available from the diving facility.

Conclusion

Both DCS and LS can present challenges for differential diagnosis. Careful consideration of the differential is critical in cases where presentation is atypical. The pulmonary nodule, along with ambiguous constitutive symptoms and the benign nature of the dive profiles, could raise the suspicion of sarcoidosis. It is reasonable to include sarcoidosis in the differential diagnosis of patients presenting with DCS-like symptoms.

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Letter to the Editor

Gas micronuclei that underlie decompression bubbles and decompression sickness have most probably been identified – in response to the Letter to the Editor from Dr David Doolette

In the March 2019 issue of *Diving and Hyperbaric Medicine*, Dr David Doolette expressed a degree of skepticism when he defined as speculation my assertion that nanobubbles formed on a hydrophobic surface are the source of decompression bubbles.[1] He catalogued my previously published paper,[2] which is based on a series of experimental studies, as a 'hypothesis article'.

There remains much that is uncertain about nanobubble physics, but central to our 'hypothesis' that pre-existing nanobubbles may be the precursors to decompression bubbles is the fact that nanobubbles are formed on many hydrophobic surfaces submerged in water from dissolved gas, and in some experiments where only aqueous solution was used, nanobubbles formed without supersaturation.[3]

Dr Doolette was deeply concerned about the Young-Laplace equation. A large number of studies published over the past two decades have shown that this equation and the subsequent exchange of gas is not applicable in the nano-world of bubbles. Nanobubbles (r = 50 nm) were injected into pure water and remained there for more than two weeks. The pressure within the nanobubble, twice that calculated from the surface tension, was ascribed to the strong hydrogen bond between the water molecules.[4] Numerous studies of hydrophobic surface nanobubbles have demonstrated their incompatibility with the Young-Laplace equation, inducing a similar number of attempts to explain this phenomenon. A recent study,[5] which noted that nanobubbles are stable and have low gas density, summarised the situation thus: "*We therefore suggest that current theories may lack the essential ingredient necessary for the formation and stabilization of the observed LCGM*" (layer of condensed gas molecules) from which nanobubbles bud.

The study[6] (also his reference 6), which Dr Doolette cites as a demonstration of nanobubble stability, to a great degree supports our suggested mechanism. In this study, 30 s of ultrasound irradiation resulted in the growth of surface nanobubbles. The authors related this to the well-known mechanism of rectified diffusion, where in one acoustic cycle the amount of gas that diffuses into the bubble (during the expansion phase) is greater than the amount that diffuses out (during the compression phase). This finding reinforces the notion that the nanobubbles expanded due to differences in gas tension and may thus also expand on decompression. In our experiments with silicon wafers,[2] degassing of the water ensured the elimination of any accidental gas micronuclei. Decompression bubbles then developed on hydrophobic but not hydrophilic wafers. The only reasonable explanation we could find was that surface nanobubbles were the precursors of these decompression bubbles. Dr Doolette expresses his disagreement with this, but fails to provide an alternative explanation.

The idea that surface nanobubbles develop on any other hydrophobic surface tested, but not on a hydrophobic surface within the body, is questionable. Because it is more than likely that our decompression bubbles had their origin in nanobubbles on the hydrophobic surface of the silicon wafers, it is likewise more than probable that the bubbles which developed at the active hydrophobic spots on the blood vessels of sheep originated in the same way. As far as we can interpret the wealth of experimental data, it is indeed a tenable proposition that decompression bubbles develop from pre-existing nanobubbles on hydrophobic surfaces within our body. Strong support for this hypothesis may be seen in the explanation it can provide for the numerous and varied features of decompression illness (timing, acclimation, risk on a second dive, endothelial injury, microparticles, taravana, local white matter lesions, spinal and vestibular DCS and joint pain, among others), as we found in our investigations of active hydrophobic spots summarised in the recent overview article.[2]

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Obituaries

Carl Wilfrid Edmonds OAM, LCDR RAN (Ret) MB, BS. MRCP (Lond), FRACP, Dip DHM, DPM, FRANZCP, MRCPsych, FAFOM

Carl Edmonds, diving medicine pioneer, Foundation President of the South Pacific Underwater Medicine Society (SPUMS) and first Editor of the *SPUMS Journal*, died on Friday 1 November 2019, aged 83 years. He passed away looking out across the vast Pacific Ocean; an ocean which embraced him during countless dives and an ocean that inspired him to contribute 50 years of dedicated service to diving medicine, safety and academia.

Carl was born in 1935 in Granville, Sydney. In the early years of WWII, while Carl was still a young boy, his father tragically died in a Lancaster accident during a mine laying mission in the North Sea. Carl was raised primarily by his grandparents and to make ends meet he had to work when not at school. He found work as a golf caddy, sold confectionery at the local Granville theatre and delivered milk. Later, in his teenage years, he found himself fighting fires as a forestry worker. After legacy assisted him with his high school education, he was awarded a Repatriation Department Scholarship to attend Sydney University. For the first couple of years, his attendance was dependent on the surf conditions; if there were no waves Carl would attend lectures. Sydney is renowned for great surf and subsequently Carl failed his second-year exams. The failure spurred him into action and, with renewed diligence during his clinical years, he gained no less than a distinction average thereafter.

Carl graduated with a Bachelor of Medicine and Bachelor of Surgery from the University of Sydney in 1960. While on a trip to Hawaii in 1962, uncharacteristically calm surf led him beneath the waves where he fell in love with the subaquatic world. He initially completed specialist training in psychiatry and worked in the UK and Australia, including a stint in northwest Western Australia (WA) where he worked for the Royal Flying Doctors and saw his first marine animal injuries. It was on his ocean passage to WA that he met his wife, Cynthia, who played a huge role in his life and was by his side right up until his passing. Carl and Cynthia married at the Presbyterian Church in Perth WA. As quoted by his daughter Briony, in Carl's Eulogy, Carl's relationship with Cynthia was "*one extraordinary partnership, equal in humour, intelligence, and love of adventure*".

Carl returned to Sydney and was working in psychiatry when in 1967 he joined the Royal Australian Navy School of Underwater Medicine (RANSUM). The school was co-located with the diving school at *HMAS Rushcutter*. In 1968, shortly after Carl joined RANSUM, it was moved to *HMAS Penguin* on the foreshore of Middle Harbour where it currently stands.

Carl was recruited as a psychiatrist to conduct a study into the high failure rate of the navy's clearance diver trainees at the RAN Diving School. Carl set to work immediately conducting numerous psychiatric, physiological and medical tests on the young navy divers. The comprehensive study contributed to the completion of his thesis titled *The Diver*.

While conducting his studies of divers, Carl became intrigued by the high incidence of diving accidents on oxygen rebreathers. His ever-inquisitive mind prompted studies into the sets and the carbon dioxide scrubber canisters. This line of enquiry led him away from psychiatry and down the path of an emerging field in diving medicine that he soon found himself leading. Carl was promoted to the position of Officer-In-Charge (OIC) of the RANSUM in April 1967. He served in the role until December 1972 and then again from January 1974 to October 1975. Carl was the first OIC to pass the Clearance Divers' course. Despite initial reluctance to accept him, they finally warmed to his presence and submerged a couch off the wharf to allow him to continue consulting underwater.

During those years Carl led a tremendous amount of research that ultimately resulted in vastly improved safety in diving through the development of more reliable diving equipment and modified diving protocols. Whilst at RANSUM, Carl was also involved in establishing Australia's first 24-hour diving emergency telephone advice service. Over time, with persistent attention and political pressure from Carl and colleagues, it became the Diver Emergency Service in 1984. This was just one example of his strategic thinking in the field. Another was the establishment of the SPUMS Diploma in Diving and Hyperbaric Medicine, to fill a gap in post-graduate education. The diploma still thrives today. Carl was rightfully bestowed a foundation diploma at the time of its inception in 1974. It is readily recognised that Carl's advancement in the navy did not parallel his immense medical influence as a diving physician. It is documented that he had nil promotions, nil sea time achievements, and he averaged one official reprimand or court martial per year for nine years. He was known to attend parade wearing full scuba gear including mask and fins and would walk around base in his swimmers.

In parallel with Carl's work at the School, he co-founded the Diving Medical Centre in Mosman, Sydney in 1971. They conducted as many as 60 consultations and medicals per week for both recreational and professional divers, as

well as contributing to research and education. The centre continued to operate for 30 years, closing in 2001.

Carl had an incisive intellect and accrued an encyclopaedic knowledge of diving medicine. He was a passionate educator and lectured on diving medicine topics extensively. Frequently this occurred near the waterfront at *HMAS Penguin*. On more than one occasion he rode his windsurfer from his home across Middle Harbour, arriving in his speedos and without notes, just in time to draw some overalls from the clothing store, then proceed to inspire some budding young diving medical officers!

Carl and Cynthia were keen travellers and they naturally combined his diving medicine work with travel to exotic locations. He participated in an early diving expedition to the Antarctic and served as the Diving Medical Officer on an archeological expedition to dive the *HMS Pandora* wreck. The expedition leader told Carl that the wreck could not be the Pandora if they discovered an item on the wreck that post-dated her sinking. A couple of days later, a sand encrusted 5 cent coin was found on the wreck. The sand was attached with epoxy glue and Carl confessed to planting it, possibly after a threat of loss of bar privileges. In typical fashion, Carl described his role on the Pandora expedition as "*more as a mascot than a medic*".

Marine biology was another of Carl's passions and as divers frequently encountered marine fauna this offered him another avenue of research. Ethics approvals, being what they were at the time, meant Carl first carried out the applicable test on himself, followed by medical officers, then the scientific officer (John Pennefather) and anyone else in the office at the time. If all went well, the study was rolled out to the divers. This ethics approval process applied for most studies, even the dreaded blue bottle sting trials.

During diver training at the school one day, a diver presented with a suspected fish spine injury. Seeking advice, Carl rang the 'poisons information line' and the operator, unaware of the caller's identity, suggested he contact the expert in the field, one Dr Edmonds at the School of Underwater Medicine! It was at that point that Carl realised there was a need for a manual on the topic. He published *Dangerous Marine Animals of the Indo-Pacific* in 1975. Despite Carl wanting the cover of the book to display a venomous marine creature, his publisher had envisaged an eye-catching shark image. On what was probably a rare occasion, Carl succumbed but had the last laugh in using a photograph of a recently deceased, docile grey nurse shark to adorn the book's cover.

A continuing area of research at the school was aural barotrauma and Carl expanded this work, encouraging Frank Blackwood to become skilled in audiometry and electronystagmography. He also worked closely with ENT surgeon, John Tonkin, to whom he referred a diver with a suspected round window fistula for operative repair. This is likely to have been the first case of round window repair in a diver. Carl, with Peter Freeman, Bob Thomas, John Tonkin and Frank Blackwood later collaborated to publish *Otological Aspects of Diving* in 1973.

Carl's output of publications during his working life was prodigious. He was author or co-author of many other aquatic/diving medical books and book chapters, including *Marine Animal Injuries to Man* (1984), *The Abalone Diver* (1987), *Dangerous Marine Creatures* (1989), and *Diving Medicine for Scuba Divers* (1992). Many of the classic diving medicine textbooks from the USA contain contributions from Carl Edmonds. Carl's research papers covered many aspects of diving medicine and are too numerous to list. Topics ranged across virtually all aspects of diving medicine including fitness to dive, pearl diving, abalone diving, scuba kids, drowning, diving deaths, oxygen and recompression treatment, the science of diving medicine, long term sequelae of diving, and diving equipment. This brief list is by no means exhaustive; Carl's CV included so many papers that it was necessary to classify them by topic!

Carl's iconic *Diving and Subaquatic Medicine* co-authored with Christopher Lowry and John Pennefather was self-published in 1976; self-publication being necessary because medical editors did not see a market for the book. How wrong they were! Now in its 5th edition, (2016), this authoritative reference "AKA *the bible*" is used by diving physicians all over the world. Carl's publications and teaching have influenced all contemporary generations of diving physicians, and he is truly regarded as a founding father of marine medicine.

As a humorist, Carl's textbooks possess an easy readability and a casual style. They are characteristically peppered with Bart McKenzie's cartoons of divers in precarious situations and contained numerous anecdotes to support the science. In classic Carl form the first few editions of *Diving and Subaquatic Medicine* were dedicated to his beagle, named Pluto, who witnessed the arguments in drafting the first two editions, and reportedly settled a few disagreements.

Carl, in collaboration with Bob Thomas and Bart McKenzie, published a subsequent book titled, *Diving Medicine for SCUBA Divers,* to ensure that the educational aspects of *Diving and Subaquatic Medicine* became accessible to a wider audience. In recent years, a revised online edition with John Pennefather as an additional author has been made available for free download.

Many diving doctors, who had the great fortune of listening to Carl lecture, will recall his focus on the dangers of hyperventilation prior to breath-hold diving, particularly children competing in home swimming pools. His close attention to this topic followed a promise he made to the father of a young boy who died in such a circumstance.

Carl was always prepared to do battle for justice and safety.

He appeared in court for a diver (or the diver's surviving relatives) in numerous cases including a notable murder case where Carl and associates fought and succeeded in reversing a conviction. His extensive knowledge and quick wit led one lawyer to comment that he thought Carl was the first witness he had called who actually enjoyed the legal contest. In that particular case, Carl anticipated the likely questions, collected some unpublished data and demolished the opposition's argument. Carl's drive for justice combined with his strategic approach resulted in a diver's widow being awarded considerable compensation.

An obituary about Carl Edmonds is incomplete without describing his founding role in establishing the SPUMS, and the Society's Journal (now *Diving and Hyperbaric Medicine*). During his tenure at the RANSUM, informal discussions between Carl and his colleagues led to the creation of a medical society with a focus on matters significant to professional and recreational divers. They opted to be both flippant and accurate and called it the South Pacific Underwater Medicine Society – SPUMS. SPUMS was founded in the wardroom of HMAS Penguin on Monday, 03 May 1971. Carl was elected as Founding President of SPUMS and held the position until 1976. The first SPUMS "*newsletter*" was produced by Carl as Editor in May 1972; a hand-typed, 18-page document.

His first editorial recorded; "*A small group of people interested in diving medicine and physiology met at HMAS Penguin on 3rd May 1971. The intention was to form a small but select society of medical and paramedical workers currently involved in this field. We assumed that there would be less than 30 people or so involved. Prior to the meeting we envisaged an annual or bi-annual meeting, often having social as well as academic interests at heart, conducted in an informal manner.*"

The newsletter recorded minutes of the meeting which was the birth of SPUMS, several presentations on diving medicine and strategic planning – to document the recompression facilities in Australia. The newsletter also concluded with a membership drive: *"Do you know of any doctors interested in underwater physiology or diving? If so, perhaps you could pass on this newsletter. Even an inveterate gossip like the editor cannot know everyone who dips his stethoscope in the briney."*

Later that year, Carl heralded the first Annual Scientific Meeting to be held in 1972, "*on the second Monday of June, for a period of five days.*" The theme for the meeting was "*Diving Safety – What Not to Do!*". Carl's 'newsletter' evolved into the highly respected and leading scientific journal, *Diving and Hyperbaric Medicine*. Indeed, all divers today benefit from Carl's tireless dedication to improving the safety of the sport and occupation that he so loved.

During his life, Carl accumulated an extensive library of diving medical and marine texts. In keeping with his highly organised mind, the library was sorted and catalogued in great detail. In June 2014, Carl arranged for his whole library to be transported to the Royal Hobart Hospital (RHH) hyperbaric facility as its future home. His generous donation also included construction of three beautiful Tasmanian blackwood cabinets to house the library. The library is now located in the new RHH hyperbaric facility and accessible for future generations. Many of the texts and monographs are unprocurable, even in this electronic age. RHH staff are truly honoured to be the future custodians of Carl's reference collection.

Carl Edmond's contributions to the field of diving medicine were recognised by SPUMS in 1989 when he was awarded life membership. He has had numerous other awards during his career. These include the UHMS Craig Hoffman Memorial award for services to diver safety, Diver's Alert Network (SE Asia Pacific) award for medical advisory services to the diving industry, the UHMS Charles W Schilling award, the DAN America award, and an ANZCA Citation for contribution to diving and hyperbaric medicine. In 2008, Carl was honoured with the Order of Australia Medal in recognition of his service to diving and hyperbaric medicine as a practitioner, researcher, educator, and to the advancement of diving safety.

Carl's most recent research focus was scuba divers' pulmonary oedema and he continued to work on several papers right to his death. SPUMS offers our deepest condolences to his wife Cynthia, his children Scott, Kirsten, Mark, Briony, and five granddaughters. We share your loss. Carl's life, ideas, literary papers, and books will continue to inspire, challenge and guide divers and diving doctors for many more generations to come. Carl will be sadly missed, but his influence lives on.

Carl's death notice quoted McGovern's poem, "*The Old Salt*", which is a fitting tribute to such a great man:

What greater honour, when a man moves forward,
he leaves behind in each of us
the best of what he was.

A defender, protector, supporter, victor, a warrior,
the last of the breed from an era
when ships were made of wood
and men were made of steel.

Joel Hissink, SPUMS Webmaster, formerly Officer-in-Charge SUMU, HMAS Penguin

David Smart, SPUMS President

Douglas Falconer, SPUMS Secretary, Senior Medical Advisor Diving Medicine, SUMU, HMAS Penguin

John Pennefather, formerly SUMU Scientific Officer, HMAS Penguin

Robert 'Bob' Crighton Ramsay

Bob Ramsay passed away in September 2019, following a gallant battle with illness. I was privileged and moved to be part of the August 2019 HTNA Conference audience when Bob gave his final presentation. Bob began diving in the 1960's and became a commercial diver in 1971. With skills as a welder/fitter, he commenced saturation diving in the North Sea between 1972–76. During this time, Bob undertook some very deep dives (180m), and witnessed multiple other diving colleagues die during their diving activities.

Bob moved to Australia in 1978 and his involvement with hyperbaric facilities in Australia began when he project-managed the installation of South Australia's first recompression facility in 1980. Five years later, the Royal Adelaide Hospital (RAH) took over the role of state referral centre. In 1989, Bob was approached to work as a senior technical officer at that facility. He worked at the RAH Hyperbaric facility for 10 years. Bob played a significant role as committee chairman in drafting the Hyperbaric Oxygen Therapy Facility Industry Guidelines (HOTFIG). These guidelines were the precursor to the modern-day AS/NZ 4774.2 Standard that guides everyday clinical practice in diving and hyperbaric medicine. Bob was a founding member of the Hyperbaric Technicians and Nurses Association (HTNA), the Asian Hyperbaric and Diving Medical Association, and a founding board member of Divers Alert Network (DAN) South East Asia Pacific (SEAP).

Bob moved from occupational to recreational diving in the 1980's working as an open-water dive instructor and running a dive store. His interest in instruction and diver safety brought him in contact with John Lippmann, and he provided great support when John established DAN-SEAP. Bob also provided consultancy services for hyperbaric facilities around the Asia-Pacific region. He was the founding president of the Historical Diving Society South East Asia Pacific. A premier role in that regard was his consultancy work to assist the Deep-Sea Challenger project in 2011–12.

Bob worked for Hyperbaric Health as International Operations Manager and Safety Director for over a decade. His influence on the operation of regional hyperbaric facilities was extensive and he had a deep understanding of the issues affecting indigenous divers in the Pacific. Bob contributed to multiple HTNA conference attendances over nearly three decades (including the most recent 2019 conference), presenting many scientific papers on the topics of equipment, safety, oxygen therapy and hyperbaric safety. Bob also instigated the *Bob Ramsay Award* at HTNA meetings, for HTNA members who have outstanding achievements in the field of diving or hyperbaric medicine.

Bob has received several awards during his career. These include The Diving Industry of Australia Scuba Excellence Award 1996, the ER Cross Award from the Historical Diving Society USA in 2000, the DAN-SEAP Diving Safety Award 1999, and he was elected as a life member of DAN-SEAP. Bob has always been a modest collector of diving memorabilia and books. His interests in remote underwater sensing with side-scanning sonars and magnetometers has also led to his involvement in searching for, or documenting several shipwrecks in South Australia, Northern Territory and Tasmania.

Bob's deep commitment to hyperbaric chamber safety will always be remembered. His lasting contribution in the genesis of AS/NZS 4774.2 and hyperbaric facility governance continues to influence hyperbaric practice. SPUMS offers our deepest condolences and warm regards to Elizabeth, Andrew and family on Bob's passing.

David Smart, Hon President SPUMS

Fiona Catherine Sharp MBBS, DA(UK), FANZCA

Fiona Catherine Sharp died while diving using a rebreather on 17 October this year, aged 55. The incident occurred on the last day of Fiona's diving trip to Bonaire, located in the Leeward Antilles, Caribbean Sea. Her premature death has precipitated a considerable outpouring of sadness among diving and medical communities.

Fiona attended high school at Mercedes College in Perth, Western Australia where she was college dux. She studied medicine at the University of Western Australia, graduating in 1989 with her basic MBBS degree. Following her intern year at Sir Charles Gairdner Hospital, Fiona spent time travelling in her early resident years to New South Wales and the UK, at the Southend General Hospital Essex. During this time her interest in anaesthesia was sparked. She undertook her Diploma of Anaesthesia in the UK in 1992. Returning to her home state in 1993, Fiona joined the anaesthesia training programme, rotating around most of the Perth metropolitan hospitals during her registrar years 1993–1999. Fiona spent further time in the UK, as a locum consultant in anaesthesia from 1999 to 2005. She was awarded her FANZCA in 2004. Her time in the UK allowed her to accumulate experience as a diving medical examiner, and as a hyperbaric and diving physician with the Diving Diseases Research Centre (DDRC), Plymouth UK. Fiona returned to Australia as a specialist anaesthetist at Joondalup Health Campus in 2005, before being appointed later that year to Fremantle Hospital, and to Fiona Stanley Hospital in 2014. Fiona was a highly respected authority in diving medicine having practiced for more than 20 years in the area.

Fiona was an enthusiastic participant in many hyperbaric and diving medicine courses and conferences, commencing in the 1990's, initially as a delegate, and later as a teacher. Her first SPUMS conference was in Layang Layang Malaysia (1999), and she attended her first EUBS conference the following year in Malta. Fiona has not missed a SPUMS conference since 2005. Fiona's energetic presence has also been felt at multiple EUBS, UHMS, BHA and ANZCA conferences. Fiona was a long time highly cherished member of the EUBS and was Member-at-Large for EUBS during 2011–2014 contributing to the society work and getting the EUBS on to Facebook. She attended many EUBS meetings over time and she will be highly missed by many members and colleagues especially within the diving medical field in Europe. In her role at Fiona Stanley Hospital, Fiona has been a regular teacher of diving and hyperbaric medicine to medical students, nurses, other doctors, dive groups and technical divers. Fiona always considered herself very lucky to have a medical career path that was so in harmony with her recreational interests. As an active scuba and rebreather diver, she logged thousands of hours underwater.

SPUMS conferences will not be the same without Fiona. She was a colourful character and contributed greatly to those meetings both with her ability to get straight to the point and her friendly determination to get everyone involved. Fiona was also a fierce supporter of the recent moves within ANZCA to establish the Diploma of Advanced DHM and successfully sat the examination for this qualification. She had undertaken a blinded research project investigating the ability of experienced divers to distinguish between an air dive and one using oxygen enriched air, but sadly, she never found the time to write up the project that would have completed her requirements for the Diploma. She was determined to see DHM more fully recognised as a serious clinical and academic pursuit and was a great advocate for the integration of both diving and hyperbaric medicine into the mainstream of specialist medical practice both here and across the world.

Fiona had a great love and enthusiasm for diving. She started diving in her late teens, and extended her scuba skillset to divemaster, cave diving then rebreather diving using multiple types of apparatus. Diving became her all-encompassing passion, which then merged with her medical career. Diving was to a large extent, Fiona's life. There has been a considerable outpouring of grief from her diving colleagues. Perhaps it is possible to take some comfort from this tragedy in saying that Fiona perished doing what she loved. Fiona was very proud of her family. Our thoughts go out to her family and loved ones and we join the global diving community in mourning her loss. We have lost a valued friend and colleague. She will be sadly missed.

David Smart, Hon President SPUMS

Ole Hyldegaard, Hon President EUBS

Neil Banham, Medical Director, Diving and Hyperbaric Medicine, Fiona Stanley Hospital Western Australia, SPUMS President Elect

Notices and news

SPUMS society information and news is to be found mainly on the society website: www.spums.org.au

SPUMS President's message

David Smart

SPUMS, ocean health and advocacy for the underwater environment

Since its formation in 1971, SPUMS has maintained a consistent set of fundamental purposes:

- To promote and facilitate the study of all aspects of underwater and hyperbaric medicine.
- To provide information on underwater and hyperbaric medicine.
- To promote communication between members of the association and to publish a journal for the association.
- To convene members of the association annually at a scientific conference and to hold meetings and other functions or activities to inform, and to develop fellowship and friendship amongst members of the association.

These purposes have served the organisation well and have provided stability for SPUMS to maintain its position as the leading organisation for underwater and hyperbaric medicine in the region. I have had the privilege of leading our organisation for the last five years and I am now in my final year as SPUMS President.

Diving doctors have a unique medical perspective. It permits us not only to be supporting the health of humans as they work underwater and enjoy the ocean for recreation, but many of us also can observe the health of the oceans first-hand when diving.

It is from that perspective that I have formed the opinion that SPUMS should broaden its purposes to advocate for ocean health. We should support and collaborate with our scientific colleagues and other marine advocacy groups to elevate climate change as the number one issue affecting the strategic directions of our countries' decisions, as a matter of urgency. In a nutshell, without healthy oceans, the field of diving medicine may become a historical relic. All of this may sound nihilistic, but the adverse effects of climate change are already happening in a huge way.

Australia's Great Barrier Reef (GBR) is in serious trouble. Climate driven coral bleaching is now occurring at very short intervals, preventing recovery between episodes. In surveyed GBR areas, less than 10% remain unaffected by coral bleaching, and there were back to back bleaching events in 2016-17.[1,2] This year, I witnessed the effects of a mass bleaching event in Liku Liku Bay, Waya Island in Fiji. In March, a prolonged elevation in ocean temperature (31°C) occurred for more than four weeks. The usual background ocean temperature is 27°C. What was once a pristine coastal reef, has now had 95% of the coral affected by bleaching.

Diving in my home state of Tasmania, Australia, I have observed substantial increases in ocean temperature off our east coast, over the last 35+ years. When my wife and I learned to dive in the 1980's in winter (June), water temperatures were 7–8°C. In our June dives for the last three years, water temperatures have been over 15°C. Summer temperatures last year peaked at 23°C in some bays. In the last 50 years, the average temperature of Tasmanian waters has increased by approximately 2°C. This has led to the introduction of over 100 new fish species and the proliferation of destructive invasive species, such as long spined sea urchins (*Centrostephanus rodgersii*) which have played a key role in the destruction of giant kelp forests. Over 95% of Tasmanian kelp forests have been lost in recent decades, and they are now listed as endangered.[3,4] Harmful ocean algal blooms which produce paralytic shellfish toxin (PST) are now an annual occurrence in Tasmania.[5] High levels of PST lead to fishery closures and pose a danger to human health if consumed in fish.[6]

The interdependencies between reefs and other marine species (including fisheries) are complex. Changes observed in one foundation species affect the whole ecological system. Tasmania has a high economic dependence on its marine environment with its fisheries representing 31% of the Australian gross fishery value in 2017 ($946m AUD).[7] As the marine environment rapidly changes, so will economic fortunes that are derived from such activities. The impacts of climate change are widespread; affecting marine, freshwater and terrestrial ecosystems on an unprecedented global scale.

SPUMS members who attended this years' ASM, noted the amount of plastic in the marine environment around Honiara. Unfortunately, plastic pollution at this scale is a common occurrence and is also a global issue for ocean health. Changes in the health of the ocean will impact on the health of humans. Advocating for the marine environment needs to occur through multiple channels to be effective. I hope that SPUMS members share my concerns for the future of our planet.

I firmly believe that SPUMS needs to take a stand on issues that affect ocean health and where necessary, join forces with other organisations and groups to lobby for a healthier

marine environment. Establishing a fundamental set of values for SPUMS which support the marine environment is an important first step. This sits naturally with SPUMS original purposes. I will be moving for SPUMS to add marine conservation and advocacy to our core values. We can use this as a platform for future ocean advocacy.

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Key words
Diving; Environment; Ecology; Health; Climate change

Clinical Professor David Smart
Hon President SPUMS

SPUMS Facebook page

Remember to like us at:
http://www.facebook.com/pages/SPUMS-South-Pacific-Underwater-Medicine-Society/221855494509119

The Australian and New Zealand Hyperbaric Medicine Group

Introductory Course in
Diving and Hyperbaric Medicine 2020

Dates: 24 February–06 March 2020
Venue: Hougoumont Hotel, Fremantle, Western Australia
Cost: AUD2,600 for two weeks

The course is for medical graduates with an interest in diving and hyperbaric medicine. It is designed both for those wishing to pursue a career in this specialised field and those whose primary interest lies in related areas. The course will be held in Fremantle with excursions to the Fiona Stanley Hyperbaric Medicine Unit, HMAS Stirling and the local Royal Flying Doctor base. The course is accredited with the South Pacific Underwater Medicine Society and ANZCA for the Diploma of Diving and Hyperbaric Medicine.

The course content includes:

- History of diving medicine and hyperbaric oxygen
- Physics and physiology of diving and compressed gases
- Presentation, diagnosis and management of diving injuries
- Assessment of fitness to dive
- Visit to RFDS base for flying and diving workshop
- Accepted indications for hyperbaric oxygen treatment
- Hyperbaric oxygen evidence-based medicine
- Wound management and transcutaneous oximetry
- In water rescue and management of a seriously ill diver
- Visit to HMAS Stirling
- Practical workshops
- Marine Envenomation

Contact for information:

Sue Conlon, Course Administrator
Phone: *+61-(0)8-6152-5222*
Fax: *+61-(0)8-6152-4943*
Email: *fsh.hyperbaric@health.wa.gov.au*

Accommodation information can be provided on request.

The SPUMS website is at
www.spums.org.au

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.

SPUMS 49th Annual Scientific Meeting

Diving Medical Support: Off the Beaten Track

19–24 April 2020

Venue: Oceans Resort, Tutukaka, New Zealand

The scientific programme for 2020 is coming together and looking good – '*Diving medical support: off the beaten track*', featuring Richard Harris and David Doolette as Keynote Speakers. Add to that some of the best subtropical diving on the planet at the Poor Knights Islands Marine Reserve and this is an event not to be missed!

Conference website for more information and registration is here: http://www.spums2020.nz

See you in Tutukaka in April 2020.

Keynote Speakers: Richard Harris, Adelaide, Australia, David Doolette, Panama City, Florida
Convenor: Greg van der Hulst
Scientific Convenors: Hanna van Waart and Xavier Vrijdag

Australian and New Zealand College of Anaesthetists Diving and Hyperbaric Medicine Special Interest Group

The new Diploma of Advanced Diving and Hyperbaric Medicine was launched on 31 July 2017. Those interested in training are directed to the ANZCA website http://www.anzca.edu.au/training/diving-and-hyperbaric-medicine.

Training
Documents to be found at this site are:

- Regulation 36, which provides for the conduct of training leading to the ANZCA Dip Adv DHM, and the continuing professional development requirements for diplomats and holders of the ANZCA Certificate of DHM;
- ANZCA Advanced DHM Curriculum which defines the required learning, teaching and assessment of the diploma training programme; and
- ANZCA Handbook for Advanced DHM Training which sets out in detail the requirements expected of trainees and accredited units for training.

Examination dates for 2020
Viva examination: TBC

Accreditation
The ANZCA Handbook for Advanced DHM accreditation, which provides information for units seeking accreditation, is awaiting approval by Standards Australia and cannot yet be accessed online. Currently six units are accredited for DHM training and these can be found on the College website.

Transition to new qualification
Transitional arrangements for holders of the ANZCA Certificate in Diving and Hyperbaric Medicine and highly experienced practitioners of DHM seeking recognition of prior experience lapsed on 31 January 2019.

All enquries should be submitted to dhm@anzca.edu.au.

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 www.spums.org.au or at 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: www.nhmrc.gov.au/_files_nhmrc/publications/attachments/r39.pdf, or the equivalent requirement of the country in which the research is conducted. All research involving humans, 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 January 2016, the SPUMS Academic Board consists of:

Dr David Wilkinson, Education Officer, Adelaide;
Professor Simon Mitchell, Auckand;
Dr Denise Blake, Townsville.

All enquiries and applications should be addressed to:
David Wilkinson
education@spums.org.au

Key words
Qualifications; Underwater medicine; Hyperbaric oxygen; Research; Medical society

Notices and news

EUBS notices and news and all other society information is now to be found mainly on the society's website: www.eubs.org

Membership News

It is with great sadness that the EUBS ExCom - and all her friends in our society – pay tribute to Dr Fiona Sharp, who died on 17 October during a rebreather dive off the coast of Bonaire, Dutch Caribbean. Fiona was our most faithful Australian member, and was Member-at-Large from 2011 to 2014; her joyful, witty, loud and crazy passionate personality were a constant at virtually all EUBS meetings. She was intelligent, honest and fun to be around. She had no pretense at all and was so easy to like.

For those of us who knew her – we will have similar, indelible but ultimately unique memories of Fiona. For those who never met her, her loss has caused a surge of remembrance on social media, so if you take some time to read the tributes, you should get a measure of the person she was, and how missed she will be.

Our meetings will have a Fiona-shaped hole in them in the future.

We also learnt recently of the death of Dr Vincent Hong, also during diving, on 27 September. Vincent was an anesthetist working at the Hull Hyperbaric Centre, and had become a member two years ago. Those who attended TRICON2018 in Durban will remember Vincent as the one who bravely confronted a black-tip shark during the baited shark dive, and who got himself discharged from hospital in time to tell us about his adventure in a plenary session.

EUBS ExCom extend their condolences to the family and friends of Fiona and Vincent.

EUBS 2019 Meeting

The 45th EUBS Annual Scientific Meeting – 'EUBS2019: Hyperbaric Medicine and the Brain' was attended by 345 registered participants from EUBS, SPUMS, SAUHMA and UHMS (and also 37 who are not a member of any of these Societies – yet), and 30 spouses. The scientific program, the diving workshops and the social events were greatly appreciated and EUBS would like to thank the Organising and Scientific Committee, the local Congress organisers Dr Yair Bechor, Mr Yonatan Zemel and Dr Zemer Wang, as well as the Secretary General, Dr Shai Efrati and the Scientific Committee, for a job well done.

EUBS Annual General Assembly

The EUBS GA was held in Tel Aviv, Israel, on Thursday 12 September 2019 from 08.30 to 09.30, prior to the last scientific session and the Closing Ceremony of the 45th EUBS Annual Scientific Meeting – EUBS2019. There were 78 EUBS members present. The GA presentation and financial information has been placed on the EUBS website, in the Members Area section.

EUBS Executive Committee

To replace Bengusu Mirasoglu after serving a three-year term, Gerardo (Dino) Bosco from Padova, Italy, has been elected as new Member-at-Large 2019. The Executive Committee wish to express their gratitude for Bengu's contributions to the ExCom activities. However, she will remain active in the ExCom, and will continue to develop EUBS's social media policy.

EUBS Social Media

Thanks to outgoing Member-at-Large Bengusu Mirasoglu, we now have, as well as our Facebook page, a Twitter and Instagram account!

While the 'EUBS website news' email messages will continue to be a way to communicate important information directly to our EUBS members, Twitter and Instagram will be used to keep non-members updated and interested in our Society.

Here are the links to bookmark and follow:
Facebook: https://www.facebook.com/European-Underwater-and-Baromedical-Society-283981285037017/
Twitter: @eubsofficial
Instagram: @eubsofficial

Announcement of EUBS 2020

In 2020, our EUBS Annual Scientific Meeting will be held in Prague, Czech Republic, from 16–20 September 2020.

Prague is a charming city with rich history, which has been a political, cultural and economic centre of

Central Europe. Due to its central location, Prague has direct air links with most European capitals and through Frankfurt, Germany, overseas flights to other continents can have a easy connection.

In 2020 it will be the 55th anniversary of the establishment of hyperbaric medicine in this country, and the first time the EUBS conference will be held in the Czech Republic and the second time in the countries of the former so-called Eastern Bloc. The conference will focus on the research, physiological and medical aspects of hyperbaric and diving medicine and evidence-based medicine. The local organizing team, headed by Dr Michal Hajek, are preparing an interesting and exciting social program.

You can find all information regarding this Conference on the website https://eubs2020.com, or by visiting the EUBS website.

Please bookmark the dates and register early, as favorable airfare and prices are dependent on early booking.

EUBS 2019 Annual Scientific Meeting Awards

At the EUBS Annual General Assembly on 29 September 2018, the Zetterström Committee, composed of Phil Bryson, Bengusu Mirasoglu and Costantino Balestra, awarded the Arne Zetterström Award for best poster presentation to:

HYPERBARIC OXYGEN THERAPY FOR THE TREATMENT OF PERIANAL FISTULAS IN CROHN'S DISEASE (HOT-TOPIC TRIAL): PRELIMINARY RESULTS

Nina Lansdorp, Krisztina B Gecse, Christianne J Buskens, Mark Löwenberg, Jaap Stoker, Willem A Bemelman, Geert RAM D'Haens, Rob A van Hulst

Arne Zetterström (1917–1945) is best known for his research with the breathing mixture hydrox for the Swedish Navy. Zetterström first described the use of hydrogen as a breathing gas in 1943. From 1943 to 1944, a total of six ocean dives were made utilising this mixture with the deepest to 160 meters (96% hydrogen and 4% oxygen). On 07 August 1945 Zetterström experienced technical problems diving from HSwMS Belos. His support divers misread his signals, and this was followed by a rapid ascent that resulted in severe decompression sickness and hypoxia, resulting in his untimely death.

The Patrick Musimu Award for best contribution, either oral or poster presentation, in the area of breathhold diving, was instituted in 2011 by the Belgian Society for Diving and Hyperbaric Medicine.

Patrick Musimu (1970–2011) was a Belgian freediver, sport business manager, marketing and event manager, and physiotherapist. He was born in Kinshasa, Zaire. On 30 June 2005, he beat the previous 'No Limits' world record in freediving by almost 40 meters by diving to 209 meters. Upon his request, this dive was done without the supervision of the International Association for Freediving agency, from which Musimu dissociated since 2002. According to him, extreme deep freediving should not be considered as a sport but as an adventure. Musimu began freediving in 1999 at the age of 28. His secret lay in years of training and preparation, but special attention should be given to his ear clearing technique: instead of equalizing his ears by the regular maneuvers, he flooded his air spaces (sinus and middle ears) with seawater before reaching the depth where ordinary equalization would become hard. On 21 July 2011 Musimu died while pool training alone in his home in Brussels, Belgium.

In Tel Aviv, the jury decided not to award this prize. It is felt that more research should be conducted in this field, and the jury, speaking for the Belgian Society for Diving and Hyperbaric Medicine, would like to encourage this further.

EUBS and ECHM (European Committee for Hyperbaric Medicine)

The scope and goals of the European Committee for Hyperbaric Medicine (ECHM) are defined as follows:

- Studying and defining common indications for hyperbaric therapy, research and therapy protocols, common standards for therapeutic and technical procedures, equipment and personnel, cost-benefit and cost-effectiveness criteria.
- Acting as a representative body with the European health authorities.
- Promoting further cooperation among existing scientific organizations involved in the field of Diving and Hyperbaric Medicine.

During the EUBS ExCom Meeting, an open discussion was started between EUBS and the European Committee for Hyperbaric Medicine (ECHM) (http://www.echm.org/) regarding a merging of the two entities. This is judged necessary in order to stimulate cooperation, avoid unnecessary redundancy, increase clarity of the system, extend the scope of the EUBS and ensure constant refreshment of the ECHM structures.

During the Executive Board (EB) and Board of Representatives (BR) meetings in Tel Aviv, the ECHM elected a new Executive Committee, now composed of Jacek Kot (President), Alessandro Marroni (Vice-President) and Willi Welslau (General Secretary).

A working group has been composed, in order to prepare a draft proposal for this merger. For ECHM, the members are Jacek Kot, Alessandro Marroni and Karin Hasmiller; for EUBS, Ole Hyldegaard, Peter Germonpré and Jacek Kot.

EUBS Website

Please visit the EUBS website for the latest news and updates. Specifically, an 'EUBS History' section has been added under the Menu item 'The Society'. There is still some information missing in the list of EUBS Meetings, Presidents and Members-at-Large, please dig into your memories and help us complete this list.

By popular demand, EUBS members can now also download the complete Abstract Book of previous EUBS Meetings since 2008 from the members area.

OXYNET Database to be updated

Since 2004, a public online database of European Hyperbaric Chambers and Centres has been available, started and initially maintained by the OXYNET Working Group of the COST B14 project of the European Commission, later by the European Committee for Hyperbaric Medicine (ECHM). The database can be accessed on http://www.echm.org/.

However, over the past few years, the list and contact information of the OXYNET database has not been maintained regularly, and EUBS ExCom has proposed to take over this task and not only update the information but also to modernize the database and its functionality.

In order to do this, we can use all the help we can get. Please visit the OXYNET and verify the information that is listed for your own hyperbaric centre. Then, rather than using the online form to correct the information, send an email to oxynet@eubs.org with the updated information. If you could collect information for more than one centre in your area or country, please do.

Once the OXYNET database has been relocated and restructured, a direct link will be placed also on the EUBS website, however, we will maintain the address http://www.echm.org/ as well.

Association Internationale des Centres Hyperbares Francophones (ICHF)

An initiative of EUBS members Rodrigue Pignel (Geneva, Switzerland) and Mathieu Coulange (Marseilles, France) with Thierry Joffre (Lyon, France), a two-monthly video conference meeting with French-language hyperbaric physicians, operators and nurses has seen an increasing attendance over three years. The 2–3 hour long teleconferences are held on a streaming web platform and allow not only slide presentations, but also video and documents to be shared among all participants. The exchange of information and discussions about case reports, clinical experience (but success and failures) and projects and research opportunities is considered a significant educational asset, and more and more centres are added to the ICHF membership.

On 07–09 November 2019, the ICHF organized the 1st International French Language Scientific Congress for Hyperbaric and Diving Medicine, in Geneva, Switzerland. Themes were Education by Simulation, the Hyperbaric Team, Extreme Tech Diving Expeditions, Diving Medical Fitness and Hyperbaric Emergencies; there were also free communications and poster presentations. This meeting was patronized by most French-language diving and hyperbaric medicine societies (MedSubHyp, AreSub, SUHMS, CUHMA/ACMHS, ACHOBEL and SBMHS/BVOOG) and was a great success.

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

The EUBS website is at **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.

Courses and meetings

Scott Haldane Foundation

As an institute dedicated to education in diving medicine, over the past 25 years the Scott Haldane Foundation has organized more than 290 courses all over the world. The SHF is increasingly reaching a wider, international audience with courses across the world. Below are the upcoming SHF-courses in 2020.

The courses 'Medical Examiner of Diver' (part I and II) 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).

2020
08 February: Management of Diving Medical, Utrecht, NL
27–28 March: Medical Examiner of Divers part 1, Zeist, NL
02–04 April: Medical Examiner of Divers part 2, Amsterdam University Medical Centre, NL
22–23 April: Internship different types of diving (level 2d), Royal Dutch Navy, Den Helder, NL
09–16 May: Medical Examiner of Divers part 2, Bonaire
12–13 June: In-depth course Diving with your heart (2d), NL

On request: Internship HBOT (level 2d certification), NL/Belgium

The course calendar will be supplemented regularly.

For the latest information: https://www.scotthaldane.org

Hyperbaric oxygen lectures

Welcome to: http://www.hyperbaricoxygen.se/
This site offers publications and high-quality lectures from leading investigators in hyperbaric medicine. Please register to obtain a password via email. Once registered, watch online, or download to your smart device or computer for later viewing.
For information contact: folke.lind@gmail.se

Diving and Hyperbaric Medicine is now on Facebook.
Like us at:
https://www.facebook.com/divingandhyperbaricmedicine/

German Society for Diving and Hyperbaric Medicine (GTÜM)

An overview of basic and refresher courses in diving and hyperbaric medicine, accredited by GTÜM according to EDTC/ECHM curricula, can be found on the website:
http://www.gtuem.org/212/Kurse_/_Termine/Kurse.html

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

P O Box 347, Dingley Village
Victoria, 3172, Australia
Email: hdsaustraliapacific@hotmail.com.au
Website: www.classicdiver.org

Hyperbaric Oxygen, Karolinska

Welcome to: http://www.hyperbaricoxygen.se/

This site, supported by the Karolinska University Hospital, Stockholm, Sweden, offers publications and high-quality lectures from leading investigators in hyperbaric medicine. Please register to obtain a password via email. Once registered, watch on line, or download to your iPhone, iPad or computer for later viewing.

For further information contact via email:
folke.lind@karolinska.se

Advertising in *Diving and Hyperbaric Medicine*

Companies and organisations within the diving, hyperbaric medicine and wound-care communities wishing to advertise their goods and services in *Diving and Hyperbaric Medicine* are welcome. The advertising policy of the parent societies appears on the journal website: http://www.dhmjournal.com

Details of advertising rates and formatting requirements are available on request from:
Email: editorialassist@dhmjournal.com

Diving and Hyperbaric Medicine: Instructions for Authors (summary)

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, members of the diving and hyperbaric industries, and divers. Manuscripts must be offered exclusively to *Diving and Hyperbaric Medicine*, unless clearly authenticated copyright exemption accompanies the manuscript. All manuscripts will be subject to peer review. Accepted contributions will also be subject to editing.

Address: The Editor, Department of Anaesthesiology, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand
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Editorial Assistant: editorialassist@dhmjournal.com
Information: info@dhmjournal.com

Contributions should be submitted electronically by following the link:
http://www.manuscriptmanager.net/dhm
There is on-screen help on the platform to assist authors as they assemble their submission. In order to submit, the corresponding author needs to create an 'account' with a 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 word count); structure of the article and abstract is at the author(s)' discretion.

Case reports, Short communications, Work in progress reports, etc: 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 and historical articles, Commentaries, Consensus and other meeting reports, etc., 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.

Formatting of manuscripts

All submissions must comply with the requirements set out in the full instructions on the DHM website. Non-compliant manuscripts will be suspended whilst the authors correct their submission. Guidance on the general structure for the different types of articles is given above.

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 2018
- DHM Mandatory Submission Form 2018
- Trial design analysis and presentation
- EASE participation and conflict of interest statement
- English as a second language
- Guideline to authorship in DHM 2015
- Helsinki Declaration revised 2013
- Is ethics approval needed?

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Scholarships for Diving Medical Training for Doctors

The Australasian Diving Safety Foundation (ADSF) are proud to offer four 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 program. These scholarships are mainly available to doctors who reside in Australia. However, some 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 AUD3,000.

Interested persons should complete the Application Form at:
https://adsf.org.au/grants/scholarships/diving-medical-training and send it by email to johnl@adsf.org.au.
