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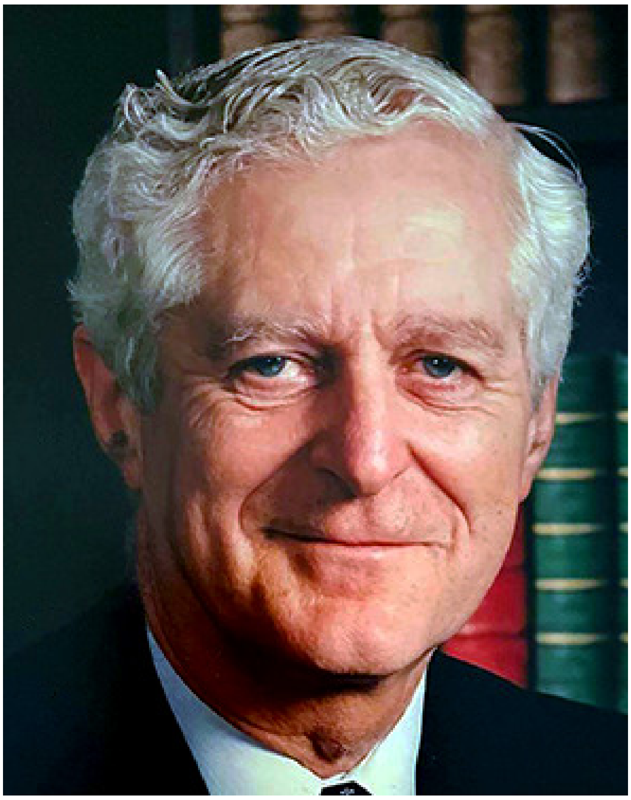

Professor David Hallen Elliott 1932–2022

Oxygen breathing and skin temperature in diabetics

Ceiling controlled versus staged decompression

Health of active scuba divers in the USA

Ear health in UK scuba divers

HBOT for cystitis after chemotherapy and stem cell transplant

Post-COVID-19 fitness to dive

Scenarios for hyperbaric medicine simulation training

Bailout rebreathers in extended range diving

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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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The Editor's offering

The March 2022 issue of Diving and Hyperbaric Medicine marks the passing of Professor David Elliott (cover photo: used with permission from the British Medical Journal), one of our field's true elder statesmen. David's contributions to diving medicine are immense; none more so than his co-editorship of four editions of the iconic textbook Bennett and Elliott's Physiology and Medicine of Diving. Even though it was last published in 2003, it remains a standard work in the field. David unfailingly exhibited a collegial and gentlemanly demeanour, something I will always remember from my junior years in the field. He was a mentor and inspiration to me. I am very grateful to the authors of David's obituary which appears on page 68.

In this issue there is an interesting collection of papers addressing topics in both diving and hyperbaric medical sub-disciplines.

Dr Kwan Au-Yeung and colleagues conducted a preliminary investigation of infrared thermometry in evaluating distal lower limb skin temperature change during oxygen inhalation in healthy subjects and patients with diabetic ulcers. The general aim was to compare temperature change responses in these groups, with a longer term view to developing thermometry as a predictor of response to hyperbaric oxygen treatment among diabetic ulcer patients.

Dr Sergio Angelini and colleagues compare the effect on duration of decompression achieved by continuously following the decompression ceiling compared to the more common approach of decompressing using stops at progressively shallower depths. Their calculations reveal a 'ceiling approach' is shorter. Although this is arguably predictable, technical divers will find it fascinating to see the difference quantified. As the authors point out, ceiling decompression comes at the cost of greater supersaturations in faster tissues, and the effect of this on risk of decompression sickness is unknown.

Dr Peter Buzzacott and colleagues contribute to an exciting trend toward the use of 'big data' in describing divers. They tap into a large database compiled from an annual survey of activity among US adults to describe typical socio-economic characteristics of American recreational divers. Once again, although some findings are arguably predictable, it is nevertheless extremely useful to have hard confirmatory data.

Marguerite St Leger Dowse and colleagues surveyed UK recreational divers on aural health problems, and report a high prevalence of these problems among divers. Their work affirms the oft quoted notion that ear problems are the most common medical complications of diving. They also confirm that divers have poor awareness of existing guidelines to avoid such problems.

Dr Handan Ozturk and colleagues report a series of 25 haemorrhagic cystitis cases precipitated by chemotherapy or haematopoietic stem cell transplant. These cases, treated with hyperbaric oxygen, exhibited healing or improvement in a substantial majority. It is difficult to draw strong conclusions on the basis of an uncontrolled case series, but these results appear better than the natural history would predict. A controlled trial would be desirable but, as the authors suggest, this would be difficult in these relatively rare problems with few therapeutic options.

Dr Bengusu Mirasoglu and colleagues report on their experience with assessing recreational and occupational divers who wish to return to diving after COVID-19 infection. This is an extremely topical subject, and will no doubt be the focus of more publications in the coming year or so.

Dr Sylvain Boet and colleagues describe a Delphi study performed to derive a list of core scenarios that would inform a simulation curriculum in hyperbaric training. Immersive interprofessional team simulation is seen as a gold standard in clinical training, and is a strategy that hyperbaric medicine has arguably been slow to adopt. It is extremely gratifying to see physicians with an academic interest in medical education advancing this cause.

Dr Derek Covington and colleagues provide a perspective on the strengths and weaknesses of using a second closed circuit rebreather as a back up for gas supply redundancy in extended range cave diving. This is a timely account given that cave divers are pushing well beyond the distances and durations for which adequate open circuit scuba bailout gas (in case of rebreather failure) can easily be provided. Technical divers will find this article particularly interesting.

This issue contains case reports of symptomatic pneumorrhachis treated with hyperbaric oxygen, the consequences of incidentally discovering a COVID-19 positive patient during a hyperbaric oxygen course, and dental barotrauma in a hyperbaric physician supervising hyperbaric oxygen treatment. I would also draw particular attention to the letter from the University of California San Diego group who update their previously published recommendations for investigation of a diver wishing to return to diving after COVID-19 infection.

As we enter the third year of the pandemic, it is hoped that 2022 may mark a return to productive face to face meetings run by the relevant societies. The SPUMS meeting in early May will be virtual due to the continuing omicron outbreaks in New Zealand and Australia. However, the UHMS is proceeding with a face to face meeting in late May, and hopefully the EUBS will also be able to run their planned meeting in Prague in mid-September.

Prof Simon Mitchell
Editor, Diving and Hyperbaric Medicine Journal

Original articles

Effect of enriched oxygen inhalation on lower limb skin temperatures in diabetic and healthy humans: a pilot study

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Key words
Chronic wounds; Diabetes; Hyperoxia; Skin thermometry; Vasoconstriction

Abstract
(Au-Yeung KL, Selvaraj C, Amin T, Ma LK, Bennett MH. Effect of enriched oxygen inhalation on lower limb skin temperatures in diabetic and healthy humans: a pilot study. Diving and Hyperbaric Medicine. 2022 March 31;52(1):2–6. doi: 10.28920/dhm52.1.2-6. PMID: 35313366.)
Introduction: Measurement of skin temperature with infrared thermometry has been utilised for assessing metabolic activity and may be useful in identifying patients with ulcers suitable for hyperbaric oxygen treatment and monitoring their treatment progress. Since oxygen promotes vasoconstriction in the peripheral circulation, we hypothesised that oxygen administration may lower skin temperature and complicate the interpretation of temperatures obtained. This pilot study investigated the effect of oxygen administration on lower limb skin temperature in healthy subjects and diabetic patients.
Methods: Volunteers were recruited from healthy staff members (n = 10) and from patients with diabetic foot ulcers (n = 10) at our facility. Foot skin surface temperatures were measured by infra-red thermometry while breathing three different concentrations of oxygen (21%, 50% and 100%).
Results: Skin temperature changes were observed with increasing partial pressure of oxygen in both groups. The mean (SD) foot temperatures of diabetic patients and healthy controls at air-breathing baseline were 30.1°C (3.6) versus 29.0°C (3.7) respectively, at FiO_2 0.5 were 30.1°C (3.6) versus 28.5°C (4.1) and at FiO_2 1.0 were 28.3°C (3.2) versus 29.2°C (4.3). None of these differences between groups were statistically significant.
Conclusions: Data from this small study may indicate a difference in thermal responses between healthy subjects and diabetic patients when inhaling oxygen; however, none of the results were statistically significant. Further investigations on a larger scale are warranted in order to draw firm conclusions.

Introduction

Infrared thermometry (IRT) is an effective tool in monitoring disease progression and predicting diabetic foot ulceration.[1–5] By measuring skin surface temperature elevation, IRT allows early detection of ulceration at home by patients themselves.[6–8] Another non-invasive technology used in the management of diabetic ulcers is transcutaneous oximetry measurement (TCOM). It is used both for assessing the suitability of a problem wound for treatment with hyperbaric oxygen treatment (HBOT) and for monitoring progress during the course of a therapy.[9] Transcutaneous oximetry measures the partial pressures of oxygen in subcutaneous tissue ($PtcO_2$) immediately surrounding a wound, usually while breathing air or a high concentration of oxygen. To measure the $PtcO_2$, the intact skin surrounding the wound is warmed in order to 'arterialise' the area and facilitate diffusion of oxygen from the subcutaneous tissue for estimation by the Clarke electrode. Elevation of the $PtcO_2$ by oxygen administration under normobaric and hyperbaric conditions as measured by TCOM is associated with treatment success with HBOT.[9–12] Transcutaneous oximetry is a lengthy and technically challenging task, and prone to the production of puzzling or clearly erroneous results that require careful interpretation.[13] While well-established in hyperbaric practice, the search nevertheless continues for a more time-efficient and reliable measure of the potential success of HBOT in individual patients.

The use of IRT as an estimate of metabolic activity in skin wounds is a promising alternative to TCOM. Results are dependent on the integrity of the peripheral vasculature and the vasomotor responses which in turn have direct effects on the dermal temperature. There are, to our knowledge, no data available on the effect of inspired oxygen on skin temperature. We hypothesised that in normal individuals, vasoconstriction at high tissue PO_2 might lower skin temperature while in diabetic patients this phenomenon might be blunted by poor vasomotor responses. Furthermore, we hypothesised the improvement of wound metabolism in poorly healing ulcers over a course of HBOT might be reflected in peri-wound temperatures.

In the present small-scale pilot study, we have embarked on a series of investigations to evaluate the suitability of IRT to both select suitable problem wounds for treatment with HBOT and to monitor wound progress. A higher temperature at a problem wound suggests either a more metabolically active wound resulting from inflammation or infection, or an impaired autonomic response with vasodilation. On the other hand, vasomotor responses to hyperoxia may reduce flow and thus temperature of a wound despite suitable healing. As a first step, this study simulated the conditions of TCOM assessment by having subjects breathe different fractions of inspired oxygen while measuring skin temperatures by IRT. The primary aim was to identify any potentially reliable signals in either normal individuals or diabetic patients during oxygen administration up to an FiO_2 of 1.0 at 101.3 kPa (1 atmosphere absolute).

Methods

Following ethics committee approval (HREC 15/255 -LNR/15/POWH/463), two groups of volunteers were enrolled: diabetic patients with chronic lower leg wounds, present for at least three months, and receiving wound care at our hyperbaric facility (n = 10); and healthy controls (members of staff of the hyperbaric facility with no established diagnoses relevant to perfusion of the lower limbs) (n = 10). Patients with clinical signs and symptoms of large vessel disease or a primary diagnosis other than an ulcer due to diabetes mellitus were excluded. Patients who were unable to provide informed consent were also not included. Volunteer staff were matched for gender with the patient group. The primary outcome was comparison of the mean wound skin temperatures in each group (healthy volunteers and diabetic foot patients) in response to breathing three different oxygen fractions at 101.3 kPa, while the secondary outcome was to compare the temperature changes between these two groups at each concentration.

Each subject was given a study information sheet and provided written, informed consent prior to commencement. Temperature measurements were taken in an air-conditioned examination room. When wounds were present on both lower legs, one leg was chosen by toss of a coin. The same applied to the choice of limb of the healthy control subjects. For the diabetic group, the selected lower legs were cleaned with soap-free pH-balanced wash by hyperbaric nurses, and were then dried and covered with sterile sheets. Staff volunteers had their legs cleansed then covered with a sterile sheet in the same manner. Body temperature was measured by tympanic membrane thermometer (Braun Pro 4000 Thermoscan, Welch Allyn) and the room temperature was recorded. Skin temperature images (STI) were captured by a handheld FLIR E6 1.0 infra-red camera (FLIR Systems, Wilsonville OR, USA) with the following settings: alignment distance of 0.3 meter; emissivity ε0.98 hu (for skin); and reflected temperature at 22°C. The camera displayed values in increments of 0.1°C and provided a thermal sensitivity of < 0.06°C. The temperature at any point selected in the image was displayed on the screen. The camera continuously auto-calibrated and was accurate to within +/-2%.

All subjects were seated on the same chair in a semi-reclined position of about 45 degrees to horizontal. After a 10-minute rest breathing room air (FiO_2 = 0.21) with the lower legs covered, the first images were taken. These were of the index ulcer and the equivalent area in the gender-matched healthy volunteer pair. Subjects then had their legs re-covered and breathed an FiO_2 of 0.5 using a calibrated Venturi mask (Hudson RCI® Teleflex medical, USA) for ten minutes before a second set of STIs of the same area were captured. The mask was removed, the legs re-covered and the mask replaced with an oxygen hood (Amron™ Oxygen Treatment Hood, Amron International, USA) supplied with 100% oxygen at 15 $L{\cdot}min^{-1}$ for a further 10 minutes. Previous investigation suggested this will provide a mean (95% CI) FiO_2 of 0.94 (0.14).[14] The third set of STIs was then taken. Finally, the wound patients had their dressing procedure completed as normal. The entry and exit of the dressing room was kept to a minimum to avoid producing any draft which may affect the surface temperature.

The STIs were analysed using a proprietary software program provided with the camera (FLIR Tools version 1.18.8). Skin temperatures were recorded at eight points circumferentially around the wound edge and two points over the wound on patients' legs, and at the corresponding anatomical locations in control subjects' legs according to the gender matched pair. The mean temperatures of these areas at different inspiratory concentrations of oxygen were analysed.

Average skin temperatures were compared between groups by mixed-design analysis of variance (ANOVA) using SPSS Statistics version 26.0 (IBM, Armonk, USA). Individual group measurements were expressed as mean (standard deviation). Statistically significant differences were considered to exist at $P < 0.05$.

Results

The individual baseline data for the two groups are shown in Tables 1 and 2. Independent sample t-tests failed to reveal any significant differences between the control participants and the patients in body temperature at baseline, $t\ (18) = -0.3$, $P = 0.077$.

Skin temperature changes with changing inspired oxygen concentrations for both groups are shown in Figure 1. The skin temperatures changed little in either group between room

Table 1
Characteristics of the healthy volunteers

Control	Sex/Age (years)	Room temp (°C)	Body temp (°C)
1	M/44	22.0	36.6
2	M/45	22.7	36.7
3	M/43	23.5	36.7
4	M/46	23.5	36.5
5	M/44	24.0	36.7
6	M/45	25.5	36.9
7	F/39	25.5	37.0
8	M/41	23.6	36.7
9	M/64	21.0	36.7
10	M/24	21.0	36.7
Mean (SD)	43.5 (9.7)	23.2 (1.6)	36.7 (0.1)

Figure 1
Mean skin temperatures (SD) with increasing inspired oxygen over the wound sites

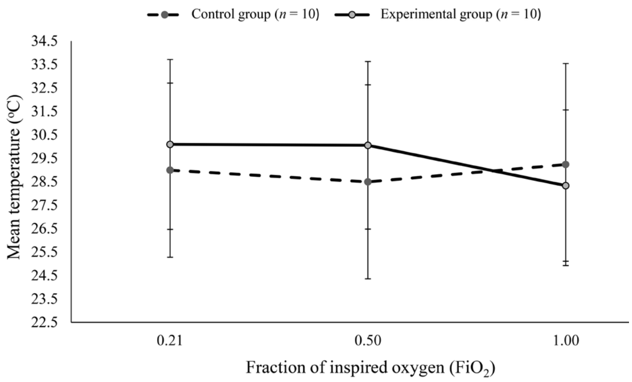

Table 2
Characteristics of the diabetic wound patients

Patient	Sex/Age (years)	Room temp (°C)	Body temp (°C)	Wound location	Wound size (mm)	Duration (months)
1	M 69	21.0	36.0	Right sole below MTPJ 1	29 x 2.5	4
2	M 58	22.0	36.3	Left lateral sole	22 x 22	7
3	M 62	23.0	36.5	Right sole medial to MTPJ 1	43 x 44	9
4	M 71	24.0	36.6	Proximal right big toe	10 x 11	6
5	M 56	23.7	37.1	Right big toe	6 x 8	4
6	M 68	25.5	37.1	Right heel	40 x 32	4
7	F 58	23.4	36.9	Left heel	60 x 52	5
8	M 67	21.8	36.7	Right shin	40 x 41	12
9	M 63	21.0	37.2	Right 5th toe amputation	6 x 5	6
10	M 66	21.0	37.2	Right heel	10 x 8	12
Mean (SD)	63.8 (5.2)	22.6 (1.5)	36.8 (0.4)			

air and an FiO_2 of 0.5, but changed in opposing directions when breathing an FiO_2 of 1.0. In this small cohort, none of the observed differences were significantly different from baseline temperatures using repeated-measures ANOVA and analysing the control versus ulcerated subjects at the three levels of FiO_2 ($P = 0.089$). The mean (SD) measurements were: room air, patient group 30.1°C (3.6) versus healthy control 29.0°C (3.7); FiO_2 0.5, 30.1°C (3.6) versus 28.5°C (4.1); FiO_2 1.0, 28.3°C (3.2) versus 29.2 (4.3).

Discussion

The present study constitutes a pilot endeavour to examine the potential of IRT in providing important information on the suitability of a diabetic wound for HBOT and/or the monitoring of progress during treatment. Specifically, we intended to investigate the feasibility of the testing regimen under clinical conditions and to seek an indication that individuals with lower leg ulcers might display differences in skin/wound temperature compared to normal controls when breathing high concentrations of oxygen. We broadly simulated the TCOM testing process for this trial, with the addition of a period of 50% oxygen breathing. We measured skin surface temperatures under three conditions in two small groups of subjects, normal controls and diabetic patients with lower leg ulcers. We believe this work has generated two findings worthy of discussion and potentially helpful in guiding further investigations.

First, there were temperature changes with increasing inspired oxygen fraction above 0.5 in both normal subjects and diabetic wound patients. Second, those changes demonstrated a difference in trajectory between groups (albeit not statistically significant). Diabetic patients showed a mean drop in temperature of about 1.5°C when breathing 100% oxygen, whereas normal individuals displayed an increase in skin temperature. This may be an important observation if confirmed in more definitive studies.

Major determinants of skin temperature include blood vessels, sweat glands, endocrine glands and skeletal muscle. Vasodilation of the skin venous plexus increases blood flow which results in a rise of the skin temperature and the dissipation of heat during heat exposure or exercise and the opposite happens with cold exposure.[15] These vasomotor responses to environmental thermal stresses are controlled by reflex innervation and neurotransmitters.[16,17] The effects of arterial oxygen tension (PaO_2) on mechanisms of vasomotor responses in human skin have been studied.[18,19] We are not, however, aware of any investigation(s) to date on the effect of hyperoxia on human skin temperature. In this small cohort there was a signal that skin temperature may vary with FiO_2 under a relatively stable environmental temperature. It was observed that in normal subjects the skin temperature may drop initially when the FiO_2 is increased from 0.21 to 0.5, followed by an unexpected rebound increase in skin temperature when the FiO_2 was further increased to 1.0. The (non-significant) observed initial drop in skin temperature was consistent with the findings of previous physiologic studies investigating vasoconstriction under hyperoxia.[15] However, the observation of a subsequent rise in skin temperature when the FiO_2 was further increased to 1.0 was not expected as hyperoxia should lead to vasoconstriction, which in turn should result in skin temperature drop. This observation suggests vasodilatation, instead of vasoconstriction, may have occurred in response to a further increase in oxygenation or under prolonged hyperoxia. The latter suggestion (that sustained hyperoxia may result in increased flow) is supported by the recent reporting of increased skin perfusion in the foot early after an initial decrease during exposure of healthy subjects to hyperbaric oxygen.[20] While our finding may simply be a Type II error attributable to our small sample size, this observation is interesting and justifies further investigation in appropriately powered studies. Definitive conclusions cannot be drawn at this stage.

As observed in this study, the corresponding skin/wound surface temperatures in the legs of diabetics did not seem to respond in the same way on exposure to increasing FiO_2. There was no indication of significant surface temperature change when the FiO_2 increased from 0.21 to 0.5; however, a drop of skin temperature at an FiO_2 of 1.0 was noted. The lack of temperature change to the initial rise in FiO_2 may reflect the blunted vasomotor response among diabetic patients and this is consistent with the findings in physiologic studies on the diabetic vasculature under different conditions.[21,22] The temperature drop when FiO_2 rose further could be a reflection of skin temperature being equilibrated with the environmental temperature given that the environmental room temperatures throughout the study period (21.0–25.5°C) were lower than the limb temperatures of either group. The baseline skin temperatures among diabetic patients were observed to be higher than normal subjects. This could be the result of the chronic inflammation associated with the ulcers and this is consistent with published observations.[23] This temperature drop may indicate the unmasking of an underlying failing of the temperature-regulating physiology during high FiO_2 breathing among the diabetic group. The observed values may be the result of a true difference between the groups or simply a random event of no importance. We believe this observation deserves further study and justifies future investigation designed to either confirm or refute our hypothesis concerning impaired responses to oxygen in the diabetic group.

Future investigations will not only require a larger study cohort but also improved environmental control of ambient temperature and careful attention to the inclusion criteria for the control group in order to more closely match the diabetic patients. In the present study our staff volunteers in the control group were an average of 20 years younger than the experimental group and this could constitute an important reason for the difference observed between groups. Senescent changes in the skin and underlying vessel may well be important in this regard.

Measurement error of the thermal camera would also need to be considered. The manufacturer claimed a thermal sensitivity of < 0.06°C, and that this camera auto-calibrates continuously and is accurate to within ± 2%. It is unlikely our observed differences represent a measurement error. Achieving a gold standard of calibration is difficult with electronic instruments and repeated measurements may help to reduce the measurement error. Nine of the ten patients recruited had wounds over the foot while only one had wound located on the lower leg. The statistical analysis was repeated with the non-pedal wound excluded and the results are similar. Having said that, we would recommend separate analyses of pedal and non-pedal wounds in future studies due to potential differences in vasomotor responses. Although it is not easy to nail down a gold standard for comparison in this area, we suggest future studies should compare the IRT with both ABI values and TCOM results under hyperoxic conditions. In regard to the demographic data collection, details on tobacco and caffeine consumption, current vasomotor medications use and documentation of presence of peripheral sensory neuropathy and/or autonomic neuropathy would also be important factors that may affect the vasomotor response of the dermal vasculature. Given the environmental temperature is likely to significantly confound any difference in response in the diabetic group, any future investigation will need to be undertaken under tight control of the room temperature for all study subjects through the study period.

Conclusions

Data from this limited pilot study may indicate a difference in thermal responses between healthy subjects and diabetic patients when inhaling oxygen. None of the results were statistically significant, and further appropriately powered investigations with better matched controls and experimental subjects under rigorous environmental temperature control are needed before any definitive conclusions be drawn.

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Ceiling-controlled versus staged decompression: comparison between decompression duration and tissue tensions

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Abstract
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Introduction: In dissolved gas decompression algorithms, the ceiling is the depth at which the dissolved gas pressure in at least one tissue equals the maximum tolerated value defined by the algorithm. Staged decompression prescribes stationary stops in three-metre intervals so as to never exceed this maximum tolerated value. This keeps the diver deeper than the ceiling until the ceiling itself decreases to coincide with the next, three-metre shallower stage. Ceiling-controlled decompression follows the ceiling in a continuous ascent.
Methods: Mathematical simulations using the ZH-L16C decompression algorithm and gradient factors were carried out for several dive profiles to compare patterns of tissue gas supersaturation and overall decompression times for decompressions based on these approaches.
Results: During a stationary staged decompression stop the available pressure gradient for inert gas washout diminished as inert gas is washed out while inhaled inert gas partial pressure remained unchanged. Ceiling-controlled decompression, on the other hand, maintained the available pressure gradient for inert gas washout at its maximum tolerated level. Decompressions were 4–12% shorter using ceiling-controlled approaches but at the cost of exposing tissues with faster half times to higher levels of supersaturation than they would experience during staged decompression.
Conclusions: Ceiling controlled approaches accelerate decompression but the effect of this on the risk of decompression sickness is unknown.

Introduction

A compressed gas dive causes accumulation of inert gas (usually nitrogen and/or helium) in the body through diffusion driven by the difference between inhaled inert gas partial pressure and inert gas pressure (also called tension) in the blood and tissues. The higher this inert gas pressure gradient, the faster the accumulation of inert gas into tissues. The process is reversed and inert gas is eliminated ('washed out') during ascent when the partial pressure of the inhaled gas falls below the pressure of that same gas in the blood and tissues. If during an ascent the ambient pressure drops below the sum of gas partial pressures in a tissue (supersaturation), bubbles can form. The presence of bubbles can lead to decompression sickness with manifestations ranging from mild discomfort to paralysis and even death.

Managing inert gas washout with the goal of minimising the probability of undesired consequences is the goal of 'decompression' procedures. Decompression usually involves an ascent with stops near the surface to allow for the controlled release of excess inert gas. The prescription of this ascent is the task of decompression algorithms, which are mathematical representations solvable by a computer of the physical and physiological processes involved in decompression sickness. The ideal decompression not only brings the diver back to the surface without consequences, but does so in a time-efficient manner.

This paper considers the dissolved gas algorithm, first proposed by Haldane in 1908,[1] and, in particular, the ZH-L16C algorithm developed by Bühlmann.[2] This algorithm is based on the assumption that there is a direct relationship between maximum tolerated inert gas pressure in a tissue and ambient pressure. The algorithm represents the human body with 16 tissues, each of which takes up and washes out inert gas at a different rate, and each having a different tolerance to inert gas supersaturation. Specifically, each tissue is identified by three parameters:

The half time, which defines the rate at which gas is taken up and washed out (it is the time in minutes a tissue at a certain pressure needs to reach 50% of a different pressure that it is exposed to). Typically, tissues with short half times ('fast tissues') have higher tolerance to supersaturation while tissues with long half times (slow tissues) have low tolerance to supersaturation.

The *a* and *b* values, which define the maximum tolerated inert gas pressure $P_{t.tol}$ as a function of ambient pressure P_{amb}:

$$P_{t.tol} = \left(\frac{P_{amb}}{b}\right) + a$$

This is also referred to as M-value. From this we can derive the minimum tolerated ambient pressure $P_{amb.tol}$ for a given inert gas tissue pressure $P_{t.inert}$:

$$P_{amb.tol} = (P_{t.inert} - a) * b$$

The highest value of $P_{amb.tol}$ among the 16 tissues defines the minimum depth (decompression 'ceiling') to which a diver can ascend without violating the algorithm, and the corresponding tissue is called the 'leading' or 'controlling' tissue. As ascending beyond the ceiling would violate the decompression algorithm, this determines the depth of the first (deepest) decompression stop, which by convention is a multiple of 3 m. The diver advances from one decompression stop to the next when the inert gas in the leading tissue drops sufficiently to be compatible with the ambient pressure at the next stop, 3 m shallower; in other words, when the ceiling coincides with the next, 3 m shallower stop.

The choice of the 3 m increment dates back to 1908 and the pioneering work of Haldane who advocated that a first ascent to half of the absolute pressure could be done safely, and that "*the remainder of the decompression would evidently need to be conducted in such a way that the maximum partial pressure of nitrogen in any part of the body should diminish at double the rate of the fall in absolute pressure of the air. The ascent of a diver can be conveniently regulated from the surface by signalling to him to stop or come on* ***at every ten feet as indicated on the pressure gauge*** *attached to the pump*."[1] A different unit system may have led to different increments, but the 10 feet of sea water or three metres of sea water (msw) steps established themselves as a standard also because many experiments were carried out in hyperbaric chambers, where fixed decompression stop depths allow for easier control and repeatability of dive profiles. Given that all validation efforts to date are of empirical nature, a different choice of decompression stop depth increments would have yielded different decompression durations but would probably have been as effective. Others have performed a purely mathematical exercise applying optimisation theory to ZH-L16C to show that staged decompression stop depths other than in standard 3-msw increments can lead to shortened decompression time between 8 and 15%.[3]

Staged decompression however is fundamentally less than ideal in terms of inert gas washout, since a stay at constant depth implies that the inert gas pressure gradient is maximised only at the beginning of the stay and decreases from there as the tissue releases gas, and therefore the inert gas tension in the tissue decreases, while the inhaled partial pressure of inert gas remains constant. The fastest decompression would aim at maintaining the inert gas pressure gradient as high as possible throughout the ascent. The maximum available inert gas pressure gradient is achieved at the shallowest tolerated depth (the 'ceiling'). As inert gas washout leads to continuously decreasing inert gas tension, the ceiling moves continuously upwards. A decompression that follows the ceiling is thus a decompression with a continuously changing depth.

The effect of decompressing following the ceiling in comparison with standard staged decompression in 3 msw steps is quantified here via computer simulations of various dive profiles.

Methods

Computer simulations were carried out using ZH-L16C with gradient factors. Gradient factors[4] were defined as the ratio between inert gas pressure in tissue minus ambient pressure and maximum tolerated inert gas pressure minus ambient pressure. Using Bühlmann's terminology we get:

$$GF = \frac{P_{t.inert} - P_{amb}}{P_{t.tol} - P_{amb}} x100$$

Baker[5] used the concept of gradient factors to introduce additional conservatism in the decompression algorithm originally devised by Bühlmann. Gradient factors define a value not to be exceeded at the surface at the end of the dive (GF HIGH) and a value not to be exceeded early in the ascent (GF LOW), using the annotation GF LOW/HIGH (for example GF 30/85). Thus, GF LOW determines the depth of the first (deepest) decompression stop, while GF HIGH defines the duration of the last stop (typically at 3 m), so as to surface without exceeding GF HIGH. The stops between the deepest and the shallowest stop are calculated based on a linear interpolation between GF LOW and GF HIGH. We introduce the term GF TARGET to define the values corresponding to the various staged decompression stops resulting from this interpolation.

Note that the conservatism introduced with a given GF is not a straight percent reduction. We can rewrite the equation above as:

$$P_{t.inert} = \frac{\text{GF}}{100} * P_{t.tol} + \frac{100 - GF}{100} * P_{amb}$$

Consequently, a GF HIGH of 85 would yield a reduction in tolerated inert gas pressure equal to:

$$P_{t.tol.red} = 0.85 * P_{t.tol} + 0.15 * P_{amb}$$

Gradient factors are, in essence, a normalisation of the pressures otherwise expressed in millibars in reference to maximum tolerated values also in millibars, and they are used here to describe inert gas load in the tissues during the dive for ease of data interpretation.

The GF terminology is now commonplace and used in many modern dive computers (e.g., Shearwater, Heinrichs-Weikamp). For this discussion, in addition to GF TARGET, the following terms are defined:

GF NOW represents the instantaneous inert gas tension in the leading tissue (or in a specific tissue if so specified), calculated with the current inert gas tension, the ambient pressure corresponding to the current depth, and Bühlmann's $P_{t.tol}$ at that depth.

GF @SURF represents the result of applying the current inert gas tension in the leading tissue to surface conditions, i.e., it is calculated with the current inert gas tension, the ambient pressure at the surface, and Bühlmann's $P_{t.tol}$ at the surface.

Based on this terminology, the ceiling can be defined as the depth at which GF NOW reaches GF TARGET. It is the shallowest point the diver can reach while respecting the constraint imposed by the choice of GF LOW and GF HIGH and it maximises the inert gas pressure gradient available for washout.

All dive profiles presented here are the result of computer simulations and have been carried out for the sake of comparisons. For pressures we assumed salt water density of 1.025 $kg \cdot L^{-1}$ (1 msw = 10.055 kPa). When following the ceiling, we have chosen to do so only for depths deeper than 6 msw, as in practical terms it would be unwise to extend the continuous ascent due to the increased difficulty in maintaining a good buoyancy control close to the surface (for instance because of influence of surface wave action and the exaggerated effect of small changes in depth on changes in buoyancy).

Results

Results of our simulations are interpreted in terms of gradient factors during the ascent. Based on the terminology defined earlier, one of three situations can arise during ascent:

- GF NOW > GF TARGET: Diver is above the ceiling, the limiting criterion is violated
- GF NOW = GF TARGET: Diver is at the ceiling, inert gas washout is optimised (maximum pressure gradient exploited)
- GF NOW < GF TARGET: Diver is below the ceiling, inert gas washout is inefficient.

When performing staged decompression in 3 msw steps GF NOW = GF TARGET is achieved only upon reaching the next stop. As inert gas is washed out during the stationary staged decompression stop, GF NOW decreases. When it has decreased to the level corresponding to GF TARGET at the next, 3 msw shallower, staged decompression stop depth, the diver can ascend to that level. Throughout the stay at constant depth the pressure gradient available for inert gas washout is continuously diminishing.

This becomes evident in Figure 1, showing the results for a dive to 60 msw for 20 minutes performing staged decompression using air and GF 85/85 (constant GF TARGET = 85). The dashed black line represents the depth profile. During the ascent a first stop occurs at 15 msw, followed by stops at 12 msw, 9 msw, 6 msw and 3 msw. The dashed green line represents GF NOW. A red line is drawn at GF TARGET = 85. By definition, GF NOW is not to exceed this value at any time during the dive and in particular at the end of the dive when GF NOW usually reaches its maximum value. Figure 1 also shows GF @SURF (dashed blue line), which coincides with GF NOW at the end of the dive: it is an indication of the accumulation of inert gas produced by this dive. What is most evident in Figure 1 however is the sawtooth profile of GF NOW during ascent. As intended by the algorithm, the value of 85 is reached at the beginning of each staged stop, but decreases as inert gas is washed out and the tissue tension decreases, while the ambient pressure is constant. The algorithm computes the end of the staged stop so that, as the diver reaches the next staged stop, the GF increases to 85 again due to the decrease in ambient pressure. Discontinuities visible in the GF NOW line are due to the fact that GF NOW is referenced to the leading tissue, which changes as the dive progresses from the fastest to the next fastest and so on, and such a switch leads to a sudden change in tissue tension ($P_{t.inert}$) and in maximum tolerated inert gas pressure ($P_{t.tol}$), both of which are contained in the definition of gradient factor. The progression in leading tissue during the dive is discussed later.

Figure 2 illustrates the same staged decompression dive as in Figure 1 (dashed lines) but in addition shows the corresponding ceiling-controlled decompression (up to 6 msw) (solid lines). GF NOW stays equal to or very close to GF TARGET over the relevant part of the ascent. Following the ceiling also implies that the ascent profile is continuous and always a bit shallower. As a result of this shallower profile with maximised inert gas gradient, GF @SURF decreases faster and the dive is shorter because GF @SURF reaches the value of 85 sooner. The area between the solid green GF NOW curve (ceiling-controlled decompression) and the dashed green GF NOW curve (staged decompression) is proportional to the lost efficiency of decompressing according to the standard 3 msw stops.

Figure 3 shows a dive to the same depth and bottom time but with an ascent calculated according to GF 30/85. The red line represents GF TARGET, which is the interpolation between GF LOW (30) and GF HIGH (85). The interpolation is carried out as defined for staged decompression, resulting in the sequence of steps shown. On the ceiling decompression GF NOW closely follows GF TARGET. Since the lowering of GF LOW from 85 to 30 introduces stops deeper than in the previous case, the reduction of decompression duration

Figure 1
GF NOW and GF @SURF profiles in a simulated dive to 60 msw for 20 minutes breathing air and using GF 85/85 to calculate a staged decompression

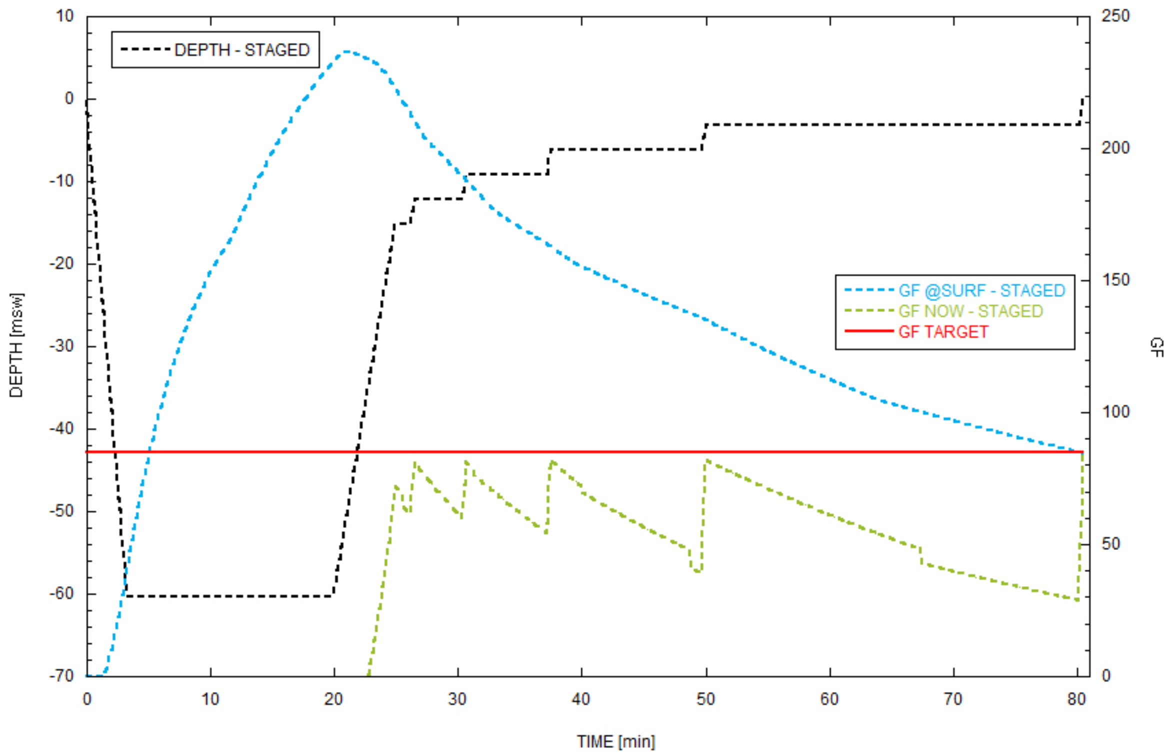

Figure 2
GF NOW and GF @SURF profiles in a simulated dive to 60 msw for 20 minutes breathing air and using GF 85/85 to calculate and compare staged decompression and ceiling-controlled decompression until reaching the 6-msw stop

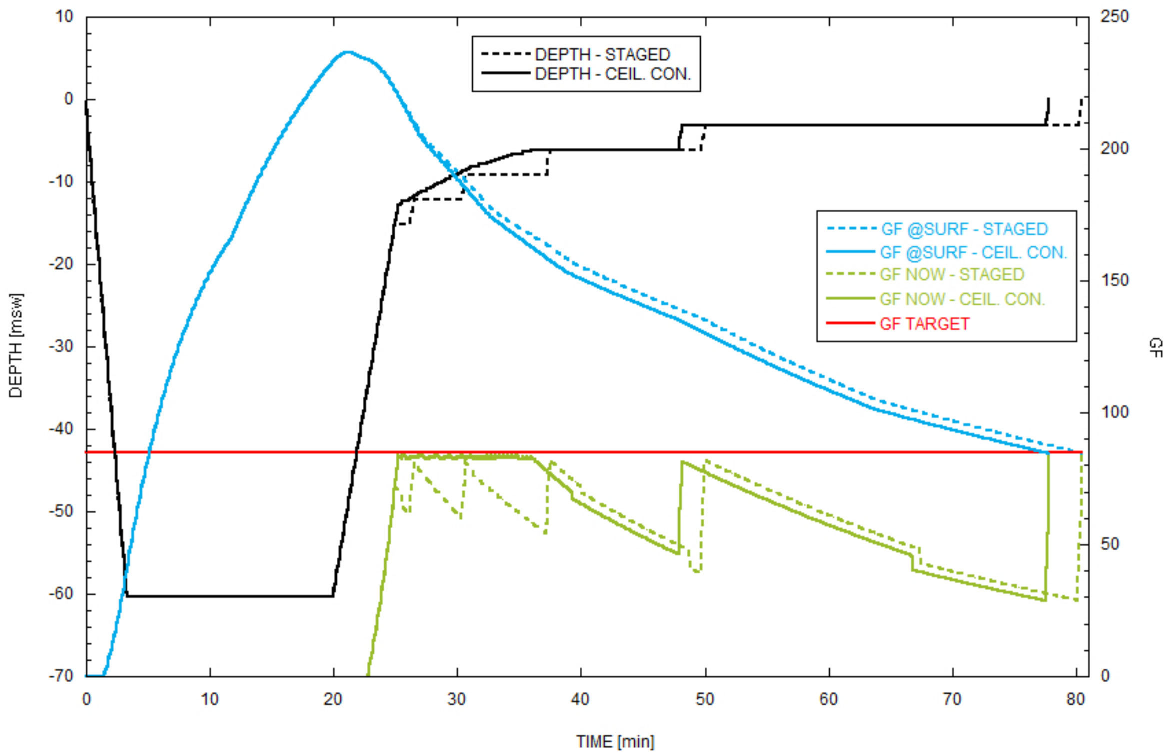

Figure 3

GF NOW and GF @SURF profiles in a simulated dive to 60 msw for 20 minutes breathing air and using GF 30/85 to calculate and compare staged decompression and ceiling-controlled decompression until reaching the 6-msw stop

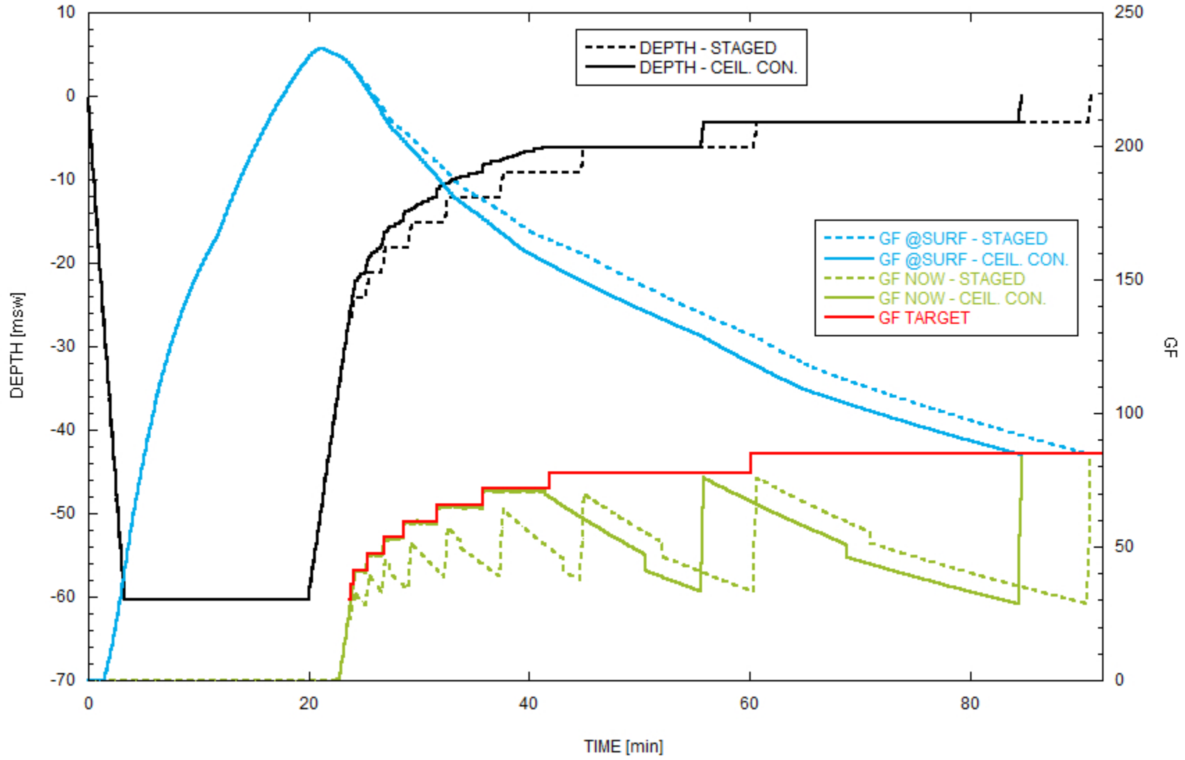

Table 1

Duration of decompression for various profiles conducted with staged or ceiling decompression, with the time advantage for ceiling-controlled decompression; EAN – enriched air nitrox (the subscript designates the oxygen fraction)

Gas(es), depth, bottom time, GF LOW/HIGH	Staged decompression (min)	Ceiling-controlled decompression (min)	Time advantage (% difference)
Air, 60 msw, 20 min, 85/85	55	53	5
Air, 60 msw, 20 min, 30/85	67	61	10
Air, EAN_{40} and EAN_{80}, 60 msw, 20 min 85/85	25	24	4
Air, EAN_{40} and EAN_{80}, 60 msw, 20 min 30/85	29	27	6
Air, EAN_{40} and EAN_{80}, 60 msw, 40 min 30/85	83	75	10
Trimix, 150 msw, 20 min, 30/85	282	249	12

achieved by following the ceiling increases. Simulations were also carried out with different bottom times, breathing gases and GF values, These results are summarised in Table 1.

Further detail of the behaviour of the individual tissues is now considered for the GF 85/85 dive. Figure 4 depicts GF NOW for the two decompression procedures previously depicted in Figure 2, but now with colours identifying which of the individual tissues (among the 16 ZH-L16C tissues) is the leading tissue. At the start of the ascent tissue T2 (half time = 8 minutes) is the leading tissue, and this role is soon passed on to tissue T3 (half time = 12.5 minutes), then T4 (half time = 18.5 minutes) and so on, and the dive ends with tissue T7 (half time = 54.3 minutes) controlling the final surfacing. This figure shows that although following the ceiling exposes the tissues to higher supersaturation, the time interval during which this higher supersaturation is at the limit of the M-value for one individual tissue is rather short, and in this particular choice of depth and bottom time only tissues T3 and T4 spend any significant time at GF = 85, and each only for 5–6 minutes. Figure 5 shows the detail

Figure 4

GF NOW profiles for tissues T2–7 (from the 16 tissues in Bühlmann's ZH-L16C algorithm) for a dive to 60 msw for 20 minutes breathing air and using GF 85/85 to calculate and compare staged decompression and ceiling-controlled decompression until reaching the 6-msw stop; the noise in the GF NOW traces is due to the choice of time and depth steps in the simulations

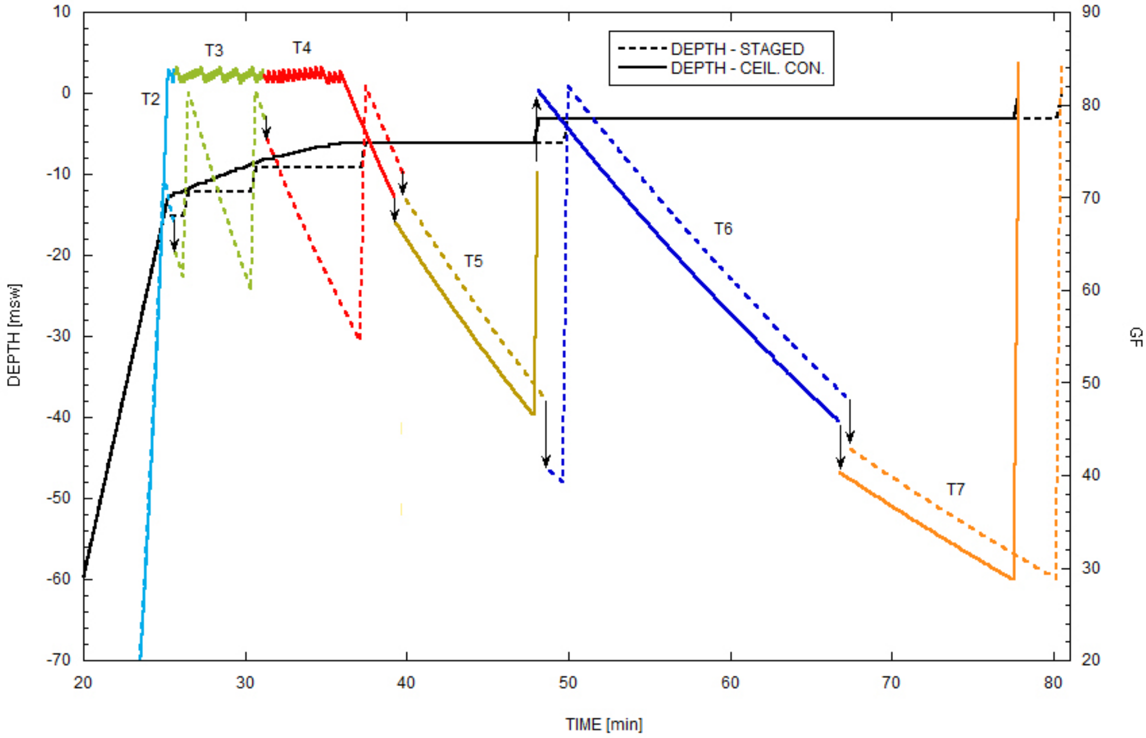

Figure 5

GF NOW profiles for tissues T3 and T4 (from the 16 tissues in Bühlmann's ZH-L16C algorithm) for a dive to 60 msw for 20 minutes breathing air and using GF 85/85 to calculate ceiling-controlled decompression until reaching the 6-msw stop; the noise in the GF NOW traces is due to the choice of time and depth steps in the simulations

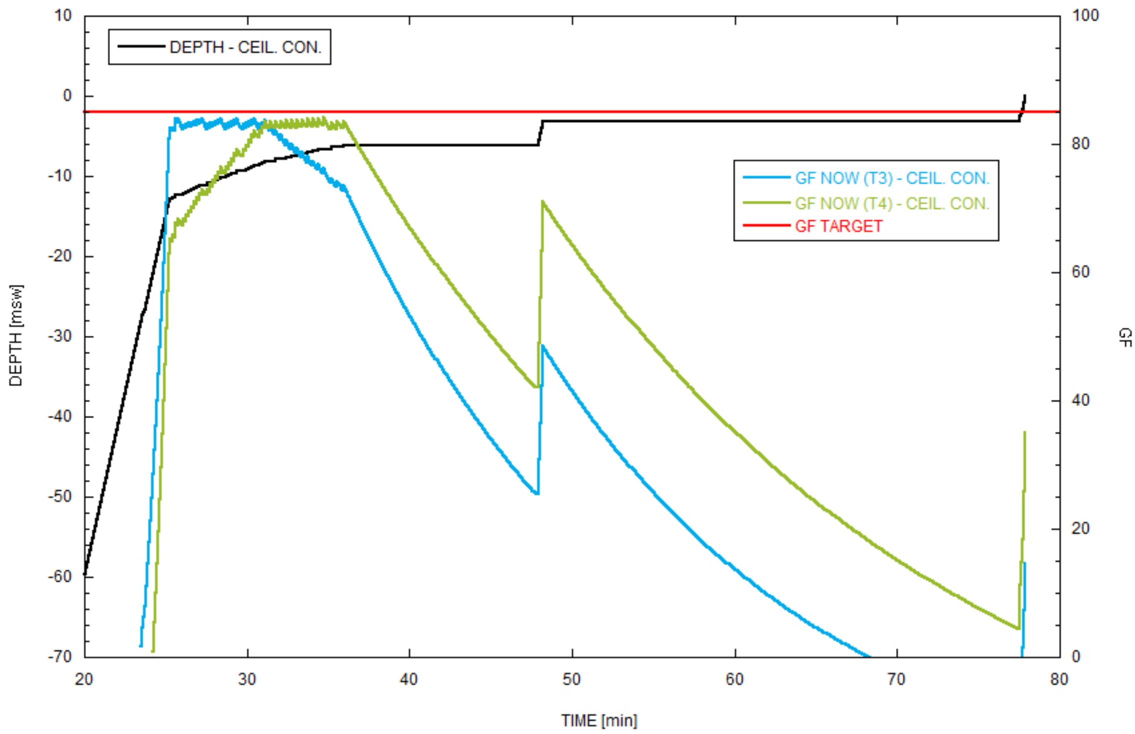

Figure 6

Tissue nitrogen tension profiles for tissues T6–9 (from the 16 tissues in Bühlmann's ZH-L16C algorithm) and inhaled nitrogen pressure for a dive to 60 msw for 20 minutes breathing air and using GF 85/85 to calculate and compare staged decompression and ceiling-controlled decompression until reaching the 6-msw stop

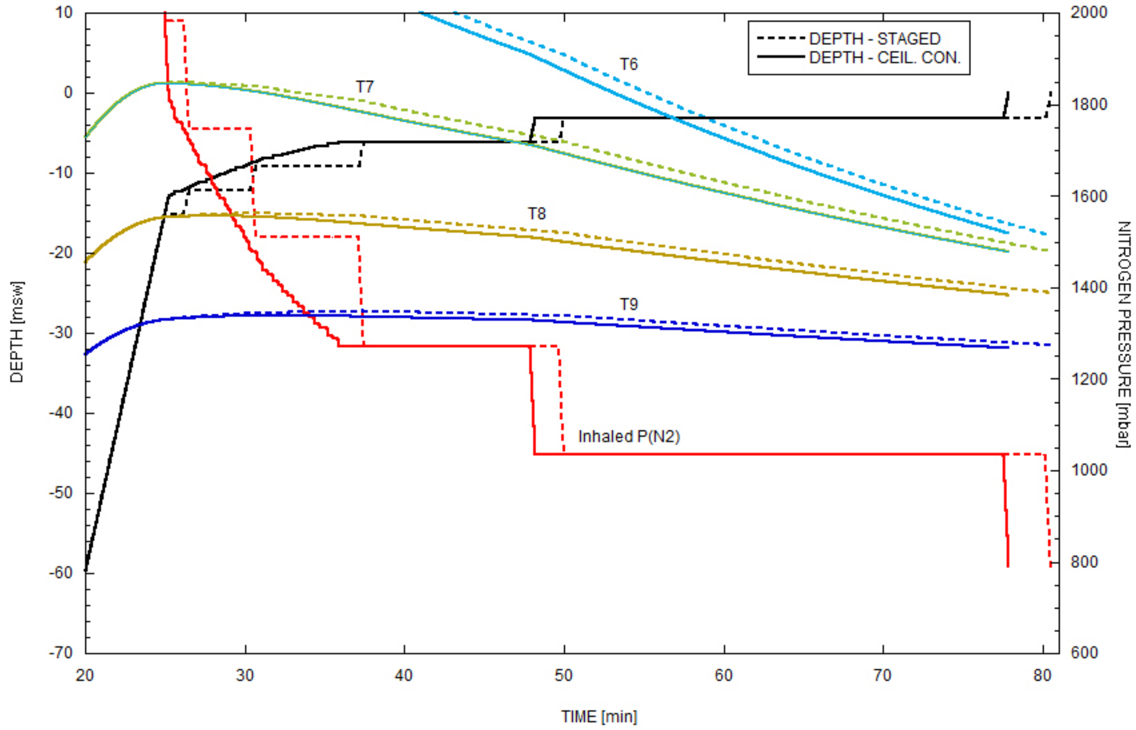

Table 2

Calculated values of tissue pressure (mbar) and maximum tolerated inert gas pressure for the 16 tissues in the Bühlmann ZH-L16C algorithm upon surfacing from a dive to 60 msw for 20 minutes breathing air and using GF 85/85 to calculate and compare staged decompression and ceiling-controlled decompression until reaching the 6-msw stop; deco – decompression

Tissue	Staged deco (mbar)	Ceiling deco (mbar)	$P_{t.tol}$ (mbar)
1	969	970	2,868
2	1,018	1,023	2,277
3	1,148	1,163	2,034
4	1,323	1,341	1,855
5	1,463	1,476	1,700
6	1,512	1,518	1,564
7	1,478	1,477	1,480
8	1,388	1,383	1,423
9	1,273	1,267	1,382
10	1,176	1,169	1,348
11	1,100	1,094	1,321
12	1,033	1,028	1,293
13	976	971	1,267
14	928	923	1,241
15	887	884	1,225
16	855	852	1,207

of inert gas pressure (expressed in terms of GF) for tissues T3 and T4 and it can be seen that when the tissue is not '*leading*', its tension is significantly lower than the M-Value (in this representation it means GF NOW << GF TARGET).

To this point the discussion has focused on fast tissues, up to and including that which is the leading tissue at surfacing (T7 in the case described in Figures 2, 4 and 5). During decompression these tissues become supersaturated and exhibit a pressure gradient in favour of inert gas wash out. It is also appropriate to discuss slow tissues, which switch from gas uptake to gas washout very late in the decompression profile, if at all. Figure 6 compares the inhaled pressure of nitrogen to the tension in tissues close to the leading tissue at the time of surfacing, specifically T6 (half time = 38.3 minutes), T7 (half time = 54.3 minutes), T8 (half time = 77 minutes) and T9 (half time = 109 minutes). Tissue 6 is, as expected, washing out nitrogen under a fairly substantial gradient all the way to the surface. Tissue 7 switches from taking up to washing out nitrogen at around 12 msw in both profiles. Tissue 8 switches at 9 msw in both profiles. Tissue 9 switches at the end of the 9 msw stop in staged decompression and at around 7 msw when following the ceiling. Tissues slower than T9 will take up nitrogen all the way to a depth of 3 msw or shallower. This means that slow tissues are undersaturated for most of the decompression, will take up less inert gas following a shallower profile, and thus can only benefit from following the ceiling.

Table 2 lists the nitrogen pressure in each tissue upon surfacing for the two ascent procedures. When following the ceiling, tissues T1 through T6 have higher ending nitrogen pressure; tissue T7 shows no difference, as is expected since it is the leading tissue upon surfacing in both cases, while tissues T8 through T16 have lower ending nitrogen pressure when following the ceiling.

Discussion

The reduction in decompression duration when following the ceiling is a logical fact, and this reduction can vary from a few percent of the total staged decompression duration to about 12% for the dive profiles we have investigated. Deeper and longer profiles, lower GF LOW and a more tailored choice of breathing gases will likely have a greater effect. The deeper the first stop, the greater the advantage from following the ceiling. The inert gas pressure in each tissue at the end of the dive also follows a predictable outcome; tissues slower than the leading tissue at the end of the dive take up inert gas almost all the way to the surface and they benefit from the shallower and shorter depth profile. Faster tissues wash out inert gas during the decompression phase and benefit from the longer times involved in staged decompression. The difference is very small, since when following the ceiling the gradients for washout are higher and thus, albeit for a shorter time, the washout is more efficient. As Table 2 shows for the 60 msw dive on air and GF 85/85, the differences are not significant, especially in light of the tolerated values at the surface.

An immediate conclusion however cannot be drawn as to the relative safety between the two procedures. Whereas the decompression algorithm has a binary outcome (either it is violated or it isn't), the impact of a dive on a human can only be described in terms of risk of decompression sickness. Countless dives, both in dedicated experiments carried out in hyperbaric chambers and in the field, have provided the empirical data to establish a scale of such risk. The vast majority if not all of this data stems from staged decompression protocols and it cannot be extrapolated, *a priori*, to ceiling-controlled dives. Following the ceiling increases the duration of supersaturation in the fast tissues and reduces it for slow tissues. This might increase, not change, or decrease the risk of decompression sickness.

The risk of decompression sickness would increase if the high supersaturation over a prolonged time interval caused (more) bubble formation and the latter had a negative impact. This would be equivalent to saying that the M-values have a time limit; they are tolerated only because in staged decompression there is only a short exposure to the highest value. It would imply that the apparent inefficiency of the staged decompression is actually an intrinsically valuable component in the process itself.

The risk of decompression sickness would not change if the higher supersaturation over a prolonged time did not have a negative impact, possibly because as seen above it is not prolonged for very long, and later these fast tissues become undersaturated and any bubble that may have formed will shrink. This would be equivalent to saying that M-values did not have an immediate, short-term time limit. It would imply that the apparent inefficiency of the staged decompression is simply that, an inefficiency.

The risk of decompression sickness would decrease if in addition to the above being true the slow tissues, favoured by a ceiling ascent, played a dominant role in causing decompression sickness.

Workman[6] first suggested the concept of time-limited validity of M-values when discussing the higher tolerance of fast tissues with respect to slow tissues, by noting that in fast tissues the excess saturation time-course (at the surface but also in staged decompression) is brief, while in slow tissues the time-course is longer and consequently the need arises to start off at a lower M-value. Workman applied the same considerations to the difference between tolerated supersaturation during ascent (high excess saturation over a prolonged time span) and staged decompression ("*periodic excess saturation*"). Another "*important factor of difference in permissible tissue tension values for various half-time tissues may well be the greater molar concentration of inert gas for some slow tissues resulting from greater solubility of inert gas in these tissues. As molar concentration of inert gas increases in a tissue the probability of bubble formation would increase upon reduction of hydrostatic pressure as a greater number of gas molecules are available in excess of that held in solution at saturation.*"[6] This could be a mechanism to describe a decrease in risk of decompression sickness mentioned above. A study comparing decompression schedules with deep stops vs shallow stops discussed the likely importance of high gas supersaturation and consequent bubble formation in slow tissues.[7] Although conceptually quite different profiles were analysed from those proposed here, there is evidence that slow tissues do play a significant role in the risk of decompression sickness. Reducing their inert gas tension, as is implicit in ceiling-controlled decompression profiles, may be beneficial overall.

Figures 4 and 5 show that the increased tissue tension reaches values near or equal to the M-value in only a few tissues, and does so for only a short time interval. Longer bottom times would increase these intervals but also spread the role of leading tissue to slower tissues. In addition, following the ceiling eliminates the sudden surges in inert gas pressure in the tissues when advancing from one stage to the next (sawtooth profiles). These surges could represent a bubble excitation mechanism. Eliminating them could represent a counterbalancing influence to the higher supersaturation. There is therefore, in our opinion, reason to believe that following the ceiling might be as safe as staged decompression and that the decompression time advantage could be exploited. Following the ceiling can also be implemented in combination with lower GF LOW/

HIGH values, sacrificing the shortened decompression time in favor of lower supersaturation, while eliminating the sawtooth profiles.

Conclusions

Ceiling-controlled decompression shortens the decompression duration at the cost of higher supersaturation in the faster tissues. While this increase in supersaturation does not lead to a breach of the limits of the decompression algorithm, one cannot *a priori* state that it does not lead to an increase in risk of decompression sickness. Computer simulations comparing dives using staged decompression and ceiling-controlled decompression and subsequent analysis of the inert gas tensions suggest that the two procedures might be similarly acceptable and thus the matter should be investigated further.

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Health and wellbeing of recently active United States scuba divers

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Key words
Demography; Diving; Medical conditions and problems; Population; Surveillance

Abstract
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Introduction: This study aimed to describe recently active adult scuba divers in the United States (US) and compare their characteristics with other active adults. The research question was: do active scuba divers have different health and wellbeing characteristics, compared with adults active in other pursuits?
Methods: The Behavioural Risk Factor Surveillance System (BRFSS) is a proportionally representative annual survey of adults in the US. It is the largest continuous population health survey in the world. Since 2011, data on scuba diving is collected biannually. A comparison group were matched on age, sex, being physically active and state of residence.
Results: The dataset comprised 103,686,087 person-years of monthly behavioural data, including 14,360 person years of monthly scuba data. The median weekly frequency of recent scuba diving was 1.0 times per week and the median weekly duration was equivalent to two dives each of one hour. Compared with the comparison group, divers more often earned > USD$50,000 per year, were less frequently married, with fewer children in the house, which they more often owned. They reported being able to afford a doctor if needed within the previous year, but more often reported excellent/good health and excellent/good mental health, despite the divers being 16% more frequently overweight.
Conclusions: The results demonstrate a relatively healthy cohort of active scuba divers, confirming previous survey results that active divers are commonly college-educated, unmarried, without children, home owning, often overweight, they often currently drink alcohol, and smoked tobacco in the past, but commonly gave up smoking ten years or more ago.

Introduction

Little is known about the health and wellbeing of active scuba divers and, despite numerous long-term prospective birth cohort studies,[1] it remains unknown whether recreational scuba diving adds to one's life expectancy or reduces it. It is estimated around three million United States (US) residents, or 1% of the population, scuba dive each year, collectively making around 30 million recreational dives annually.[2] Regardless of the inherently hazardous environment in which scuba diving takes place, recreational scuba diving morbidity and mortality is relatively low,[2,3] compared with other adventure recreation pursuits.[4] On average an estimated 1,400 divers present at US emergency departments each year,[2] and in recent years around 70 scuba diving fatalities have been recorded annually in US and Canadian recreational divers.[5] The most common injuries/illnesses reported to the Divers Alert Network are barotrauma, decompression sickness and marine envenomation, though medical complaints where fitness may play a role include pulmonary oedema, non-fatal drowning and cardiac arrhythmias.[5]

An analysis of recreational diving fatalities that occurred while supervised by a professional dive guide found 57% had a medical cause of death, (such as a sudden cardiac death), as opposed to a dive related issue, (such as running out of air).[6] After drowning, cardiac events are the most common cause of death in North American diving fatalities, accounting for at least 16%,[7] though cardiac-related disabling injuries may precede drowning and the actual proportion may be higher. Cardiovascular risk factors, (hypercholesterolaemia, body mass index, hypertension, and smoking status) have already been described in active US scuba divers.[8] Furthermore, an analysis of 100 consecutive US scuba diving autopsies found an increased prevalence of left ventricular hypertrophy (LVH) compared with an age-sex matched group of 178 autopsies from vehicle collision deaths (31% vs. 20%, $P = 0.04$).[9] A recent study of active US recreational divers aged ≥ 40 y found a prevalence of LVH at 8% which, considering the prevalence was 31% at autopsy, suggests the possibility that LVH may increase the risk of death while scuba diving.[10]

Socioeconomic factors also influence life expectancy. One study demonstrated the direct relationship between life expectancy and gross domestic product per person in 57 countries, which was interpreted as likely the effect of improved health care, rather than increased income or improved housing.[11] Access to health care, income, and housing status have not previously been described for active scuba divers. A later study of developing countries, concluded that decreased mortality was associated with gains in female autonomy, as evidenced by improved access to education.[12] Education has been shown to influence risk-taking and health behaviors (e.g., smoking status and alcohol consumption), and to be associated with longer life expectancy, especially in the US.[13,14] Marriage is also now well established to increase life expectancy, in both males and females, with 2.2 and 1.5 additional years total life expectancy respectively, and 2.4 and 2.0 years of additional active (or disability free) life expectancy respectively, compared with unmarried males and females.[15]

In recent years, mental wellbeing has diminished in US adults. The prevalence of anxiety increased from 5% in 2008 to 7% in 2018, and was associated with being never married, and having college education, but did not increase in over 50's.[16] Mental wellbeing and its relationship with marriage and college education has not previously been described in a representative sample of active recreational scuba divers. Among military veterans not currently diagnosed with post-traumatic stress disorder, psychological wellbeing has been demonstrated to improve with exposure to outdoor recreation in group settings,[17] such as are commonly experienced in recreational scuba diving, but neither the proportion of active recreational divers who are military veterans nor their psychological wellbeing have previously been described.

The aim of this study was to describe the demography, health and wellbeing of recently active adult scuba divers in the US and compare these characteristics with other recently active adults. The research question was: do active scuba divers have different health and wellbeing characteristics, compared with adults active in other pursuits?

Methods

The Behavioural Risk Factor Surveillance System (BRFSS) is a random-number mobile and landline telephone-based proportionally representative annual survey of non-institutionalised adults in all US states and territories. This system is the largest continuously conducted population health survey system in the world. Every other year since 2011 a module collects data on types, frequency and duration of physical activities. Scuba diving was included in the list of physical activities in 2011, 2013, 2015, 2017 and 2019 surveys.[18–22] The relevant BRFSS survey questions were:

- During the past month, other than your regular job, did you participate in any physical activities or exercises such as running, calisthenics, golf, gardening, or walking for exercise?
- What type of physical activity or exercise did you spend the most time doing during the past month?
- What other type of physical activity gave you the next most exercise during the past month?

BRFSS data were weighted using an iterative ranking method involving up to 16 variables and with trimming of outliers. These weightings were then used to generate person-level weights to reflect Nielsen Company intercensal population estimates. The data were de-identified and made freely available by the Centers for Disease Control and Prevention. SAS version 9.4 (Statistical Analysis System, Cary, NC) was used for the analysis. Before combining the years of data, individual weights (*w*) were adjusted (*w*') for each year (i), relative to each year's (*n* = 5) proportion of the combined dataset,[23] as shown in Equation 1.

$$w_i' = \frac{n.w_i}{\sum_{i=1}^{n} w_i} \quad \text{(Eq. 1)}$$

All reported data in this study are national estimates, generated by summing the adjusted annual weights (w_i`).[24] This is appropriate where:

- the sample is as small as it is for divers;
- the divers were proportionally distributed across the US;
- the minimum cell size for all reported variables ≥ 50;
- the relative standard error of ordinal/linear variables is < 30%.

A comparison group of active participants with a ratio of three per diver (actual participants, not weighted estimates) was compiled. This group were also physically active, (in activities other than diving), and were matched with the divers on survey year, sex, age (5-year bin), and state of residence. Frequency of scuba diving was leptokurtic and weekly duration of scuba diving positively skewed, therefore medians and interquartile ranges (IQR) are reported. National estimates and proportions for demography, health and wellbeing factors among divers and the comparison group are presented. Relative risks and 95% confidence intervals (Table 1) were also calculated. Both the Institutional Review Board (IRB) of the Divers Alert Network and the Curtin University Human Research Ethics Committee (HREC) classed this study exempt from requiring ethical approval, (letters available on request).

Results

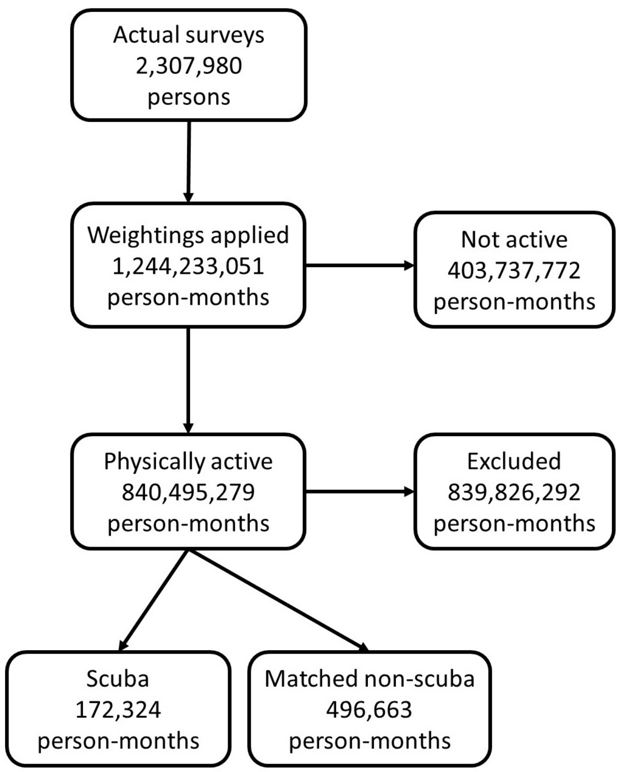
The dataset comprised a total of 2,307,980 telephone survey responses. Combined 2011–2019 BRFSS surveys with the physical activity module included (*n* = 5 years) yielded an estimate of 1,244,233,051 person-months (103,686,087 person-years) of nationally representative behavioral data. Of those, being active was self-reported for 840,495,279 (68%) previous months, and 172,324 (0.01%) identified the physical activity they had been most, or next most, active in during the previous month was scuba diving (14,360 person-years of data), 137,266 months from males (80%) and 35,058 from females (20%). The comparison group, matched on age, sex, being physically active and

Table 1

Demography, personal circumstances and health status of recently active US adult scuba divers and comparison group, 2011–2019; BMI – body mass index, normal 18.5–25.0 kg.m^{-2}, overweight 25.0–30.0 kg.m^{-2}, obese ≥ 30.0 kg.m^{-2}; N/A – too much data missing for a reliable estimate of relative risk

Parameter	Divers %	Controls %	Relative Risk (95% CI)
Males	79.7	73.9	1.28 (1.27, 1.29)
Age < 40 years	32.3	35.8	0.95 (0.95, 0.95)
Age 40–49 years	23.9	26.4	0.97 (0.96, 0.97)
Age 50–59 years	25.8	26.1	0.89 (0.89, 0.90)
Age ≥ 60 years	17.9	14.8	1.04 (1.04, 1.04)
Married (vs. divorced, widowed, separated, never)	49.9	56.8	0.86 (0.86, 0.87)
Do children live in the household?	29.7	40.4	0.85 (0.84, 0.85)
High school graduate?	18.9	19.9	0.99 (0.99, 0.99)
College one to three years?	27.8	33.8	0.92 (0.91, 0.92)
College four years or more?	41.5	34.8	1.11 (1.11, 1.12)
Annual household income < $50,000	31.1	47.7	0.76 (0.76, 0.76)
≥ $50,000	68.9	52.2	1.53 (1.52, 1.55)
Own home?	76.9	69.6	1.31 (1.30, 1.33)
Rent home?	21.4	26.7	0.93 (0.93, 0.94)
Active duty veteran?	17.8	13.7	1.05 (1.05, 1.05)
Health is excellent/very good?	63.5	52.9	1.29 (1.28, 1.30)
Physical health good every day last 30 days?	68.4	65.9	1.08 (1.07, 1.09)
Mental health good every day last 30 days?	71.6	61.9	1.34 (1.33, 1.35)
Have a health care coverage plan?	84.8	85.2	0.97 (0.96, 0.99)
Have a personal doctor?	79.1	78.4	0.99 (0.99, 0.99)
Could afford a doctor if needed in last year?	91.1	85.1	1.68 (1.65, 1.70)
Doctor routine check-up within last 1 year?	66.9	69.7	0.92 (0.91, 0.92)
Doctor routine check-up within last 5 years?	82.3	90.7	0.52 (0.52, 0.53)
BMI classification: Obese	24.6	34.6	0.87 (0.87, 0.87)
Overweight	40.0	30.6	1.16 (1.15, 1.16)
Normal/under	33.2	29.5	1.05 (1.05, 1.06)
Ever been diagnosed with high blood pressure?	23.7	30.1	0.92 (0.91, 0.92)
Currently taking blood pressure medication?	15.0	22.4	N/A
Ever been diagnosed with high cholesterol?	30.0	29.3	1.01 (1.01, 1.01)
Not had a heart attack?	97.2	97.1	1.00 (1.00, 1.00)
Not had angina or coronary heart disease?	98.8	97.4	2.15 (2.05, 2.25)
Not had a stroke?	99.6	95.2	10.60 (9.82, 11.44)
Not diagnosed with asthma?	86.1	81.9	1.30 (1.28, 1.32)
Not diagnosed with skin cancer?	95.3	94.0	1.23 (1.20, 1.26)
Not diagnosed with other types of cancer?	98.0	93.1	3.36 (3.25, 3.48)
Alcoholic drinks in last week or 30 days? Yes	70.4	62.3	1.30 (1.29, 1.31)
No	28.1	36.7	0.88 (0.88, 0.88)
Drink to excess in last 30 days? 1–30 times	24.2	22.8	N/A
No	46.2	39.5	N/A
Missing/Do not know	29.6	37.7	N/A
Most drinks on one occasion recently? 1–2	28.5	24.1	N/A
3–4	17.3	15.6	N/A
≥ 5	23.1	18.9	N/A
Missing/Do not know	31.1	41.4	N/A
Ever smoked at least 100 cigarettes?	49.3	42.1	1.14 (1.13, 1.15)
Currently smoke cigarettes?	11.6	19.2	0.91 (0.91, 0.91)
Do not currently use any other tobacco products?	97.6	94.7	2.37 (2.29, 2.45)
Gave up smoking ten years ago or more?	22.1	12.2	N/A

Figure 1
Enrolment flow diagram



state of residence, equated to an estimated national sample of 496,663 people who were physically active during the previous month (41,388 person years of data), mostly (and next mostly) in activities other than scuba diving (Figure 1).

Diving activity (matched by state in the control group) mostly occurred in residents of Florida and California, (55,508 person-months, 32%), followed by residents of Georgia, New York, Washington and Michigan respectively (41,977 person months, 24%). The median weekly frequency of recent scuba diving was 1.0 times per week (IQR 0.7–2.0) and the median total number of minutes spent scuba diving per week were 120 (IQR 60–150), equivalent to two dives each of one hour duration in a single outing.

Demography, personal circumstances and health status of both the divers and the matched comparison group are presented in Table 1. In summary, compared with the matched comparison group, the divers were more likely to have completed at least four years of college education, and were more likely to earn > USD$50,000 per year. They were less likely to be married with children in the house, which they were more likely to own. Divers were more likely to report being able to afford to see a doctor if needed within the previous year, but they were more likely to report excellent/good health in the previous 30 days, excellent/good mental health, and they were half as likely to have had a routine medical examination within the previous five years. They were 13% less likely to report being obese but 16% more likely overweight, fewer had ever been diagnosed with high blood pressure and, therefore, fewer reported currently taking blood pressure medication. The divers were twice as likely to report never having suffered angina or coronary heart disease and ten times as likely to report never having had a stroke. A history free of cancers was more commonly reported by the divers but, conversely, they were more likely to report having drunk alcohol within the previous 30 days, more commonly reported alcohol intake to excess, more commonly drank ≥ 5 standard drinks in one sitting, and were more likely to report having ever smoked more than 100 cigarettes. Lastly, more divers than the comparison group reported having given up smoking at least ten years before taking the survey and the divers were less likely than the comparison group to report using any other tobacco products, e.g., chewing tobacco.

Discussion

Certain health and wellbeing factors not previously described in active US scuba divers were self-reported for the previous month between 2011 and 2019 by a representative sample of US divers and matched controls. The divers reported a lower proportion of obesity but a higher proportion were overweight. Compared with the matched comparison group, the divers less frequently reported high blood pressure, stroke, asthma, skin cancer or other cancers, which is a similar finding to that of a previous survey of Divers Alert Network (DAN) members, which found lower prevalence of asthma, heart attack, stroke, hypercholesterolaemia, and hypertension among scuba divers, compared with the wider US population.[25] These are risk factors associated with cardiovascular and respiratory morbidity and mortality in the general population but the present study also found that the active scuba divers had better college education, higher household income and higher percentage of owning a home, all suggestive of a selection bias, possibly due to a combination of various factors such as costs associated with participation, the physical effort associated with handling the equipment, and others. Despite the lower reported prevalence of risk factors, and perhaps because of the stresses scuba diving places upon the cardiovascular system, cardiovascular events are nonetheless a leading cause of fatalities in recreational divers.[7]

Our analysis of the BRFSS data identified that recently active scuba divers self-reported good physical and mental health, excellent or very good health in general, being able to afford a doctor if needed but less frequently to have had a routine medical assessment within either the previous year or five years, in comparison with other age-sex-matched recently active adults. Given the proportion (> 40%) of divers in this study who were older than 50 years, and the prevalence of other cardiovascular risk factors, it would appear important for active divers to regularly have their fitness for diving reassessed, e.g., annually. The divers reported more frequent excessive alcohol consumption, compared with the comparison group, and they also more often reported having smoked, but also a greater proportion of the divers had given up smoking. Again, these are similar findings to the survey of DAN members which found fewer disabilities, fewer current smokers but more heavy alcohol drinkers than found in the general US population.[25] From these results, it appears possible that active scuba diving participation may be associated with an increase in likelihood of giving up smoking, though the survey study design does not allow us to conclude that. Another finding in the present study, not previously reported in active recreational divers, is that 18% of the scuba divers were veterans, compared with 14% in the matched comparison group and just 7% in the US population.[26]

The limitations of this study include that the divers described herein were self-reported to have been most, or next most, active in scuba diving during the previous month, more than in other activities. This means divers who were more active in other pursuits were not captured, nor were infrequent divers, nor ill divers. It is also possible that some of the participants were not active in any other activities, and merely nominated scuba because they had at least been diving, (yet they may have done nothing else in the previous month), although the median level of engagement does suggest an active sample of divers. In short, the population described in this study should not be considered representative of the wider US diving population. They represent a proportion of active divers found on any typical dive boat, but not all of them, and most likely they do not represent casual, infrequent divers, who may account for a substantial proportion of recreational divers.

Conclusions

Taken together, these results paint a picture of a relatively healthy cohort of active scuba divers, making the equivalent of two one-hour dives on one outing per week. These results confirm previous survey findings that active divers are commonly college-educated, not married, without children, home owning, often overweight, they often drink alcohol, and smoked tobacco in the past but commonly gave up smoking ten years or more ago. It remains to be shown if taking up scuba diving is associated with giving up smoking.

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Aural health awareness and incident prevention in UK scuba divers

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Abstract
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Introduction: Otological disorders, including Eustachian tube dysfunction (ETD), are commonly observed in divers. Data were gathered to observe the prevalence of ear disorders, and awareness of ear health recommendations for recreational divers in the United Kingdom.
Methods: An anonymous online survey included: diver/diving demographics, the validated Eustachian Tube Dysfunction Questionnaire 7 (ETDQ-7) (a mean score of ≥ 2.1 indicating the presence of dysfunction), pre-existing ear health conditions, medications, decongestants and knowledge of diving and ear health guidance.
Results: A total of 790 divers (64% males) responded (age range 16–80, median 47 years). An ETDQ-7 mean score of ≥ 2.1 was calculated in 315 of 790 respondents (40%), indicating varying degrees of ETD; 56/315 (18%) recorded a pre-existing ear condition. Ear disorders, (external, middle, and inner ear issues) since learning to dive were recorded by 628/790 (79%) of respondents; 291/628 (46%) did not seek medical advice. ETDQ-7 scores of ≥ 2.1 to 6.6 were reported by 293/628 (47%). Six reported inner ear decompression sickness. Decongestants were used by 183/790 (23%). Two hundred and seventy-seven of 790 divers (35%) had aborted a dive with ear problems. Only 214/790 (27%) of respondents were aware of the United Kingdom Diving Medical Committee guidance regarding ear health and diving.
Conclusions: Ear problems and ETD since diving were widely reported in this cohort of divers, with not all divers in this study aware of ear health recommendations and advice.

Introduction

Recreational diving encompasses a broad spectrum of ages, physical abilities, and medical conditions. Otological disorders are a significant source of diving-associated adverse events, with otitis externa being the most common ear pathology followed by middle-ear barotrauma.[1–6] A plethora of other ear pathologies have been identified affecting divers including exostoses, inner-ear barotrauma, hearing loss, vertigo, and inner ear decompression sickness (inner ear DCS).[7–14]

Ear health as a component of diving medical guidelines is an important element of scuba training and good diving practice, but the training delivered to individuals new to the sport may not be optimal to develop ear-safe and symptom-free diving.[15] It is clear that symptoms frequently go unreported to medical practitioners and, for those symptoms which are reported to physicians, it is possible that unfamiliarity with the physiology and physics of scuba diving will be detrimental to the quality of the advice given.[16,17]

This observational study aimed to determine whether self-diagnosis and treatment of ear disorders, including Eustachian tube dysfunction (ETD), is commonplace amongst scuba divers, and whether United Kingdom (UK) divers are aware of and observe the United Kingdom Diving Medical Committee (UKDMC) recommendations supporting ear health.[15,17–21]

Methods

An anonymous, observational, online survey was compiled and publicised between June and November 2017 via the DDRC Healthcare website, diving exhibitions and social media. Measures included validated diver and diving demographic questions designed and used in previous field data studies.[22,23] All participants completed the validated Eustachian Tube Dysfunction Questionnaire 7 (ETDQ-7).[24]

Information on pre-existing ear conditions, ear problems since learning to dive, medical advice obtained, and diagnoses delivered was recorded. Use of decongestants and awareness of diving and ear health guidance and the year of the diver's last physical diving medical were also recorded.

Quantitative data are reported as median. Univariate analysis, including chi-square tests were used to look at relationships between pre-existing ear disorders and ETD; a nonparametric test (Mann-Whitney U) was used to look at the difference in divers with inner- or middle-ear barotrauma and number of years diving or total lifetime dives. A significant level of $P \leq 0.05$ was used throughout. GraphPad Prism 9.2.0 (332) was used for analysis. All data were scrutinised for duplicates, and completion. Approval from a research ethics committee is not required for studies of this type in the UK.

Results

A total of 790 divers (64% males) with an age range 16–80 (median 47) years responded, with significantly younger females and older males represented (*t*-test $P < 0.001$). Diving experience ranged from a few months to 58 (median 12) years. A total lifetime dives (665,482; median 400) and dives completed in the last 12 months (47,369; median 40) were recorded. One hundred and ninety-four respondents (24%) belonged to a technical diving organisation.

Most divers, 576/790 (73%), were unaware of the UKDMC recommendations for ear health when diving. The majority, 501/790 (63%), had received a physical medical assessment since learning to dive, but 76/501 (15%) of that group had not undertaken a medical for more than 10 years. Moreover, 114/501 (23%) had only seen their general practitioner (GP) who is not usually trained in dive medicine. All respondents reported diving in the last 12 months and 32/790 (4%) had been refused fitness to dive at some point since learning to dive.

All divers completed the ETDQ-7 with the mean ETD scores assessed. ETD scores ranged from 1 to ≥ 6.16. Scores of ≥ 2.1, indicating moderate to severe ETD, were evident in 315/790 (40%) of respondents.

Pre-existing ear disorders were reported by 86/790 (11%). Of these, 56/86 (65%) recorded ETD scores of ≥ 2.1 which was significantly greater than respondents without a pre-existing issue but with an ETD score of ≥ 2.1 (Chi-square $P < 0.001$). Of divers with a pre-existing ear condition, 24/86 (28%) had never undergone a diving medical examination, and 12/86 (13%) had encountered further problems since learning to dive. The majority of these, 64/86 (74%), were unaware of the UKDMC recommendations for ear health when diving.

Overall, external, middle, and inner ear issues since learning to dive were experienced by 628/790 (79%) of respondents (Table 1). Just 337/628 (54%) of respondents with disorders sought medical advice or treatment, suggesting that many divers in this study self-diagnosed and treated their own ear problems; one respondent did not detail the diagnosis (Table 2).

There was no relationship between respondents with a pre-existing ear condition and those who went on to develop an ear problem since learning to dive (Fisher's exact test $P = 0.12$). There was no statistical difference between divers with inner or middle ear barotrauma and number of years of diving experience (Mann-Whitney U test $P = 0.30$), or their total life-time number of dives (Mann-Whitney U test $P = 0.50$).

Table 1

Otological problems reported by 628 divers since learning to dive, both self-diagnosed and physician-diagnosed, and indicated as external, middle, or inner ear problems; many divers reported more than one issue. The categorisation of 'small amount of bleeding' and 'pain and bleeding' should be treated with caution due to the lack of additional respondent data and ability to follow up

Divers (n = 628)	**External**	**Middle**	**Inner**
External ear canal red, swollen, and or itchy (307)	•		
Ear canal inflamed and partially closed (260)	•		
Outer ear painful to touch (225)	•	•	
Any other discharge from the ear (99)	•	•	
Both pain and bleeding from the ear (28)	•	•	
Small amount of bleeding from ear (27)	•	•	
Feeling of fullness in the ear (383)	•	•	
Muffled hearing (445)	•	•	•
Vertigo/dizzy (242)			•
Loud tinnitus, ringing or roaring in the ear (161)		•	•
Hearing loss (151)	•	•	•
Vomiting (55)			•

Table 2
Physician-diagnosed otological problems in 336 divers who sought a medical opinion; one respondent did not provide additional detail

Physician diagnosis	*n*
Outer ear infection / otitis externa	147
Middle ear infection / otitis media	79
Middle ear barotrauma	46
Tympanic membrane / eardrum rupture	41
Inner ear barotrauma / round or oval window rupture	12
Inner ear decompression sickness	6
External ear canal superficial vessel rupture	5
Total	336

Inner ear DCS was diagnosed by a physician in six divers (median age 54 years), but no data were recorded concerning the dive profiles and breathing gases used on the dives resulting in inner-ear DCS. One diver reported being diagnosed with a persistent foramen ovale (PFO) but the timing of diagnosis in relation to the incidence of inner ear DCS was not revealed.

Dives aborted because of ear problems were reported by 277/790 (35%) of respondents, with 254/277 (92%) aborting on descent, with 17 of these divers requiring assistance. In this group, 135/277 (49%) scored an ETD of ≥ 2.1. Overall, significantly more females (114/286) than males (163/504) aborted a dive due to ear issues (Fisher's exact $P = 0.04$). Decongestant use was reported by 183/709 (23%) with 40 of these divers routinely using a decongestant before every dive.

Discussion

The majority of responding divers encountered otological problems during their sport diving activities, with many respondents reporting more than one episode. Some divers joined the sport with unassessed pre-existing ear problems which remained undeclared. The reason for failure to seek medical review in divers with pre-existing ear problems remains unclear. There are several potential reasons for this such as a lack of awareness of relevant medical guidelines, a poor understanding that diving with a pre-existing ear condition may lead to sequelae or a willingness to ignore the potential damage that may be sustained whilst diving (possibly to ensure they are not excluded from the sport). It is also possible, as otological symptoms are common in the general population, that a diver may consider them too trivial to seek medical advice. A small number of divers with pre-existing otological issues did consult with their GP, but not all GPs are familiar with diving medicine, relevant guidelines and associated health issues.[22,23]

Although most respondents scored an ETDQ-7 score of ≤ 2, the 40% with an ETD of ≥ 2.1 included divers with pre-existing ear health problems. The routine use of ETD testing for divers to prevent further ear injury has been suggested.[17–21] Our data failed to demonstrate a relationship between ETDQ-7 measures and an increased number of aborted dives or greater development of ear problems, potentially due to adaptation of diving habits and diving more conservatively.

Many respondents sought medical advice or treatment for perceived problems or injury, but a large number of respondents also chose to self-diagnose and self-treat. Free text suggested that a fear of being prevented from diving was one of the main considerations in failing to seek a medical opinion combined with the ease of hiding the issue through the self-declaration process.[22,23,25]

In Table 1 there were insufficient additional details from respondents to definitively distinguish between 'small amount of bleeding' and 'pain and bleeding'. More severe issues such as inner ear DCS are not always reported or accurately diagnosed.[3,7,25] The present data (Table 1) suggested that divers may experience symptoms of inner ear DCS but choose not to seek advice. Inner ear DCS was physician-diagnosed in six respondents, but dive profiles including gas mix and depth, pre-existing persistent (patent) foramen ovale, treatments and outcomes were not revealed. The increasing prevalence of inner ear DCS has been observed in recreational dive populations and discussed.[14] This may be due to technical advances in dive equipment, as well as mixed gas diving enabling more divers in general to access greater diving depths than in the past. Although three technical divers reported inner ear DCS these data should be treated with caution as this finding is likely due to small numbers and/or reporting bias.[1,12–14]

Decongestants were successfully used in a quarter of all respondents with some using decongestants prophylactically for every dive. There was no statistical difference between decongestant use and the rate of inner and/or middle ear barotrauma, suggesting that decongestants were being self-administered without negative outcomes.

Divers generally showed a poor awareness and understanding of the ear health recommendations published by the UKDMC.[15] It is unknown whether better informed divers would have been at lower risk of inner ear DCS in this cohort. It is likely that the rate of aborted dives and the high level of unreported and self-treated ear problems could be significantly reduced through better education and timely review (if there has been a change in ear health) by an appropriately trained physician; this coupled with a more discerning view on whether to dive given their ear-health status at any time.

The diver and diving demographics in this cohort were consistent with UK diving club culture, which accounts for more dives per annum per head than might be expected in sport divers from other geographical areas.[22,23]

LIMITATIONS

This was an anonymous, self-reporting survey with no controls or the ability to follow up divers who reported issues. Although the ETDQ-7 is a useful and reliable tool it is only a window of information regarding the respondents' ear status covering the one-month period immediately prior to completion of the questionnaire. No further auditory testing was performed on our respondents. It is widely accepted that surveys of this type may suffer from bias with divers experiencing problems more likely to respond, but conversely the anonymity of the study allows gathering data that may be lost otherwise to the researcher.

Conclusions

Some divers joined the sport with unassessed, pre-existing otological problems. Of 790 respondents to this survey, 628 (79%) reported ear problems during their diving career, almost half of whom were undertaking preventative measures pre-dive and self-diagnosing and self-treating symptoms rather than seeking medical advice. Education of divers and diving instructors on medical guidelines, equalisation techniques and encouragement to seek medical advice where appropriate should be encouraged.

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Hyperbaric oxygen treatment for refractory haemorrhagic cystitis occurring after chemotherapy and haematopoietic stem cell transplantation: retrospective analysis of 25 patients

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Key words
Cyclophosphamide; Hematopoietic stem cell transplantation; Hemorrhagic cystitis; Hyperbaric research

Abstract
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Introduction: Intractable haemorrhagic cystitis (HC) is a serious complication of chemotherapy (CT) and haematopoietic stem cell transplantation (HSCT). Hyperbaric oxygen treatment (HBOT) is a promising treatment option based on the similarities in injury pattern and observed histological changes with radiation induced HC, which is an approved indication. We present our experience with HBOT in HC occurring after CT and HSCT.
Methods: Medical files of patients who underwent HBOT between the years 2000–2020 for HC that developed after chemotherapy and/or HSCT were reviewed. Demographic data, primary diagnosis, history of HC and details of HBOT were documented. Treatment outcomes were grouped as complete and partial healing, no response and deterioration.
Results: Twenty-five patients underwent a median of 12 HBOT sessions for HC occurring after CT and HSCT. Complete healing was observed in 11 patients whereas haematuria improved in seven patients. HC grades after HBOT were significantly better than referral grades. A significant correlation was shown with the number of HBOT sessions and change in haematuria. Patients who underwent seven or more HBOT sessions benefitted most.
Conclusions: HBOT appears to be a safe and effective treatment for refractory HC following CT and HSCT. Higher quality evidence would be needed to prove efficacy. However, given the difficulty of conducting randomised controlled trials on such a vulnerable and small group of patients with few treatment options, and given the consistency of current observational evidence, HC occurring after CT and HSCT may be considered as an optional or investigational indication for HBOT.

Introduction

Haemorrhagic cystitis (HC) is a diffuse bladder inflammation that causes haematuria and other urinary tract complaints. Clinical presentation can vary from painless microscopic haematuria to severe occlusive haematuria that causes renal failure. It can be a life-threatening situation requiring challenging treatments with prolonged hospitalisation, multiple transfusions and sometimes aggressive interventions while impairing quality of life. Acute HC is mostly caused by bacterial infections and responds well to treatment.[1,2] Chronic or intractable HC is related mostly to treatment of malignancy and can be induced by radiotherapy, some chemotherapeutics (particularly cyclophosphamide) and haematopoietic stem cell transplantation (HSCT).[3] Interstitial cystitis is another but comparatively rare cause.

Cyclophosphamide is used for preconditioning before HSCT and in the treatment of certain solid tumours and lymphoma, as well as some immune-inflammatory conditions like systemic lupus erythematosus or Wegener's granulomatosis.[4] Cyclophosphamide induces HC through its urotoxic metabolite acrolein which impairs the integrity of urothelium when comes in direct contact and causes mucosal and submucosal oedema, ischaemia and cell loss. Consequent bleeding from telangiectasic capillaries develops.[5] In immunocompromised patients, specifically after HSCT, urotropic viruses like BK Polyoma virus, John Cunningham virus or adenovirus types reactivate and replicate in the already injured mucosa.[6,7] Finally, it is thought an immune reaction directed towards virus antigens further damages the mucosa leading to haemorrhage.[8] HC associated with HSCT is regarded as early onset when it starts between 48 hours to one week after preconditioning. Late onset HC, conversely, may occur weeks after the transplant.[3] Histologic changes in chemotherapy (CT)- and HSCT-related HC are very similar to those in radiation-induced HC, which is characterised by progressive endarteritis, mucosal and submucosal oedema and inflammation with cellular hypoxia leading to fibrosis and diffuse telangiectasia.[9,10]

Management of HC occurring after CT and HSCT is primarily based on prevention. Mesna, which binds the urotoxic metabolite acrolein in the urine, and supportive treatments like hyperhydration (forced diuresis) and continuous bladder irrigation are the common methods for prevention.[6] HC incidence after CT and HSCT has declined significantly with these measures however they are not always successful and HC may still develop.[4] Supportive treatments are first line options but their efficacy is limited once haemorrhage starts and HC may progress.[2] Spontaneous remission is also possible in some but it may take a long time with significant morbidity in the interim.[6,11]

There is no definitive treatment algorithm when prevention fails but a wide range of therapeutic approaches have been investigated. Systemic use of pentosane polysulphate sodium, oestrogens, recombinant factor VII or VIII and some growth factors are conservative options however results are inconsistent. Intravesical instillation of some agents like hyaluronic acid, prostaglandins or alum have been reported but evidence for their use is conflicting. Antivirals, specifically cidofovir (both intravenous and intravesical use) were shown to be beneficial in the presence of virus but efficacy still needs to be validated. Besides, deterioration in renal function is a serious concern. Recently cellular therapies were introduced but scientific support is still scarce. Aggressive surgical interventions ranging from clot evacuation, fibrin glue application to vesicostomy, selective arterial embolization, and even cystectomy may be necessary in unresponsive cases.[3,6,11]

Hyperbaric oxygen treatment (HBOT) has emerged as a non-invasive modality for HC occurring after CT and HSCT based on the similarity of histological changes to radiation-induced HC (an accepted indication for HBOT), and promising results have been reported.[3,5] It is proposed as a safe treatment with recommendation levels similar to other options in urological reviews and guidelines.[3–6,11] However, it is not approved in HC after CT or HSCT by the European Committee for Hyperbaric Medicine (ECHM), Undersea and Hyperbaric Medicine Society (UHMS) or our local authority (the Turkish Ministry of Health) and its use is still limited even though refractory HC caused by radiation cystitis is approved.[12,13] Taking account of cumulative evidence from observational clinical reports together with some comparative and experimental studies, HC occurring after CT and HSCT may be considered for approval as at least a weak recommendation. We report our 20-year experience of treating HC occurring after CT and HSCT with HBOT to add to the body of observational evidence.

Methods

This single centre retrospective study was approved by Istanbul Faculty of Medicine Clinical Research Ethical Board with approval number 2017/394.

Patients who underwent HBOT in our department between the years 2000–2020 for HC that developed after chemotherapy and/or HSCT were identified. Radiation-induced HC cases were not included. Patient files were reviewed and demographic data, primary diagnosis, history of HC including previous chemotherapy and HSCT data, treatment before referral and details of HBOT were documented. Severity of HC at the time of presentation and at the end of HBOT was graded as proposed elsewhere[14] (Table 1). A classification was developed to assess the response to HBOT and treatment outcomes were grouped as complete healing, partial healing, no-response and deterioration (Table 2). Complete healing and partial healing were defined as complete resolution of symptoms (HC Grade 0), or reduction in severity of symptoms without complete resolution, respectively.

HYPERBARIC OXYGEN TREATMENT

Hyperbaric oxygen was administered at 243 kPa (2.4 atmospheres absolute) in a multiplace chamber (Hipertech Zyron12, Turkey) once daily, five days per week. Treatment involved 15 minutes of compression; three 25-minute oxygen breathing periods separated by five-minute air breaks; and 15 minutes of decompression. Oxygen was administered by a mask. Medical staff attended all sessions.

The number of HBOT sessions was generally determined on a case-by-case basis depending on the patient's response and general condition. Patients were primarily followed by the referring physician by daily physical examination, blood and urine tests. HBOT was stopped when symptoms totally resolved or no further improvement was observed, or if a patient's general condition deteriorated unrelated to HBOT.

STATISTICAL ANALYSIS

Data were analysed using IBM SPSS v21.0 software. Normality of distribution was evaluated by Kolmogorov-Smirnov test. Demographic and descriptive data were expressed as mean and standard deviation or numbers and

Table 1
Haemorrhagic cystitis grading as proposed by Droller et al.[14]

Grade	Manifestations
0	No haematuria, no irritative symptoms
I	Non-visible (microscopic) haematuria, dysuria
II	Macroscopic haematuria
III	Macroscopic haematuria with small clots
IV	Gross haematuria with clots causing urinary tract obstruction requiring instrumentation for clot evacuation

Table 2
Treatment outcome groups, number of patients and mean number of sessions applied in each outcome group

Outcome	Definition	Patients *n* (%)	HBO sessions Mean (SD)
Complete healing	No residual signs or symptoms	11 (44%)	15 (13)
Partial healing	At least one grade improvement in haematuria but complete healing is not present	7 (28%)	14 (5)
No response	No change in haematuria	7 (28%)	3 (1)
Deterioration	Increase in haematuria	0	0

Table 3
Demographic and medical details of the patients; ALL – acute lymphocytic leukaemia; AML – acute myeloblastic leukaemia; CID – combined immunodeficiency; CML – chronic myeloid leukaemia; FA – Fanconi anaemia; HSCT – haematopoietic stem cell transplantation; MDS – myelodysplastic syndrome; RMS – rhabdomyosarcoma

Patient characteristics	
Female / Male, *n* (%)	9/16 (36% / 64%)
Age, mean (SD)	18.3 (9.8)
Medical details, *n* (%)	
Chemotherapy	25 (100%)
HSCT	22 (88%)
AML	6 (24%)
ALL	10 (40%)
CML	2 (8%)
MDS	4 (16%)
Other (RMS, FA, CID)	3 (12%)

percentages where appropriate. HC grades before and after HBOT were compared by Wilcoxon test for non-parametric paired samples. The Kruskal-Wallis test was used to compare number of HBOT sessions applied in all treatment outcome groups and the Mann-Whitney U test was used to compare pairs of outcome groups. Correlation between number of HBOT sessions and treatment outcomes was investigated with Spearman's rho test. The HBOT efficacy limit was determined using receiver operating characteristic (ROC) analysis. Significance was accepted at $P < 0.05$.

Results

Twenty-seven patients were treated with HBOT for HC occurring after CT or HSCT. Two patients were excluded; one had an incomplete record and one ceased treatment due to a new diagnosed bladder malignancy.

Demographic data and details of previous medical records for the 25 patients analysed are given in Table 3. Female patients (mean [SD] age = 23.7 [13.3] years) were significantly older than males (15.3 [5.6]) ($P = 0.033$). Urotropic virus presence was confirmed in 13 patients. Either no virus was detected or presence was not reported in the remaining 12 patients.

Patients had received conventional treatments after HC occurred. The combination of hyperhydration and continuous bladder irrigation was applied to all patients. Twenty-two patients had received antibiotic therapy. Thirteen patients in whom virus detection was reported had received antivirals. Patients were referred for HBOT after they remained unresponsive to their treatments.

Haemorrhagic cystitis grades at the time of referral and at the end of HBOT are given in Table 4. Grades after HBOT were significantly lower than referral grades. ($P < 0.001$) None of the patients had Grade I at the time of referral. Change in number of patients in each HC grade with HBOT is given in Figure 1. Of the 25 patients included, 11 (44%) healed completely whereas clinical condition improved in seven (28%) and did not change in seven (28%) patients. Haematuria did not worsen in any patient.

Of the seven patients who did not respond to HBOT, two refused to continue after two sessions, one quit after the sixth session due to scheduled chemotherapy and in three others HBOT was interrupted by their primary physicians after the third session due to deterioration in general condition unrelated to HBOT. Similarly, in the partial healing group, four patients' treatments were terminated by their primary physicians as soon as an improvement was observed despite our advice to continue. Complete resolution was reported in three of these patients at eight, 10 and 20 days after HBOT. Nevertheless, these patients were still classified as being in the partial healing group.

The patients underwent a mean of 12 (SD 10) HBOT sessions. The mean number of sessions patients underwent in each outcome group is given in Table 2. The number of sessions applied differed significantly between treatment outcomes ($\chi 2 = 13.13$; $P = 0.001$). There was no statistically significant difference between the number of sessions applied in the total healing and the partial healing group but the number of sessions in the no response group was significantly less than both the complete and partial healing groups ($P = 0.002$ and 0.008 respectively). A significant correlation was shown with the number of sessions applied and change in HC grades with HBOT (rho = 0.601, $P = 0.001$).

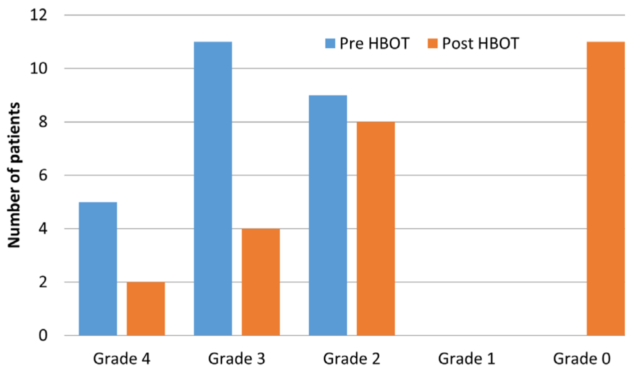
Table 4

Number of patients in each haemorrhagic cystitis grade group before and after HBOT; * no response; † partial healing; ‡ complete healing

Haemorrhagic cystitis grade before HBOT	Haemorrhagic cystitis grade after HBOT (*n*)				
	Grade IV (*n* = 2)	Grade III (*n* = 4)	Grade II (*n* = 8)	Grade I (*n* = 0)	No haematuria (*n* = 11)
Grade IV (*n* =5)	2*	2†	0	0	1‡
Grade III (*n* = 11)		2*	5†	0	4‡
Grade II (*n* = 9)			3*	0	6‡
Grade I (*n* = 0)				0	0

Figure 1

Change in the number of patients in each haemorrhagic cystitis grade group before and after HBOT



ROC analysis revealed that patients who underwent seven (sensitivity = 0.889; specificity = 1.000) or more HBOT sessions benefitted from the treatment more (area under curve = 0.964; %95 GA: 0.803–0.999; $P < 0.0001$).

Discussion

The first reports of HBOT use in cyclophosphamide-induced HC dates back to the beginning of the 1990s.[15,16] Since then a number of studies have been published. All these studies have a few points in common. (1) Almost all of them are either case reports or series. (2) HBOT was applied as a last resort after all available treatments of the time had been tried. (3) Generally severe cases were referred. (4) Almost all studies report successful results with complete cessation of haemorrhage. (5) An exact mechanism of action was not proposed either in these clinical studies or in the few experimental studies conducted later. (6) Similar to many other applications of HBOT, treatment protocol (pressure, time, frequency, total number of sessions) varied among studies. (7) Haematuria generally did not recur during the follow up time indicated.

There are no controlled trials of HBOT in HC occurring after CT and HSCT but there are several case reports all with successful results.[17–32] It is possible that only cases responding well to HBOT were reported in single case reports so case series may provide a more objective evaluation of the efficacy of HBOT. Complete healing was reported in all referred patients in two of the five case series available and few patients remained unresponsive in the other three.[9,33–36] The only patient who did not show complete healing in one report was reported to have Fanconi anaemia and received only five HBOT sessions due to "*pressure intolerance*".[33] In another study, the recovery rate with HBOT was 78%; significantly higher than achieved with prostaglandin treatment.[34] Likewise, seven of ten paediatric patients healed completely and haematuria resolved in two of the three non-recovered patients shortly after ceasing HBOT.[35] No recurrence was reported in any of the case reports or series so far.

There are few relevant experimental studies however they all show beneficial effects of HBOT on damaged bladder. The first study of acrolein-induced HC in rats, showed that HBOT applied prior to and after acrolein installation increased the amount of intact bladder epithelium.[37] Later, consecutive animal studies investigating HBOT's role in cyclophosphamide induced HC were conducted.[38–41] Initially the authors compared protective effects of HBOT and Mesna by evaluating changes in bladder weight, ratio of bladder weight to body weight and haematuria grades. It was found that when HBOT was added to Mesna, urothelial damage was minimal and evaluated parameters were comparable to the control group.[38,39] Their subsequent study investigating nitric oxide involvement in CT induced HC and its relation to HBOT, showed that HBOT decreased the necrotic area in the bladder and concluded that HBOT was more therapeutic than prophylactic. They confirmed this result in their next study that showed accelerated urothelial regeneration with HBOT.[40,41] Recently, HBOT was shown to decrease inflammation, oedema, fibrosis and tissue damage of bladder mucosa in a hydrogen peroxide-induced chronic cystitis model.[42] Results observed in experimental studies are in line with clinical reports in general. Yet, well designed experimental studies looking into possible mechanism of HBOT in HC would fill a gap.

The present retrospective analysis of 25 patients showed HBOT can be useful for HC occurring after CT and HSCT. Apart from being the largest series presented to date, this study differs from the previous ones by evaluating the response to HBOT in terms of change in haematuria severity instead of cure rate alone. This provides a clearer view on the effects of HBOT. In our study group, haematuria ceased in eleven patients and improved in seven, while no change was observed in the rest of the patients. Complete healing in our study was less than healing rates reported before. However, premature interruption of HBOT was common in our patient group whereas only a few patients were reported to withdraw prematurely in previous series. It can be speculated that outcomes could be better if these patients had received more sessions. Indeed, our findings revealed that number of HBOT sessions had an impact on treatment outcomes. Additionally, the minimum number of sessions for HBOT to be effective was found to be seven. Yet, all seven patients in the no response group underwent less than seven sessions due to problems unrelated to HBOT. Again, the possibility of a better outcome with additional sessions cannot be ignored.

Naturally, in a group where spontaneous remission is possible and other treatment methods are also applied it is hard to attribute healing solely to HBOT. However, in our study group all patients had received treatments that were accepted standard of care at the time they had been treated and had remained unresponsive. As was the case in most of the previous reports, improvement was observed only after they started HBOT. In a recent study that compared HBOT with conventional therapies for HC occurring after HSCT, HBOT was found to have higher complete resolution rates and shorter treatment times.[43] A similar result was revealed in a study in which HBOT was compared to prostaglandin instillations.[34]

HBOT increases tissue oxygenation and vascular endothelial growth factor, initiates stem cell mobilisation, capillary angiogenesis and fibroblast proliferation, decreases oedema and fibrosis, improves granulation and epithelialization, all leading to healing in damaged and ischaemic tissue. Moreover, by modulating leukocyte function, it reduces pathological inflammation and enhances immune responses to pathogens.[9,44] Both in cyclophosphamide- and virus-induced HC pathological findings show inflammation and ulceration in bladder mucosa. The underlying mechanism is thought to be ischaemia which leads to mucosal breakdown.[7,10] HBOT elevates tissue oxygen tension in hypoxic urothelium, normalising tissue healing and so helping the repair of damaged bladder mucosa. Provision of permanent healing is attributed to this mucosal repair.[18,19,23]

There is no definitive HBOT protocol for HC occurring after CT and HSCT and data about number of sessions required for efficacy and treatment schedules are inconsistent. The minimum number of sessions at which a response to treatment was observed is three. In a few other cases, haematuria or tamponade were reported to resolve with a maximum of five sessions.[20,27,28] However, various numbers of sessions are reported and an objective analysis about minimum effective sessions is not available. Our findings may contribute to treatment planning in this regard.

The total number of sessions applied also varies in the existing literature but is generally less than 40. Four patients were reported to undergo higher number of sessions (56, 58, 60 and 84 sessions) until complete healing was achieved.[22,24,33,34] In the present study, the majority of patients received less than 20 sessions. Two patients who eventually healed completely underwent 39 and 42 sessions. It is clear that a maximum number of sessions can't be proposed with the limited data available. Nevertheless, when the similarity of pathophysiology is considered, common practice for radiation induced HC may be adapted.

A similar uncertainty is present about the timing of HBOT. In most of the reported cases, HBOT has been used after all other treatments fail. However, HBOT is expected to be more beneficial in the earlier period when its possible mechanisms of action are considered.[19] Besides, HBOT does not interfere with other treatment options so can be applied as an adjuvant. In fact, one study showed that haematuria resolved significantly faster in the patients who started HBOT early in the clinical course.[33] Several authors suggest early referral for HBOT instead of using it as a last resort.[18,23]

HBOT is a relatively safe modality. The most common side effect is middle ear barotrauma which is reversible and serious side effects are very rare. No side effects were recorded in our patients. The most unusual event reported in previous articles is a capillary leak syndrome in a patient with Fanconi anaemia.[45] This patient developed generalised oedema, hallucinations and confusion after the ninth HBOT session and all symptoms disappeared when HBOT was ceased. The authors speculatively related this condition to toxic effects of oxygen and recommended avoiding HBOT in HC patients with Fanconi anaemia. Interestingly the only patient who remained unresponsive to HBOT in another study also had Fanconi anaemia which the author presented as a relative contraindication. Apparently, the patient withdrew from treatment after five sessions not due to a recognized side effect but a condition defined as "*pressure intolerance*".[33] Our Fanconi anaemia patient discontinued after 11 sessions due to deterioration in general condition. His haematuria had improved at the time of cessation and later resolved completely. He was included in the partial healing group as mentioned earlier. We cannot exclude the possibility of an adverse effect since the primary physician did not provide details about the patient's condition.

A more prominent threat to these patients would be cross infection during their visits to hyperbaric chamber. They are generally immunosuppressed and prone to infection, but in daily practice many patients, specifically wound care patients, with resistant nosocomial infections are also treated in hyperbaric chambers. Therefore, management of HC patients at hyperbaric unit and in the chamber would require particular care.[10] Such a complication has not been reported before however all our patients underwent exclusive HBOT sessions scheduled as the first session of the day and the chamber was disinfected before each session. Moreover, patients who require continuous irrigation may have difficulties especially in monoplace chambers. In one report, an in-chamber continuous irrigation scheme initially used was abandoned due to a bladder rupture that developed during a session.[46,47]

Although remarkable healing has been reported with HBOT, its use in HC occurring after CT and HSCT is relatively uncommon. This is probably due to the scarcity of robust evidence for its use. On the other hand, almost all other current and commonly adapted methods also have similar or weaker evidence.[3,11,48] In the 6th European Conference of Infections in Leukaemia (ECIL) treatment guidelines, HBOT has similar levels of evidence and recommendation to intravenous cidofovir and fibrin glue for the treatment of HC after HSCT whereas other approaches are not recommended at all.[11] In a recent systematic review of BK virus-related HC, HBOT was considered to be "*effective and safe*" for treatment and stated to have level 4 evidence with a grade C recommendation. A higher level of evidence (Level 3) was defined only for intravenous cidofovir in this review.[6] Also, in the Canadian Urological Association's best practice report for paediatric HC, HBOT is again presented as "*safe, effective and relatively low risk*" and stated to have Level 3 evidence with a grade B recommendation. Similar or weaker evidence was identified for all other therapeutic modalities and even preventive measures like hydration or Mesna.[3]

In hyperbaric medicine guidelines, however, HC occurring after CT and HSCT is not included while other common intractable HC states are. Radiation-induced HC is an approved indication by both the ECHM and UHMS. Until very recently there was only one randomised trial which actually compared efficacy of hyaluronic acid and HBOT in radiation cystitis and other support came from retrospective observational studies. It was only in 2019 that a randomised clinical trial demonstrating effectiveness of HBOT for radiation cystitis was published.[49] Interstitial cystitis is also an ECHM-approved indication although with a weak recommendation (type 3; reasonable to use).[12] The level of evidence is stated to be low and similarities in the mucosal injury with radiation-induced HC forms the basis for approval. HC occurring after CT and HSCT also exhibits a similar injury pattern and histological change.[9,10,19] Although there are not any high-level evidence studies like RCTs on HBOT use in HC occurring after CT and HSCT, numerous observational clinical studies and some comparative studies have consistently reported successful results. Experimental studies also show reparative effect of HBOT on damaged bladder mucosa. When evaluated collectively, there is support for evaluation of HC occurring after CT and HSCT as an indication for HBOT.

LIMITATIONS

This is the largest series of CT and HSCT-related HC treated with HBOT to date but it has some limitations due to the retrospective nature of the study. First, long term follow-up information is absent. Yet, in previous reports, only one recurrence which later recovered was reported during follow ups extending to 136 months.[9,50] Indeed, HBOT is considered to provide "*permanent healing*" and was even proposed to be "*disease modifying*" by some authors.[17,25]

Also, analysis about viral loads and how they were modified with HBOT as well as correlations between treatment outcome and onset of HC could not be performed since there were missing data in patient files. In the studies in which viraemia and viruria during HBOT was followed, significant decreases in virus counts were observed.[4,6,51] HBOT does not have a known antiviral effect. Therefore, this decrease is probably due to recovery of the hypoxic and inflamed bladder mucosa, which may be a convenient environment for the opportunistic viruses in these immunocompromised patients.

Another important drawback of the study is absence of specific treatment guidelines for the patient group who were treated. Decisions on the referral for HBOT and the course of treatments were made on a case-by-case basis. The heterogeneity of the collected data made evaluation harder. In addition, neither the referring physicians nor the HBOT specialists were blinded to the treatments. Therefore, possibility of bias in interpreting the clinical course cannot be excluded. There is a need for prospective randomised controlled trails with clear treatment guidelines and outcome reporting.

Conclusions

Haemorrhagic cystits patients have primary diseases which are life threatening and have been generally treated with hard, sophisticated and expensive therapies. However, HC itself can be more serious than the primary disease due to the suffering and morbidity it causes. Our study and others have shown HBOT is safe and can benefit these patients. It is evident that studies investigating the mechanism of action of HBOT specifically in HC and prospective controlled clinical studies are required. Given the difficulty of conducting randomised trials on such a vulnerable and small group of patients with few treatment options, and given the consistency of current observational evidence, HC occurring after CT and HSCT may be considered as an optional or investigational indication for HBOT.

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Post COVID-19 fitness to dive assessment findings in occupational and recreational divers

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Pulmonary barotrauma; Radiological imaging; SARS-CoV-2; Scuba diving

Abstract
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Introduction: It is now known that COVID-19 has long term effects that may not correlate with clinical severity of disease. The known pulmonary and cardiovascular changes as well as thrombotic tendency could predispose to diving accidents. We aimed to investigate COVID-19 related changes that may cause disqualification from diving among divers who recovered from the disease.
Methods: Occupational and recreational divers who applied for fitness to dive (FTD) assessment after COVID-19 infection were included. Routine FTD assessments were performed. Details of COVID-19 history were evaluated. Lung computed tomography (CT) scans were advised if not previously performed or if there were COVID-19 related changes in previous scans. Divers with pathological findings were restrained from diving and followed prospectively.
Results: Forty-three divers were analysed. Thirteen divers were restrained from diving, all due to persistent COVID-19 related changes in lung CT. The prevalence of CT with at least one lung lesion was 68.2% at the time of diagnosis, 73.3% in the first three months after diagnosis and 19.2% later. The most common CT findings were glass ground opacities and fibrotic changes. Demographic characteristics and COVID-19 history of divers deemed ‘unfit’ were similar to those deemed ‘fit’.
Conclusions: Divers who recover from COVID-19 should undergo FTD assessments before resuming diving. A chest CT performed at least three months after diagnosis may be suggested.

Introduction

Severe acute respiratory syndrome caused by the SARS-CoV-2 virus commonly referred as COVID-19, is a multisystem infection although the major insult is to the lungs. The pathophysiology and course are still not fully understood but it is clear that COVID-19 can have persistent effects. These effects do not correlate reliably with the severity of the disease and even asymptomatic patients have been shown to have lingering manifestations.[1,2] The most common persistent effect is pulmonary damage and this can vary from mild radiological changes to severe respiratory dysfunction that would require long term oxygen therapy. Cardiovascular problems, a thrombotic tendency and some neurological problems have also been reported frequently.[3] These sequelae may have physiological and social consequences both on patients and health system.

Diving, either occupational or recreational, can be a challenging activity due to the effects of immersion and pressure change on human physiology and sometimes strenuous exercise. Increased venous return and peripheral vasoconstriction caused by immersion and cold increase both the preload and afterload putting a considerable stress on cardiac function. Respiratory work increases as density of breathing gas and airway resistance increases with the increase in ambient pressure. When additional physical effort is needed during a dive this cardiac and respiratory stress may intensify.[4] Pressure changes may also cause reciprocal volume changes in gas filled spaces in the body, primarily lungs. Pressure equalisation or volume compensation is required for these bodily spaces during a dive. Existence of air trapping lesions or inability to compensate these variations in volume may lead to serious barotrauma.[5] Therefore, an adequate health and physical condition are prerequisite for safe diving.

When there are health risks fitness to dive (FTD) assessment is needed for divers. Indeed, it is obligatory for occupational divers to be medically certified. They undergo periodic examinations and are screened to exclude any conditions that may cause unconsciousness, decrease exercise capacity and predispose to barotrauma, especially in the lungs.[6] Failing to meet health standards may result in job loss for occupational divers. Regular examinations are strongly advised for recreational divers as well, although this advice is frequently not followed.

Given the potential long-term effects of COVID-19, the possible risks of diving for people who recovered from the disease have been a concern to diving community.[7] Several guidelines and position documents about returning to diving after COVID-19 have been published, but they are mainly based on general coronavirus infections knowledge.[8,9] Thus, data describing the post-COVID-19 condition of divers is important for development of more specific guidelines. In this cross-sectional observational study, we aimed to screen the divers who applied for FTD assessments after recovering from COVID-19 for symptoms and sequelae which could interfere with diving. Here we report our preliminary findings which may help physicians involved in FTD assessments and to develop guidelines.

Methods

This study was approved by the Istanbul Faculty of Medicine Clinical Research Ethical Board (approval number 2022/72).

After the recognition of long-term sequelae of COVID-19, we informed local divers about the potential effects of the disease on FTD in webinars or with repeated statements shared in social media platforms. We advised all divers who recovered from COVID-19 to take a FTD assessment before resuming diving.

Divers who applied to our department for FTD assessments after COVID-19 infection were evaluated retrospectively. Divers who had a confirmed COVID-19 diagnosis either through a positive polymerase chain reaction (PCR) test or suggestive history and chest computed tomography (CT) findings in the absence of a positive PCR test, who had at least one pulmonary imaging study, were 18 years or older and agreed to share their medical records were included in the study. Demographic data (age, gender, weight, height, previous disease and medication, smoking, alcohol and drug use) and diving history (diving experience, certification, intention) of the divers were recorded. Divers who did not present any radiological or laboratory results to confirm COVID-19 infection were excluded from analysis.

FTD ASSESSMENTS

Routine FTD assessments involved blood testing (fasting glucose, liver and renal function tests, lipids, total blood count) and urinalysis, audiological evaluation, respiratory function testing, electrocardiogram (for divers older than 40) and radiologic imaging of joints, sinus and lungs (when necessary). A thorough physical examination was conducted. We advised low dose chest CT to the divers who had not undergone a CT during or after the COVID-19 diagnosis. Divers were referred to the cardiology department if there was a decrease in effort capacity or any other cardiovascular condition related to COVID-19 was suspected or reported by the diver. Although respiratory function tests are usually mandatory in routine assessments, they could not be performed for most of the divers because of concerns around associated risk of disease transmission.

CT IMAGING AND GROUPS

All lung CT images were evaluated by the same pulmonology specialist with a 30-year experience in the field. The presence of air trapping lesions (pneumatoceles); fibrotic sequelae, reticulations; architectural distortion; honeycombing; traction bronchiectasis; mucus plugging, ground glass opacities, parenchymal lesions and others (crazy paving pattern; nodules; pleural thickening or pleural effusion) were assessed. If a condition considered an absolute contraindication to diving was detected the diver was permanently disqualified irrespective of whether the finding seemed related or unrelated to COVID-19.

Divers were broadly classified according to the availability of CT scans prior to the FTD assessment.

Divers who had one CT scan performed before they applied for FTD assessment were grouped as ‘during diagnosis’ if the scan was performed in the first week of diagnosis, ‘first three months’ if the scan was performed anytime between the end of the first week and beginning of the fourth month after the diagnosis, and ‘later than three months’ if performed after the beginning of the fourth month (regardless of the time of FTD assessment). If no pathological finding related to COVID-19 was detected in their scan the diver was cleared for diving. If a COVID-19 related finding was observed the diver was considered temporarily unfit for diving and a follow-up CT scan at least three months after initial one was advised. Follow-up CT scan results were added to groups ‘first three months’ and ‘later than three months’ according to their timing.

Some divers had undergone more than one CT scan before they applied for FTD assessment of their own volition or at the request of another physician. Timing of these scans was again classified as described above. In these cases the most recent CT scan was taken into consideration for FTD assessment. If a COVID-19 related finding was observed, the diver was considered temporarily unfit for diving and a follow-up CT scan was advised.

COVID-19 HISTORY

A detailed COVID-19 history was taken. The time and method (PCR test/CT scan) of diagnosis, symptoms and signs, blood tests (involving acute phase reactants, total blood count, metabolic parameters, liver and renal function tests, sedimentation, coagulation parameters, D-dimer where available), other diagnostic and imaging studies performed during the course of the disease, medication and other treatments (high flow oxygen, positioning, convalescent immune plasma therapy), duration of hospitalisation and days in intensive care unit where applicable were recorded. If

Table 1
Demographic and diving data of the divers included in the analysis. BMI – body mass index

Parameter	Male (*n* = 35)	Female (*n* = 8)	Total (*n* = 43)
Age (years), mean (SD)	41.7 (10.8)	36.3 (10.7)	40.9 (10.6)
BMI (kg·m^{-2}), mean (SD)	28.1 (4.7)	25.2 (3.8)	26.9 (4.6)
Smoking, *n*	10	–	10
Professional diver, *n* (%)	15 (40.6%)	2 (25%)	17 (37.5%)
Total diving years, mean (SD)	13.1 (9.6)	8 (6.4)	12.4 (9.3)
Total dives, mean (SD)	1,703 (3,301)	2,644 (7,017)	1,882 (4,161)
Divers with comorbidity, *n*	10	2	12
Comorbidities			
Cardiovascular disease	4	1	5
Lung disease	3	–	3
Diabetes	3	–	3
Other	1	1	2

Table 2
Common COVID-19 symptoms among 43 divers and number of divers who reported each symptom

Symptom	Divers *n* (%)
Fever	29 (67.4)
Fatigue	26 (60.4)
Body and muscle ache	24 (55.8)
Dyspnoea	18 (41.9)
Loss of smell/taste	17 (39.5)
Cough	16 (37.2)
Chilling	11 (25.6)
Headache	8 (18.6)
Sore throat	8 (18.6)
Gastrointestinal symptoms	6 (13.9)
Runny nose	2 (4.7)

any follow up tests were performed before FTD assessment, these were also taken into account.

ANALYSIS

Numerical results from blood and urine tests were presented as in normal range, increased or decreased. Demographic and descriptive data were expressed as mean and standard deviation or numbers and percentages where appropriate. Statistical analysis was performed using the Med-Calc® for Windows (version 11.2.1.0). Data distribution was evaluated using the Kolmogorov-Smirnov test. A Student's *t*-test was used to compare paired samples and the 'N-1' Chi-square test was used to compare proportions. Significance was accepted at $P < 0.05$.

Results

Fifty divers who recovered from COVID-19 presented to our department for FTD assessment over four months until the end of April 2021. Six divers did not have any prior pulmonary imaging (CT or X-ray) or undergo one so were not included in the analysis. One other diver was excluded as he was younger than 18. Forty-three divers (eight female, 35 male) were evaluated. Demographic data and the diving history of the divers are presented in Table 1. Mean time to apply for FTD after COVID-19 was 5.3 months.

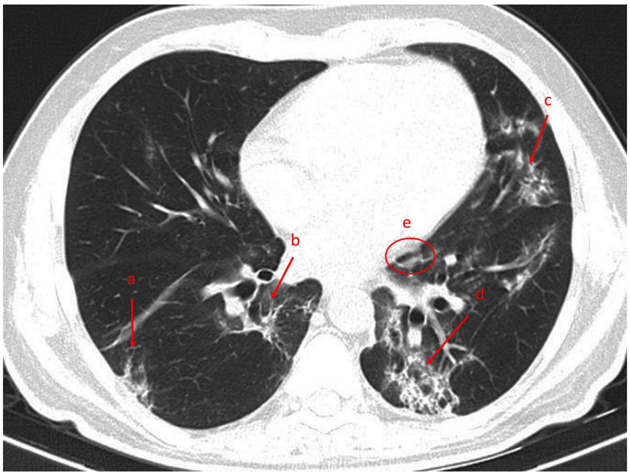
Thirty-three divers were non-smokers. Twenty-five (seven female, 18 male) had not smoked at all and eight had quit at least five years ago. Twenty-nine divers (six female, 23 male) had not experienced any serious health problem. Cardiovascular problems were cerebrovascular accident, hypertension and hypercholesterolaemia. Pulmonary problems (other than COVID-19) included mild asthma and previous tuberculosis. One male had Buerger's disease and one female diver had Hashimoto thyroiditis.

The COVID-19 history was heterogeneous among divers. Six male divers were asymptomatic and were detected via contact tracing. All other divers had symptomatic COVID-19 of variable severity. The most common symptoms were fever, fatigue and body and muscle aches. Reported symptoms and prevalence are given in Table 2. Eleven divers (eight male) were hospitalised. One of the three hospitalised female divers was admitted because she was giving birth. Intensive care admission was required for only one diver who had respiratory failure and a thromboembolic event.

Antivirals (*n* = 33), hydroxychloroquine (*n* = 8) and anticoagulants and/or antiplatelet drugs (*n* = 19) were commonly used for treatment. Favipiravir was the mostly prescribed antiviral and only one diver was given oseltamivir. Four divers received convalescent immune plasma therapy

Figure 1

An example of a pulmonary CT image of a diver who was deemed unfit for diving due to residual COVID-19-related findings; a – fibrotic changes affecting the pleura; b and c – fibrotic changes with bronchiectasis; d – fibrotic cystic changes; e – air cysts



and one diver received Interleukin 6 antibody. Inhaled corticosteroids were required for two divers. Two divers took colchicine during the course of their treatment. Five divers, one female who was giving birth, and four males, did not take any medication for COVID-19.

All divers but one who was pregnant at the time of diagnosis underwent at least one CT scan; the exception presented with an X-ray performed one month after diagnosis and no COVID-19 related finding was detected. Twenty-two divers had CT scans at the time of diagnosis. There was a total of 15 and 26 divers who underwent CT imaging in the first three months and later than three months respectively. Prevalence of CT imaging with COVID-19 related pathological findings and common findings in each group are summarised in Table 3. The most common COVID-19 related findings in all CT scans were ground glass opacities (GGO), fibrotic changes, alveolar consolidation and emphysematous change. An example of a pulmonary CT image with residual COVID-19 related findings is presented in Figure 1. Of the fifteen divers with a COVID-19 related finding in CT scanning at diagnosis, seven underwent a follow up CT in the first three months while eight divers underwent CT later. Four divers underwent two follow-up CT scans (CT scans at all three time points).

Two male divers one of whom was professional were found to have tuberculosis related changes. They were not included in the COVID-19 related findings table. Two divers who had normal CT scans at diagnosis had COVID-19 related changes in their scans performed in the first three months. Both resolved after a further three months.

Laboratory testing also varied greatly. Sixteen divers had blood test results from the time of diagnosis. Complete blood count and C-reactive protein (CRP) were studied in all. Lymphopenia was detected only in two divers and CRP elevation, mostly mild, was found in four divers. D-dimer was above the normal range in five of the 14 divers who were tested. Lactate dehydrogenase (LDH) and liver function tests (LFT) were elevated in six and five divers respectively whereas renal function tests and urinalysis were invariably normal. Six divers did not have any abnormal results. Complete blood count, coagulation tests and inflammatory markers were normal at the time of FTD assessments for all divers. No abnormality was detected in liver and renal function tests and urine analysis during FTD assessments.

No thromboembolic or cardiac sequelae were found during FTD assessments. Physical examination did not reveal any significant findings in any of the divers. Fifteen divers (one female, 14 male) were found unfit to dive all due to pathological findings in chest CTs. Of these, two male divers, one of whom was professional, were found to have tuberculosis related changes, and thirteen divers, seven professional and six recreational, had persistent COVID-19 related changes. Details of demographic data, COVID-19 history, treatment and CT imaging of the 13 divers who were deemed unfit due to COVID-19-related findings are presented in Table 4.

One professional diver had an air trapping lesion in the CT performed in the third month following COVID-19 diagnosis and was permanently disqualified. A re-assessment at least three months later was scheduled for the other twelve divers regardless of their initial time of assessment in our department.

Divers who were deemed unfit for diving because of COVID-19 effects (n = 13) were not different from the rest with respect to age (P = 0.124), body mass index (P = 0.531), rate of comorbidity (P = 0.887) and smoking (P = 0.519). Severity of disease among unfit divers varied from asymptomatic to ICU requirement and their hospitalisation rate (6/13 divers, 46.2%) was higher than fit divers (5/28 divers, 10.7%). Also, all divers who were found to have elevated D-dimer and lymphopenia were among the unfit divers. Seven of the 28 divers who were found fit to dive had pathological CT findings in their previous imaging studies performed either at diagnosis or in the first three months after diagnosis but normal CT at the time of FTD assessment. Details of demographic data, COVID-19 history, treatment and CT imaging of these seven divers are also presented in Table 4.

Discussion

Our experience suggests that divers who apply for FTD assessments after COVID-19 may have persistent changes on CT scanning involving GGO's, consolidations, reticulations and air trapping regardless of the severity of the disease. General characteristics and prevalence of the lesions in our cohort are similar to data previously reported.[1,3] In many of the follow up studies, mosaic attenuation pattern marked

Table 3
Number of first and follow-up CT scans performed at diagnosis, in the first three months after diagnosis and after the first three months, and number of CT scans that were found to have at least one COVID-19 related finding, with numbers of common findings

Parameter	At diagnosis	First 3 months	Later than 3 months
CT imaging performed (*n*, first time/follow up)	22/NA	7/8	12/14
CT imaging with COVID-19 -related finding (*n*, %)	15 (68.2%)	11 (73.3%)	5 (19.2%)
Common findings *(n)*			
GGO	10	5	0
Consolidation	5	2	0
Fibrotic changes	3	4	5
Emphysema-air trapping	3	2	1
Parenchymal infiltration	2	2	0
Nodule	1	0	0

with hypo- and hyper-inflated zones, bronchiectasis and reticulations which are all associated with pulmonary fibrosis and attributed to small airway disease and air trapping have been reported.[10–13] These residual lesions of COVID-19 may predispose pulmonary barotrauma (PBt) in divers.

It is well known that air trapping may cause overdistention of the lung tissue during ascent when intrapulmonary gas expands as ambient pressure decreases resulting in alveolar rupture.[5] There are a number of reports that present divers who experienced PBt without a provocative incident such as breath holding or rapid ascent and were found to have air trapping lesions.[14–16] Moreover, PBt occurrence either non-invasive or invasive ventilation-associated is found to be higher in COVID-19 compared to other acute respiratory distress syndrome conditions and it is possible COVID-19 may have a unique mechanism that increases the risk.[17,18] It can be speculated that there may also be an increased risk of diving-related PBt in these patients. While this remains to be verified, the possibility that lung damage occurring in COVID-19 can predispose to diving-related PBt should be kept in mind.

Radiologic abnormalities after COVID-19 are shown to regress and change characteristics in time. Many studies report decrease in prevalence of lung lesions during follow-up.[10,11] Also, as GGO's and consolidations are the most common findings in earlier chest CT images, fibrotic like changes are observed to be more prevalent in later radiologic workups.[12,13] That said, an optimum time for radiologic follow-up after COVID-19 has not been defined yet but based on the clinical observations and previous reports, 12 weeks has been suggested. This period is thought to be optimal as most of the radiological abnormalities would resolve and persistent ones that could pose a risk for impairment would be identified as early as possible.[19] In our study, total abnormal radiological findings were reduced in the repeat scans performed later than three months after recovery. Also, some of the divers who were assessed in the first three months and shown to have COVID-19-related lung lesions completely recovered after three months. In this regard, three months or more after recovery seems to be an appropriate time for FTD assessments based on available data.

The optimum method to follow these long-term radiological changes is also a controversial subject. Although chest X-rays are the widely accepted imaging method mostly due to lower radiation exposure compared to CT, their usefulness in follow-up is limited. Fibrosis or fibrotic-like changes in the post-COVID setting have been shown to develop in up to 60% of patients especially in the first three months.[11,12,20] Subtle changes may be clinically irrelevant however sensitivity of X-rays to detect these persistent lung lesions, regardless of severity has been shown to be low.[21,22] In addition, it is now well known that clinical severity of COVID-19 is not a reliable predictor for pulmonary changes in CT.[1,21] It has been an ongoing discussion whether CT scans would be more useful compared to X-rays in FTD assessments but they are generally deemed unnecessary as the rate of diving related pulmonary events in the wider diving population is very low and CT scans may cause overdiagnosis.[23] In contrast, in divers recovering from COVID-19 the potential associated risks and unpredictability of pulmonary lesions that could predispose to PBt may justify CT scanning.

Hypercoagulability along with cardiac damage and stroke are also common after COVID-19 and can even be seen in mild infections.[24] These late effects are specifically relevant for diver assessments after COVID-19 since they can directly interfere with diving safety. Physiological effects of diving and its physical challenges require an adequate exercise capacity. Failing to meet this demand may result in diving accidents. Indeed, cardiac problems are an important cause of diving-related deaths.[25] COVID-19-related cardiac injury which is mostly associated with systemic

Table 4

Details of demographic data, COVID-19 history, hospitalisation and treatments, and COVID related findings in the CT imaging performed at diagnosis, in the first three months, and later than three months for the 13 divers who were deemed unfit for diving, and seven divers who had COVID related findings previously but later were cleared for diving (cleared divers); A.bio – antibiotics; A.coag – anticoagulant drugs; A.plat – antiplatelet drugs; ALV.cons – alveolar consolidation; ATL –air trapping lesion; CPl – convalescent plasma; DM – diabetes mellitus; EC – emphysematous change; F – female; FC – fibrotic change; FPV – favipiravir; GGO – ground glass opacities; HQ –hydroxychloroquine; HT– hypertension; I –inhaled; IGT– impaired glucose tolerance; IL-6 AB – interleukin 6 antibody; M – male; O – oral; P – professional diver; PI –parenchymal infiltrations ; py – pack years; R – recreational diver; vit – vitamin C

	Age/ Sex	BMI	P/R	Smoking	Comorbidity	Symptoms	Hospital admission	Treatment	CT at diagnosis	CT < 3 months	CT > 3 months
Unfit to dive											
1	58/F	25	P	Ex	↑ cholesterol	Fever, fatigue, chills, dyspnoea, cough, muscle/body ache	–	FPV, Vit	–	FC	–
2	34/M	25	P	10 py	–	Fever, dyspnoea, cough, muscle/body ache, taste/ smell loss	–	FPV, HQ	ATL	ATL, FC	
3	50/M	25	R	None	HT, IGT, asthma	Fever, chills	–	FPV, A.plat, A.coag	PI, FC	–	FC
4	52/M	25	R	None	–	Fever, fatigue dyspnoea, cough, taste/smell loss	37 days (23 in ICU)	FPV, A.coag, steroids(I), IL-6 AB	GGO (diffuse)	FC, Al. Cons.,	GGO, FC
5	41/M	23	R	None	–	Fatigue, chills, taste/ smell loss	–	FPV	–	–	FC
6	53/M	28	R	None	Mild asthma	Dyspnoea, cough, muscle/ body ache	6 days	FPV, A.plat, A.coag, CPl,	GGO (diffuse)	GGO, PI	–
7	38/M	39	P	None	–	Fever, fatigue muscle/ body ache	–	FPV, A.plat, vit	GGO	–	–
8	35/M	33	P	None	–	Chilling, fatigue dyspnoea, cough	5 days	FPV, A.coag, A.bio	GGO, FC	GGO (diffuse)	–
9	52/M	28	P	None	Splenectomy	Fever. dyspnoea, cough, muscle/body ache	8 days	FPV, HQ, Steroids(I)	GGO, FC	GGO	

Table 4 continued.

10	55/M	31	P	15 py	HT, insulin resistance	Fever, dyspnoea, cough, muscle/body ache	–	FPV, A.coag, steroids (O), A.bio, colchicine	GGO (diffuse)		
11	56/M	26	R	Ex	–	Fever, fatigue, muscle/ body ache, taste/smell loss	3 days	HQ, A.bio		FC, Cysts?	
12	38/M	27	R	None	None but job with chemicals	Fever, fatigue, dyspnoea	4 days	FPV, A.plat, A.coag, Steroids (I)	GGO, FC, EC		GGO
13	28/M	24	P	5 py	–	None	–	FPV, A.plat, Colchicine	GGO (diffuse)		
Divers cleared to dive											
1	61/M	36	P	None	–	Muscle ache, head ache	–	FPV, HQ	GGO (diffuse) PI	GGO	Normal
2	45/F	25	P	None	–	Fever, fatigue, Sore throat, taste/smell loss	–	FPV, A.coag	GGO, FC	GGO	Normal
3	50/M	29	P	None	None	Fever, chills, muscle ache	–	FPV	Alv.cons, FC	–	Normal
4	44/M	37	P	6 py	TIA, myelitis, HT	None	–	FPV, A.plat	Alv.cons., FC, ATL	–	Normal
5	44/F	36	R	–	Ototiroiditis	Fatigue, dyspnoea, cough	4 days	FPV, A.coag, A.bio	FC	–	Normal
6	53/M	28	P	20 py	Type 2 DM	Fever, fatigue, muscle/body ache	–	FPV, vit	Alv.cons., nodule	–	Normal
7	44/M	29	R	None	–	Sore throat, fatigue, dyspnoea, muscle ache	5 days	FPV, A.plat, A.coag, CPl	–	PI, GGO, septal thickening	Normal

inflammation, hypercoagulability or systemic hypoxia arising from respiratory problems may add to cardiac risk in diving.[26] Decompression sickness, a major diving injury, has a complex pathophysiology in which the coagulation system and inflammatory mechanisms are thought to be involved. Thus, increased risk of decompression sickness due to a hypercoagulable state and hyperinflammation after COVID-19 is another concern for these divers. In addition, acute thromboembolic incidents may complicate differential diagnosis in diving accidents as well as increasing the risks. Fortunately, none of these late effects were encountered in our diver group although minor changes in laboratory findings were observed in a few divers, but these changes were not clinically relevant. Divers taking FTD assessments after COVID-19 need to be scrutinised with respect to cardiac and thrombotic effects.

There are several limitations to our study. The major one is the heterogeneity of the study group, FTD assessment times and evaluated parameters. This was inevitable due to the design of the study and variations in presentation and management of the disease. We tried to minimise this limitation by providing individualised and detailed data as much as possible. Another limitation may be the absence of pulmonary function tests. Spirometric studies do not provide data on structural abnormalities but could have presented a more comprehensive evaluation of pulmonary changes in divers. However, these tests were temporarily ceased in most of the centres due to contamination risks and could not be performed. Finally, we don't have any data about previous diseases or baseline pulmonary problems so some identified abnormalities could have been present before COVID-19. On the other hand, almost half of the divers (n = 7) who had persistent lesions in their chest CT either in first three months or later were occupational divers. Since FTD assessments and certification are an obligation for occupational divers, these divers should have been in perfect health previously. For recreational divers on the other hand there is no obligation for medical screening but since they were actively involved in diving these divers can also be expected to be healthy. Yet, presence of radiological abnormalities before COVID-19 cannot be ignored.

Conclusions

Divers may present with COVID-19-related pulmonary changes that may pose a serious health risk in diving and also cause job loss. Thus, FTD assessment after COVID-19 is of critical importance. Meticulous and timely evaluation with appropriate methods and scheduling re-evaluations to follow possible resolution of residual effects if needed may help optimise FTD assessments.

To our knowledge this is the first report that presents late effects of COVID-19 in occupational and recreational divers. We think our results, even though preliminary, may contribute to the development of guidelines for FTD assessment after COVID-19.

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Short communication

A Delphi study to identify relevant scenarios as the first step toward an international hyperbaric medicine simulation curriculum

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Key words
Education; Hyperbaric oxygen; Safety; Training

Abstract
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Introduction: Evidence across healthcare specialties suggests that simulation-based education improves practices and patient outcomes. However, simulation has yet to be widely used in hyperbaric medicine education. We aimed to identify the most relevant clinical scenarios for inclusion in a simulation-based curriculum for hyperbaric medicine.
Methods: After ethics approval, we used a modified Delphi consensus method. We assembled an initial questionnaire and distributed it online in English and French to an international group of hyperbaric physicians and operators using a snowball recruitment technique. Participants rated the list of scenarios using a 5-point scale ranging from 1 (least relevant) to 5 (most relevant). Scenarios judged by at least 80% of participants to be relevant (score 4 or 5) were automatically included. Scenarios that did not meet this threshold and new scenarios suggested by participants during the first round were included in a second round.
Results: Seventy-one participants from nine countries, including both physicians and non-physicians, completed the first round and 34 completed the second. Five scenarios were identified as relevant: seizure, fire, cardiac arrest, pneumothorax, and technical deficiency such as power loss while operating the chamber.
Conclusions: Five scenarios relevant for inclusion in the simulation-based curriculum in hyperbaric medicine were identified by expert consensus.

Introduction

Simulation-based education is effective for imparting technical and non-technical skills to both individuals and teams across many specialties, particularly in acute care.[1–4] Since simulation poses no risk to actual patients, it is used across the continuum of education from undergraduate and postgraduate training to continuing professional development.[4–6] Evidence suggests that skills learned during simulation transfer to clinical settings, improve team performance and, in turn, may improve patient outcomes.[3,7]

Hyperbaric medicine is widely used to treat patients of all ages with elective and urgent conditions.[8–12] Effective medical management of hyperbaric oxygen treatment (HBOT) in the hyperbaric exposure period requires both individual and team-level clinical competencies, especially in emergency situations or when complications occur.[13] For example, HBOT can involve safety events such as hyperbaric chamber fires, acute respiratory failure or seizure, and complex cases such as patients who are mechanically ventilated.[14] When a patient is inside the hyperbaric chamber, there is an added layer of complexity as the patient cannot be immediately accessed as the chamber must first be decompressed, which may take up to several minutes. Therefore, it is imperative that healthcare professionals who provide HBOT become proficient in technical and non-technical skills; such skills include effective teamwork supported by interprofessional collaboration.

Despite the broad implementation of simulation-based education in the majority of healthcare areas, simulation has yet to be widely used in the context of hyperbaric medicine education. In fact, in our recent systematic search of the literature, we found only one anecdotal case report published in German involving simulation in hyperbaric medicine.[15,16] Without an established curriculum for hyperbaric medicine simulation, healthcare professionals may be missing out on an important opportunity to improve quality of care and patient safety.

In this study, we used a modified Delphi consensus process to identify the most relevant clinical situations in hyperbaric medicine that would benefit from simulated practice.

Methods

We obtained institutional ethics approval for this project from the Ottawa Health Science Network Research Ethics Board (OHSN-REB; Protocol #20190203-01H). Participants who volunteered to participate in the survey were presented with the informed consent document, which explained that they implied their consent by completing the survey.

STUDY DESIGN

We used a modified Delphi consensus process to identify the most relevant clinical situations that would benefit from simulated practice. The Delphi approach is a widely used, rigorous, and accepted method in healthcare for obtaining expert consensus through an iterative ranking process.[17] The Delphi survey was distributed online using SurveyMonkey rather than through an in-person consensus meeting to facilitate participation among diverse healthcare professionals who often have busy and conflicting schedules and who are located around the world.[17]

PRIORITISATION OF SCENARIOS

The initial Delphi survey containing nine scenarios was assembled by the team of co-investigators who are practicing clinicians in hyperbaric medicine, including hyperbaric medicine physicians and non-physicians (e.g., nurses, respiratory therapist, technicians – depending on the healthcare system) (Appendix 1). The survey was pilot tested with members of the target population to ensure it was comprehensible, interpreted consistently across respondents, and provided enough information to allow respondents to make informed decisions. The survey was available either in French or in English at the participant's discretion.

Participants rated which HBOT scenarios they considered to be relevant to simulation-based education, based on two criteria. First, the clinical scenario should be either high stakes (i.e., if an optimal course of action is not implemented in a timely manner, the patient may suffer severe consequences) or lower stakes but with a high potential for becoming critical if the optimal actions are not followed (e.g., intubated and ventilated child who undergoes HBOT). Second, training on the clinical scenario should be best done with the use of a full-body mannequin versus other potential educational modalities.

During Round 1, participants were also invited to suggest additional scenarios at the end of the survey. We collected participants' institutional email addresses to ensure their participation could be tracked across each survey round and to enter them into a draw for a gift card valued at $200. Email addresses were unlinked from specific survey responses to preserve privacy.

RECRUITMENT

Our target population was hyperbaric physicians and operators. We recruited participants from hospitals internationally across a range of hyperbaric medicine units using a snowball sampling technique. Each participant was invited to forward the survey to their colleagues.

To facilitate international recruitment, we obtained endorsement of our project from several hyperbaric medicine international organisations (e.g., Canadian Undersea and Hyperbaric Medicine Association [CUHMA]; Association Internationale des Centres Hyperbares Francophones [ICHF]), which distributed the initial recruitment email to their members. Through this network we also assembled a group of international volunteer centres who committed to assist with recruitment and participation.

SAMPLE SIZE

When using the Delphi process, the appropriate sample size depends on the characteristics of the target population. A smaller sample size (20–30) can result in stable response, provided that the population is homogenous, such as participants with similar training and expertise.[18] Since this was the case in our population, we aimed to recruit a minimum of 30 participants who would complete both rounds. Assuming a 50% response rate, we planned to sample at least 60 healthcare professionals in the first round (60 x 0.50 = 30). We determined a priori to stop recruitment after we have collected the sample size targeted at each round (Round 1 – 60 participants; Round 2 – 30 participants).

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

ANALYSIS AND CONSENSUS

Scenarios rated as relevant (score of 4 or 5) by at least 80% of participants were automatically included for curriculum development; scenarios that did not meet this threshold and new scenarios that were suggested by participants during the first round were included in the second round. The survey for the second round included the median rating each scenario received in the first round.

Results

PARTICIPANTS

Seventy-one hyperbaric medicine professionals from nine countries completed the first round of the survey, and 34 completed the second round. Participants included hyperbaric medicine clinicians, both physicians and non-physicians. The vast majority of respondents were on staff as opposed to trainees. Detailed demographics of participants are reported in Table 1.

RELEVANT SCENARIOS

One scenario, 'Seizure in the hyperbaric chamber', met the prespecified threshold to be included after the first round. Eight main new scenarios were suggested by participants during round one. The co-investigators reviewed all the suggested scenarios and combined similar scenarios, resulting in five new scenarios added to round two (Table 2).

At the end of the second round, four more scenarios met the threshold for inclusion in the final list of scenarios: 'Cardiac arrest in the chamber'; 'Fire in or immediately outside of the chamber'; 'Pneumothorax in the chamber'; and 'Technical deficiency such as power loss while operating the hyperbaric chamber'.

The detailed scores for each scenario across each round are presented in Table 2.

Table 1
Characteristics of study participants

Characteristics	Round 1 (*n* = 71)	Round 2 (*n* = 34)
Profession		
Physician	31 (44%)	15 (44%)
Non-physicians	40 (56%)	19 (56%)
-Registered nurse	28	12
-Respiratory therapist	4	2
-Hyperbaric operator	4	4
-Licenced practical nurse	2	0
-Clinical healthcare technician	1	0
-Hyperbaric therapist	1	0
-Hyperbaric safety director	0	1
Trainee status	6 (8%)	1(3%)
Country of practice		
Australia	4	0
Belgium	8	6
Canada	8	3
France	28	11
New Zealand	1	0
Switzerland	12	13
Tanzania	1	0
Tunisia	1	0
United States	7	1
Not specified	1	0
Years in practice		
Mean	13.6	15.6
Median	12	11
Interquartile range	7–19	7–25

Discussion

Via expert consensus this Delphi study identified five scenarios relevant for inclusion in a future simulation-based curriculum in hyperbaric medicine.

This is the first step toward the creation of an evidence-based international hyperbaric medicine simulation curriculum. Our prespecified thresholds allowed us to make clear decisions on the most relevant scenarios to hyperbaric medicine based on participants' clinical experience and expertise. The Delphi technique also allowed for suggestions of possible relevant scenarios directly from participants. This is an important advantage of the Delphi method as it may improve the buy-in from participants when the time comes to implement the simulation-based curriculum.

Identifying relevant scenarios is only the first step for creating and implementing a simulation-based curriculum. Following the same consensus-based approach, future steps should include the design of the five identified scenarios, and the pilot test of the simulations in several centres with various degrees of simulation experience. Scenarios will need to include human factors and the possibility to use cognitive aids in order to best adapt to local practices. Finally, debriefing is crucial for effectiveness of learning in simulation-based education.[19,20] Solid debriefing guides will be required to maximise the learning opportunities for all, regardless of simulation expertise in centres.

Our study has several limitations. First, we had a limited number of participants. However, we reached our target sample size. Also, given the range of professions and countries of practice among our participants, we are confident in the external validity of our findings. Second, we recognise that the threshold to include or exclude a scenario from the curriculum is arbitrary. We suggest considering the five scenarios identified in this study as a starting point for a curriculum development in hyperbaric medicine and certainly not an end point. Finally, in the clinical setting, scenarios often present with a 'symptom', e.g., sudden onset hypotension, or hypoxaemia, or a combination of symptoms rather than a clear definitive diagnosis. It will be key to

Table 2
Decision process and final decisions for proposed clinical scenarios

Clinical scenario	Round 1			Round 2		
	Number of votes	Score 4 or 5 (%)	Decision	Number of votes	Score 4 or 5 (%)	Decision
Seizure in the chamber	69	81.2	**Final Inclusion**	Already included in Round 1		
Fire in or immediately outside of the chamber	68	76.5	Included for Round 2	34	97.1	**Final Inclusion**
Cardiac arrest in the chamber	70	71.4	Included for Round 2	34	82.4	**Final Inclusion**
Pneumothorax in the chamber	70	71.4	Included for Round 2	34	82.4	**Final Inclusion**
Intubated and ventilated patient in the chamber	71	64.8	Included for Round 2	32	78.1	Exclusion
Chest pain in the chamber	72	58.3	Included for Round 2	34	73.5	Exclusion
Shortness of breath in the chamber	72	52.8	Included for Round 2	11	54.6	Exclusion
Onset of (non-seizure) neurological symptoms such as anxiety or hypoglycaemia while in the chamber	70	47.1	Included for Round 2	34	50.0	Exclusion
Newborn patient in the chamber	68	32.4	Included for Round 2	30	23.3	Exclusion
Technical deficiency such as power loss while operating the chamber	Scenario suggested during round 1			34	85.3	**Final Inclusion**
Haemodynamic instability while in the chamber	Scenario suggested during round 1			30	63.3	Exclusion
O_2 problem in the chamber such as O_2 breakdown	Scenario suggested during round 1			28	57.1	Exclusion
Ear pain while in the chamber	Scenario suggested during round 1			34	52.9	Exclusion
Nausea while in the chamber	Scenario suggested during round 1			34	17.7	Exclusion

design simulation scenarios that account for the uncertainty over the diagnosis and the need to simultaneously diagnose and treat the problem.

Conclusions

Relying on a well-established and rigorous Delphi method, this study identified five scenarios relevant for inclusion in an evidence-based, simulation-based curriculum in hyperbaric medicine. Next steps should include designing these scenarios and implementing them into a simulation curriculum for hyperbaric medicine that will allow teams to train and optimise their practices.

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The world as it is

Is more complex safer in the case of bail-out rebreathers for extended range cave diving?

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Key words
Deep diving; Diving deaths; Equipment; Risk factors; Risk management; Safety; Technical diving

Abstract

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Nowhere is redundancy more indispensable than extended range cave diving. Training and practice in this discipline ensure divers are equipped with backup regulators, gauges, lights, and adequate breathing gas for a safe exit, emergencies, and decompression. Depending on penetration distances and depth, open circuit cave diving may require carrying more gas cylinders than can be logistically managed by the diver themselves while maintaining safe gas supply margins. Consequently, divers are forced to either stage cylinders in the cave prior to the dive or rely on resupply from support divers. Both scenarios have significant drawbacks. Due to the improved efficiency of breathing gas utilisation and other advantages, closed circuit rebreathers (CCR) have enabled extended range cave diving. With increasing depths, penetration distances, and bottom times, these divers must also plan for an increasing amount of open circuit bail-out gas in the event of CCR failure. Staged cylinders have traditionally been utilised, but this strategy has limitations due to the advanced dives needed to place them and equipment degradation due to prolonged water immersion, which can often result in cylinder and regulator corrosion with consequent leakage of contents over time. Consequently, a growing number of CCR divers are foregoing open-circuit bailout altogether by carrying an additional CCR system for bailout. Although these bailout rebreathers may facilitate further exploration and have certain advantages, the risks of diving with two complex machines remain to be clearly defined.

Introduction

"*Redundancy is expensive but indispensable.*" – Jane Jacobs

The use of closed-circuit rebreathers (CCR) for scuba diving has increased exponentially in the last decade. It is estimated that as of 2010, there were more than 14,000 active CCR divers worldwide.[1] Once confined only to military operations and to the most dedicated of technical divers, CCRs are now becoming commonplace in the recreational and scientific realms of scuba diving.

The benefits of a closed-circuit system are numerous. CCRs are much more efficient in terms of breathing gas consumption when compared to open-circuit diving, especially during deep water dives. In CCR diving, the only oxygen used is the oxygen metabolised and is therefore not depth-dependent like open-circuit scuba. Inert gases, such as nitrogen or helium, are recycled in the loop and rarely lost, allowing a very large reduction in gas consumption compared to the same dive on open-circuit. In addition, a CCR allows a diver to breathe humidified, warm gas, which becomes increasingly important during long dives when the cold, dry air of open-circuit systems can impair mucociliary transport and irritate upper airways.[2] Furthermore, CCR offers a relatively bubble-less system allowing for a serene diving experience and much more intimate contact with marine life. In the setting of a CCR cave dive, the lack of exhaust bubbles also reduces the likelihood of disturbing fragile ceilings, which could reduce visibility due to falling debris in the water column. Finally, and perhaps most importantly, the CCR allows a diver to maintain a specified partial pressure of inhaled oxygen at any depth to minimise inert gas loading during the descent and bottom phase and optimise inert gas elimination during ascent.

Notwithstanding these advantages, CCRs are not benign nor without drawbacks. It is estimated that CCR use is associated with a four to ten-fold greater risk of death compared to open-circuit scuba diving.[1] The specific etiology of this increased mortality remains unclear although the insidious failure modes in CCR which lead to hypoxia, hyperoxia and hypercapnia are not as easily detectable as failure modes in open-circuit equipment. This leads to a situation where a failure can remain unnoticed until it is too late to arrest the trajectory towards a non-life sustaining condition.

Due to the significant financial, experiential, and educational requirements for CCR certification, it is likely CCR diving attracts an older demographic on average compared to that of traditional open-circuit diving. Along with older age comes an increase in age-related health concerns, such as cardiovascular disease.[3] Accumulating evidence suggests cardiovascular etiologies underlie many scuba diving-related deaths.[4] Superimposed on these age-related health conditions, the complicated nature of CCRs and their requirement for regular and precise maintenance may also increase the risk of diving accidents and deaths.[2] A report for the UK Health and Safety Executive highlighted numerous human factors issues relating to the design, operation and training associated with CCRs, focusing on the complicated nature of the tasks and unforgiving nature of failures compared to open-circuit diving.[5] As a consequence, the report recommended that more be done to expand on the knowledge and practice of human factors in CCR diving operations and training systems.

Of the numerous critical skills mentioned above for safe CCR operation, an efficient bail-out to an open-circuit supply may be the most important of all. Bailing out when diving with a CCR involves at least six steps: closing the mouthpiece of the CCR; removing the CCR mouthpiece from the mouth; retrieving a second-stage open-circuit regulator from another gas cylinder; clearing water from the mouthpiece via exhalation or purging; breathing from the open-circuit or CCR gas supply; and lastly terminating the dive. In an effort to make these six steps a routine and even automatic event, divers rehearse the process multiple times during training and are encouraged to continue rehearsing them even after certification.

Training standards specify that CCR divers should carry enough open-circuit breathing gas to safely allow a diver to terminate the dive, exit the environment, complete any necessary decompression, and exit the water. However, as distances traveled in overhead environments and the times of the decompression extend, the amount of open-circuit bail-out gas may near the financial and logistical limits of possibility. For example, if a cave diver wishes to complete a 2,400 linear metre penetration into the Weeki Wachee/Twin Dees cave system in Florida at a depth of 90 metres of fresh water (mfw), he or she requires 22,650 L of gas, or ten standard 11 L cylinders. This conservative example assumes the diver bails out onto open-circuit gas at maximum penetration, has a respiratory minute volume (RMV) of 14 $L \cdot min^{-1}$, swims at a rate of 15 $m \cdot min^{-1}$, and does not perform decompression. Much of this gas will contain substantial amounts of helium and will be expensive. Furthermore, the placement of these bailout cylinders may be increasingly difficult due to depths and penetration distances and may require set-up dives prior to the exploration dive by the diver or other team members that further exposes divers to increased risks associated with equipment failures and physiological stresses/illnesses, especially for deeper sections. Finally, if these cylinders and regulators are left underwater for many weeks or months, as in the case of exploration of Twin Dees cave system in Florida, the cylinders and regulators may corrode and leak the contained gas (Pitkin A, Personal Communication, 2020) (Figure 1).

Figure 1

Two aluminum 11 L cylinders retrieved from the freshwater cave system Weeki Wachee/Twin Dees in Weeki Wachee, Florida after eight months of submersion. These cylinders were staged in this cave system to serve as open-circuit bailout during exploration cave dives requiring thousands of feet of linear penetration at depths exceeding 100 mfw. Note the extensive corrosion at the tank neck and tank valve interface

As a result of these complicated and expensive logistical considerations for traditional open-circuit bailout, the use of dual or bailout rebreathers has started to be adopted. Instead of multiple open-circuit gas cylinders, these divers may utilise two separate rebreathers with separate carbon dioxide scrubbers, counter-lungs and breathing loops. Although the possibility of human error may be increased even further with two rebreathers, the divers are now equipped with two separate breathing systems. No longer is a diver dependent on cylinders cached in the cave system, rather they carry their own bailout throughout the dive. A bailout rebreather utilised in this way should allow for a safe exit in the setting of most issues encountered by the primary unit, such as an exhausted scrubber, failed solenoid/oxygen sensor, or a computer/display problem. On the contrary, a bailout rebreather would likely not be helpful in the setting of a diver experiencing an increased work of breathing secondary to breathing gas density (assuming both the primary and bailout rebreather were utilising the same sources of breathing gases).

History

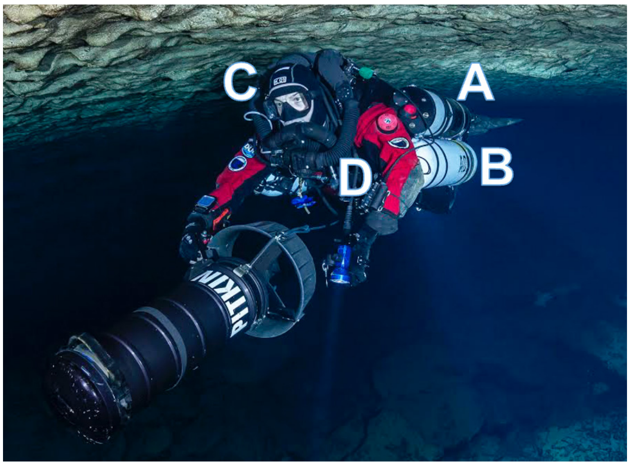
Cave divers were the pioneers of dual rebreather systems because of the large amounts of open-circuit gas required to reach the surface safely in the event of failure of a primary rebreather during a deep and/or long-distance cave penetration. The first well-documented use of a dual rebreather system was the German cave diver Jochen Hasenmayer's exploration of the Émergence du Ressel in 1981 using his Speleo-Twin Rebreather (STR-80), a dual home-built CCR, which allowed him to dive further into the system than had been possible using open-circuit scuba. Another pioneering underwater cave explorer of the time was Olivier Isler, who employed a dual semi-closed rebreather (the RI2000, designed by him and Alain Ronjat) for exploration in the Doux de Coly in 1989 and subsequently to pass Hasenmayer's limit in the Ressel in 1990. Other European divers have continued to build on their example, such as Reinhard Buchaly and Michael Waldbrenner, who explored beyond Isler in the Doux de Coly in 2002 using twin RB80s, which are semi-closed rebreathers designed by Buchaly.[6] Subsequently, as more rebreathers have become available, dual rebreather configurations are increasingly being utilised by exploration groups all over the world for deep or long-range cave exploration, and occasionally for deep open-water dives. Data regarding real world risk of this approach is not yet available.

Rebreather bailout configurations

Divers may elect to utilise redundant or dual closed-circuit rebreathers or semi-closed rebreathers (SCR). Although there are advantages to redundant CCRs, they also represent the most additional task loading and maintenance due to their complexity. As such, some divers elect to use a SCR to reduce the complicated nature of the task, while maximising additional safety. SCRs function as 'gas extenders' and continuously add enriched air nitrox (EANx) or trimix (a mixture of helium, nitrogen, and oxygen) to the breathing loop. As the diver breathes and metabolises oxygen, the equipment vents some gas to the water column, while adding additional EANx or trimix to the breathing loop.[7] Although these machines are usually mechanically simpler than CCRs to maintain and easier to operate due to the lack of electronics to measure and/or control the partial pressure of oxygen, they cannot separate oxygen from the vented gas. Thus, they are more wasteful of oxygen and inert gas when compared to CCRs.[8] Of note, as the metabolism of a diver increases, the addition of fresh gas flow must increase to match these metabolic demands. Otherwise, the diver is at risk of hypoxia, unconsciousness, and potentially death.[9] This increase in gas flow is not possible with a SCR mid-dive.

Despite the fresh gas flow cautions of a SCR, the advantages of these units as bailout rebreathers remain. For example, many divers estimate that a SCR is capable of extending the use of open-circuit bail-out by four to ten times. As a result, the diver is usually able to carry sufficient open-circuit bailout gas and a SCR to be capable of individual bailout in the event of primary CCR failure. Divers exploring Twin Dees/Weekie Wachee cave system have recently employed Halcyon RB80 SCRs to facilitate individual bail-out and eliminate the need for the expensive and problematic staging of cylinders in the cave. The Halcyon RB80 is a non-depth-compensated, passive addition SCR (pSCR) in which gas addition is tied to respiratory minute volume (RMV). Its outer dimensions are similar to those of a standard aluminum 80 (AL80 or 11 litre) cylinder. As a result, this unit can be side-mounted, which makes for a more streamlined set-up for a diver with two rebreathers (Figure 2).[10]

Figure 2
A cave diver uses a diver propulsion vehicle and two rebreathers to explore a flooded subterranean cave in southwest Florida. Note the (A) side-mounted SCR , (B) side-mounted open-circuit bailout gas/diluent, (C) breathing loop from back-mounted rebreather, and (D) breathing loop from side-mounted SCR.



Some divers maintain that a fully functional CCR provides the most optimised redundancy while minimising or eliminating the need to carry open-circuit gas. Thus, divers are increasingly incorporating two separate CCRs in their configurations. Some divers utilise both CCRs throughout the dive by regularly switching between the two units, while others utilise one CCR and only periodically check the status of their 'bailout' units. There are certainly disadvantages to these configurations. For instance, a diver now must undertake maintenance of two separate CCRs, which require more work compared to SCRs because of their electronics, computers, and oxygen cells. In addition, a diver must now control and monitor the partial pressure of oxygen and inert gases of not one CCR, but two. Furthermore, unless the team are diving standardised equipment for primary and secondary CCRs (or SCRs), the dive team need to be aware of failure modes and emergency protocols for the team's differing equipment. This increases the initial training burden and continuation training to ensure that competency for emergency drills is both acquired and maintained.

Benefits of a dual CCR approach

While it may seem counterintuitive to suggest that adding a second complicated machine to an already task-loaded diver improves the overall safety profile of a dive, the logistical challenges and dependency on cached open-circuit cylinders may suggest otherwise. For instance, a diver utilising a bailout or redundant rebreather is completely independent in terms of bailout. They no longer depend on carried open-circuit bailout gas or cylinders cached in the cave system which may have corroded and leaked vital gas. This diver is also not reliant on the bailout cylinders of teammates, which is the case when utilising a 'team bailout' approach. Instead, the diver depends solely on his or her two rebreathers as primary and secondary life sustaining equipment. Although an additional rebreather will certainly add to equipment and process complexity, one may interpret this as an overall improvement in safety secondary to a more robust and redundant bail-out procedure as long as a holistic-systems approach is taken to normal and abnormal operations.

In addition to the aforementioned logistical and potential safety benefits, the exploration efforts in Twin Dees/Weeki Wachee in Florida require massive amounts of expensive trimix for the staged bailout cylinders along with support divers/teams to place the cylinders in the cave. These operations are both costly and take time to arrange and to execute. The use of a bailout rebreather allows smaller teams to operate in a more efficient manner.

Risks of a dual CCR approach

Cave diving is an inherently unsafe activity. Therefore, there is always a risk of harm (injury or death) occurring. However, risks can be both negative and positive (opportunities), and the management aspect involves trading one risk against another to achieve a goal influenced by a number of external and internal factors, limitations and constraints. The negative risk of a second rebreather is the potential for an increase in the number and type of error-producing conditions which, if not predicted, detected and corrected, will lead to an increased number of diving injuries or deaths.

The WITH or TWIN model, which was generated by studying human performance in nuclear power operations, considers Workplace design, Individual Capabilities, Task Demands and Human Nature to describe error-producing conditions [Table 1].[11] The WITH/TWIN model considers these error-producing conditions as they are pre-cursors to adverse events rather than outcomes such as 'failure to fill a scrubber', 'failure to properly pack a scrubber', 'failure to fill an oxygen cylinder', and 'failure to turn on an oxygen cylinder'.

These error-producing conditions exist for all levels of diving, but not predicting, detecting and correcting the error when in a underwater cave system and effectively dealing with a failed primary rebreather, individually or as a team, can have fatal consequences.

One specific example from the table above pertains to workload. Research evaluating human productivity in the

Table 1
Examples of error-producing conditions as described by the WITH/TWIN model

Workplace design	Individual capability	Task demands	Human nature
Distractions/ interruptions	New techniques, not used before	Time pressures (in a hurry)	Stress
Changes/departures from routine	Lack of knowledge (faulty mental model)	High workload	Assumptions
Confusing displays or controls	Unfamiliarity with task, first time	Repetitive actions/ monotony	Complacency
Hidden system or equipment responses	Unsafe attitudes	Lack of, or unclear standards	Inaccurate risk perception
Unexpected equipment conditions	Illness, fatigue, general poor health	Simultaneous, multiple actions	Limited short-term memory

setting of multi-tasking, which can occur when a person attempts to perform two tasks simultaneously, switch from one task to another, or perform two or more tasks in quick succession, repeatedly demonstrates an overall decrease in productivity.[12] Even in the case of switching between two predictable simple cognitive tasks, humans are slower to accomplish these processes compared to simple task-repeat; a phenomenon termed "*switch costs*".[13] As tasks become more complex, there are additional switch and time costs.[14] In the setting of CCR diving, especially in the case of dual rebreather configurations, it is certainly reasonable to describe the activity as requiring multitasking. As the research above illustrates, human performance may be impeded with such demands. In the setting of machine failure, bailing-out, and the subsequent stress of this scenario, it is possible that performance would suffer further. Nonetheless, this risk, and others that could be surmised with utilising two rebreathers, must be weighed against the advantages described above to fully grasp the impact of a second rebreather on diving safety.

Conclusions

In the case of extended range cave diving, the trend toward dual or bailout rebreathers may be here to stay. Their use provides significant, and potentially pivotal opportunities for extended range exploration throughout the world. However, the risks and the benefits of such a complex diving configuration should be carefully considered. Divers and explorers need to consider not just the technical aspects of operating the dual CCR as an equipment-based system, but also the socio-technical aspects and error-producing conditions that adding additional complicated equipment has to the wider system, especially when it comes to training for, and executing abnormal operations when workload levels will be high and awareness will be reduced. Nonetheless, as the use of this configuration grows, the risks and benefits will become clearer to investigators and divers alike.

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Case reports

Abnormal motor blockade after epidural analgesia caused by pneumorrhachis and the role of hyperbaric oxygen treatment: a case report

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Abstract
(Romano-Ribeiro C, Gaio-Lima C, Ferreira AP, Oliveira B, Dias-Vaz M, Camacho O. Abnormal motor blockade after epidural analgesia caused by pneumorrhachis and the role of hyperbaric oxygen treatment: a case report. Diving and Hyperbaric Medicine. 2022 March 31;52(1):54–57. doi: 10.28920/dhm52.1.54-57. PMID: 35313374.)
Introduction: Pneumorrhachis is a rare clinical entity that is usually asymptomatic. Previous reports have associated such events with epidural insertion using a loss of resistance (LOR) to air technique. This report describes a case of symptomatic epidural pneumorrhachis following epidural anaesthesia using LOR to saline.
Case report: A 32-year-old American Society of Anesthesiologists (ASA) Classification II female patient was admitted for unplanned caesarean section. Epidural anaesthesia was performed at the L3-4 space using LOR to saline. The procedure, including delivery of the neonate, was uneventful. In the recovery room, a local anaesthetic infusion via an elastomeric pump (infusion 'balloon') was started. Two hours after initiation of the infusion the patient complained of motor blockade, so it was stopped. Two hours later she remained paraparetic, and a neurologist assessment was required. A computed tomography scan showed epidural pneumorrhachis at the L2-3 level. The patient was referred for emergent hyperbaric oxygen treatment (US Navy Treatment Table 5) and following one session the patient recovered completely.
Discussion: Anaesthetists should be aware of this rare complication, which is easily overlooked. Hyperbaric oxygen treatment is a first line treatment for gas-associated lesions with neurological impairment. Timely referral is essential to prevent irreversible deficits.

Introduction

The rate of caesarean sections has increased with a similarly increasing trend to performing them under neuraxial anaesthesia.[1,2] Although there are specific advantages of this approach, a range of complications can occur and knowledge of these is essential to an early diagnosis. These complications include mechanical injuries, vascular complications, drug-related complications or technique-related injuries. Mechanical injuries can be subdivided in direct lesions to the spinal cord or nerve roots or compressive lesions such as haematoma, pneumorrhachis or epidural abscess.

Pneumorrhachis, the presence of gas within the spinal canal, is a rare imaging finding arising from various aetiologies, mainly traumatic and iatrogenic. As imaging techniques improve, this pathologic entity has become somewhat more often diagnosed.[3,4] Computed tomography (CT) is the most reliable method of diagnosing this complication.[3,5–7]

As a result of the rareness of this complication, there are no empiric guidelines for the treatment and standards of care.[4,7] Various treatment options have been described, such as non-surgical treatment with dexamethasone, decompression and aspiration by needle, high inspired concentrations of oxygen, and hyperbaric oxygen treatment (HBOT).[5,8] In fact, the management of this condition should be based on a multidisciplinary approach contributing to an individualised plan.

In this report, we describe a case of abnormal motor blockade due to pneumorrhachis after epidural analgesia, and its successful treatment with HBOT.

Case report

The patient gave consent for the publication of her case. A healthy 32-year-old pregnant woman (G2P1) at term gestation was admitted for vaginal delivery. Her anaesthetic history included a caesarean section under spinal anaesthesia complicated by post-dural puncture headache. There was no relevant past medical history except sporadic right sciatica pain during pregnancy.

During labour, because of suspicion of cephalopelvic disproportion, it was decided to perform an unplanned caesarean section. Following a full explanation of the risks and benefits and taking account of the prior history of post-dural puncture headache, an epidural catheter was placed at L3-4 using a Tuohy 18G needle in a midline approach with loss of resistance (LOR) to saline. On the first pass the catheter was advanced 4 cm into the epidural space. Neither cerebrospinal fluid nor blood could be aspirated from the epidural catheter. Ropivacaine 0.75% 75 mg plus 10 µg sufentanil were administered. The surgery progressed uneventfully and a healthy baby was delivered.

In the recovery room, adequate motor blockade reversion was observed. Thirty minutes after the procedure, at 5 pm, a ropivacaine 0.2% infusion at 2.7 mL·h^{-1} was initiated using an elastomeric drug infusion 'balloon' (DIB). The patient was transferred to the ward without complaints.

Two hours after initiation of the ropivacaine infusion, the anaesthesiologist was called because the patient was hypotensive (systolic blood pressure 80–90 mmHg) and exhibiting bilateral motor blockade. The hypotension was treated with crystalloids and the infusion was stopped. At 8pm, although the motor blockade started to reverse on the left side she continued to exhibit right motor blockade. Therefore, urgent neurology consultation was obtained at 9 pm, two hours after the DIB had been stopped. This confirmed a patchy sensory blockade (L4 level), with an asymmetric right paraparesis grade 2/5 (hip and knee flexion, knee extension, dorsiflexion and plantar flexion of foot) without any signs of more proximal neurologic dysfunction. No headache or neck stiffness were present and she did not have any signs of dyscoordination with a negative finger-to-nose test. A cervicothoracolumbar CT scan was obtained which revealed a single bubble of epidural air (6 x 6 x 17 mm) at the L2-3 level on the right side of the rachis without significant mass effect (Figure 1). No other lesions were seen. Pneumorrhachis was assumed as the most likely cause of the paraparesis. After consultation with the hyperbaric medicine physician, a decision was made to initiate urgent HBOT and the patient was transferred with oxygen inhalation via a non-rebreather mask.

Upon arrival at the hyperbaric medicine unit at 1:15 am, she had some improvement of motor deficits but maintained altered temperature sensitivity and muscular weakness 3/5 on hip flexion and 4/5 on knee extension on the right. At 1:37 am the patient was compressed according to the US Navy Treatment Table 5 protocol (145 minutes, maximum 284 kPa [2.8 atmospheres absolute], 100% oxygen), administered in a multiplace chamber with an attending nurse and continuous clinical and vital signs monitoring. There was significant neurological improvement after the first oxygen period at 284 kPa and after the treatment she had no motor weakness though she continued to exhibit distal symmetric hyposensitivity.

Figure 1
CT scan at the L2-3 level showing a single bubble of epidural air which measured 6 x 6 x 17 mm on the right side of the rachis without significant mass effect

A re-evaluation CT was obtained showing a reduction of the epidural air. As she also had no significant clinical manifestations, she was transferred back to the referring hospital with continuous neurological monitoring.

At the time of discharge, four days later, her neurologic examination was unremarkable, and she had full strength in all extremities and an intact sensation to light touch without pain.

Discussion

Pneumorrhachis is defined as the presence of air within the epidural or subarachnoid space.[9,10] As the condition is rare, few reports are available. The causes of epidural air can be iatrogenic, spontaneous, or traumatic. Iatrogenic causes are the most common, usually after epidural injection or epidural analgesia.[5,10,11] In fact, there are some case reports of epidural, subdural or subarachnoid air after techniques with LOR to air, however none following LOR to saline (as was used in the present case).[8,9,12–16]

In this case, there is not a clear reason for prolonged motor blockade. Our first hypothesis was intrathecal instead of epidural administration of ropivacaine. However, as the right motor blockade persisted more than two hours after the discontinuation of local anesthetic perfusion, the second hypothesis was a local compressive event as the most probable cause. There are some cases reported in the literature of neurological deficits and pain thought to be complications associated with the application of intraspinal air, with descriptions of accidentally injected air into the epidural space via an epidural catheter for continuous epidural anaesthesia.[4]

The CT imaging showed epidural air (pneumorrhachis) on the side of motor blockade without evidence of compression or ischemia of the spinal cord, but with possible compression of the spinal roots near the emergence from the vertebral canal.

Another hypothesis was that air could also have been entrapped in the DIB and since the flow was slow (2.7 $mL \cdot h^{-1}$), the air did not move and became a single gaseous mass contained in the right epidural side.

Although pneumorrhachis is usually asymptomatic, reabsorbs spontaneously and the majority of patients are commonly managed conservatively, in this case the patient exhibited a persistent asymmetric right paraparesis. She had complete resolution of motor blockade after initiation of HBOT which would have immediately reduced the gas volume and then accelerated diffusion of nitrogen away from the gas mass under hyperoxic conditions. The CT imaging after treatment showed a reduction in epidural air as has been previously reported. The application of HBOT in pneumorrhachis is not well established and, to our knowledge, there are only two case reports describing its utilisation for epidural air.[12,17]

On first contact, the hyperbaric medicine physician considered this injury as the possible cause for the neurological deficits and accepted the patient for HBOT, in spite of the limited evidence available, after taking into consideration the limited improvement after stopping the local anaesthetic infusion, the exclusion of other possible causes, the severity of the neurological deficits with a risk of sequelae and the lack of therapeutic alternatives at the referring hospital.

The location and the relatively small volume of air (with no signs of compression) made it difficult to extrapolate experience in treating decompression sickness (where a US Navy Treatment Table 6 would typically be used as first-line recompression therapy) to making management decisions in this case. A shorter HBOT table was chosen since there was clinical improvement between the first neurological examination and arrival at the hyperbaric center, and the patient demonstrated fatigue in excess of what was expected in the postoperative period, attributed to the diagnostic procedures and transport to the hyperbaric center. Therefore, a US Navy Treatment Table 5 was deemed acceptable treatment, improving the patient's tolerance of the recompression treatment and permitting continuous neurological evaluation with optional extensions.

Conclusions

Despite the numerous advantages of epidural anaesthesia and analgesia, it is crucial to have a complete knowledge of the different complications and side effects that may arise from this technique. This case highlights the possibility of pneumorrhachis that, although rare, is one of the reported complications of neuraxial techniques. It is essential to ensure adequate monitoring of patients, since the key for successful management of all such complications is prompt diagnosis followed by multidisciplinary management.[18] The contributing factors for this complication have to be evaluated and appropriate interventions should be implemented.

In conclusion, when pneumorrhachis is documented, a decision to treat conservatively or surgically should be made, and consideration should be given to HBOT as a first line treatment for gas-associated lesions with neurological impairment, in addition to its established role as a complementary/synergistic or first-line treatment for other conditions.[19]

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A COVID-19 infection incidentally detected during hyperbaric oxygen treatment and preventive measures for COVID-19 transmission in a multiplace hyperbaric chamber

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Confined space; Contagion; Infectious diseases; Pressure chambers; SARS-CoV-2

Abstract
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Introduction: SARS-CoV-2 (COVID-19) was declared a global pandemic on 11 March 2020 and has become a serious threat to public health. As it can easily be transmitted through droplets and aerosols, there is an increased risk of transmission in enclosed environments such as hyperbaric oxygen treatment (HBOT) units if preventive measures are not taken.
Case report: A 16-year-old female tested positive for SARS-CoV-2 during HBOT for idiopathic sudden sensorineural hearing loss. The other patients and the inside attendant who attended the sessions with her were regarded as contacts, tested for SARS-CoV-2, and quarantined until the test results were available. Ultimately, none of them tested positive.
Discussion: As HBOT in multiplace chambers entails a high risk of SARS-CoV-2 transmission, we strictly adapted our practice to consider that every patient could be a potential asymptomatic carrier. Therefore, the negative results of all contacts in this case and the fact that no confirmed cases of COVID-19 were reported suggests that these measures successfully prevented SARS-CoV-2 transmission in our HBOT clinic. SARS-CoV-2 transmission can be prevented if sufficient protective measures are taken.

Introduction

The spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2, COVID-19) virus, was declared a global pandemic on 11 March 2020, has resulted in a worldwide threat to public health and caused economic and social disruptions that generated global upheaval. Restrictions and precautions were adopted both in routine and emergency health services, as in all areas, to prevent the spread of the virus and to reduce the patient load, especially at the intensive care level. Hyperbaric oxygen treatment (HBOT) units, in which patients inhale 100% O_2 at pressures 2–3 times higher than atmospheric pressure in hyperbaric chambers, are particular at-risk medical facilities.[1] As coronavirus is highly contagious and can easily be transmitted through droplets and aerosols in such closed units, there is a high risk of transmission in hyperbaric chambers.[2] In the early days of the pandemic, the European Committee for Hyperbaric Medicine and Undersea and Hyperbaric Medicine Society published guidelines with the aim of minimising the risk of transmission and preserving continuity of treatments in HBOT clinics[3,4] Following these guidelines, and recommendations of the Turkish Ministry of Health (TMoH) at that time, we made some necessary adjustments regarding decontamination and patient selection procedures in our HBOT unit. In this report, we present a patient who was incidentally diagnosed with COVID-19 during HBOT and the measures that we have adopted to prevent COVID-19 transmission.

Case presentation

The patient gave consent for the publication of her case. A 16-year-old female presented to the Ear, Nose and Throat department with a three-day history of left-sided tinnitus and hearing loss in September 2020. She had no history of trauma, ear surgery or ototoxic medications and diseases. Other system examinations were unremarkable. She was diagnosed with idiopathic sudden sensorineural hearing loss (ISSNHL) and referred for HBOT. Treatment was initiated once a day (excluding weekends), at 243 kPa (2.4 atmospheres absolute) pressure for 120 min including compression and decompression time, in a multiplace chamber. Nine days later an urgent HBOT session for a patient with central retinal artery occlusion (CRAO) was planned. Our ISSNHL patient and three others sharing the same routine sessions with her were also called to the session. That same evening, she presented at the emergency department with a headache, warm forehead, and general feeling of weakness and accordingly, a SARS-CoV-2 RT-PCR (reverse transcriptase-polymerase chain reaction) test was performed. Her remaining sessions were cancelled temporarily until the test result was obtained. She tested positive, HBOT was stopped, and she was quarantined.

When the patient tested positive, we questioned her close contacts, their health status, and medical histories. We were informed that the patient came to other eight sessions with her mother from a neighboring city 80 km away by car except for the fifth session day. On the fifth day, her father drove her to our clinic by car from the same city. They had been in close contact the whole way for about 1.5 hours without wearing masks. Because the patient lived with her mother, this was the first and the last time she had contact with her father throughout her treatment. On the sixth day of her treatment, her father started showing COVID-19 like symptoms. He went to the hospital on the seventh day, gave a sample on that day, and he tested positive on the eighth day. Our patient learned of this medical history of her father when she presented at the emergency department.

Due to preventive measures already in place, there had been only five patients and one inside attendant in each of our routine HBOT sessions. Four patients and the inside attendant had attended the sessions with our patient since the first day of her treatment, all of whom were the same individuals except the patient with CRAO. Upon our patient testing positive, her mother, these four patients, the CRAO patient, and the inside attendant were regarded as contacts, tested for SARS-CoV-2, and quarantined until their test results were available. All of them tested negative. They were also observed in the following days and no symptoms were declared.

Discussion

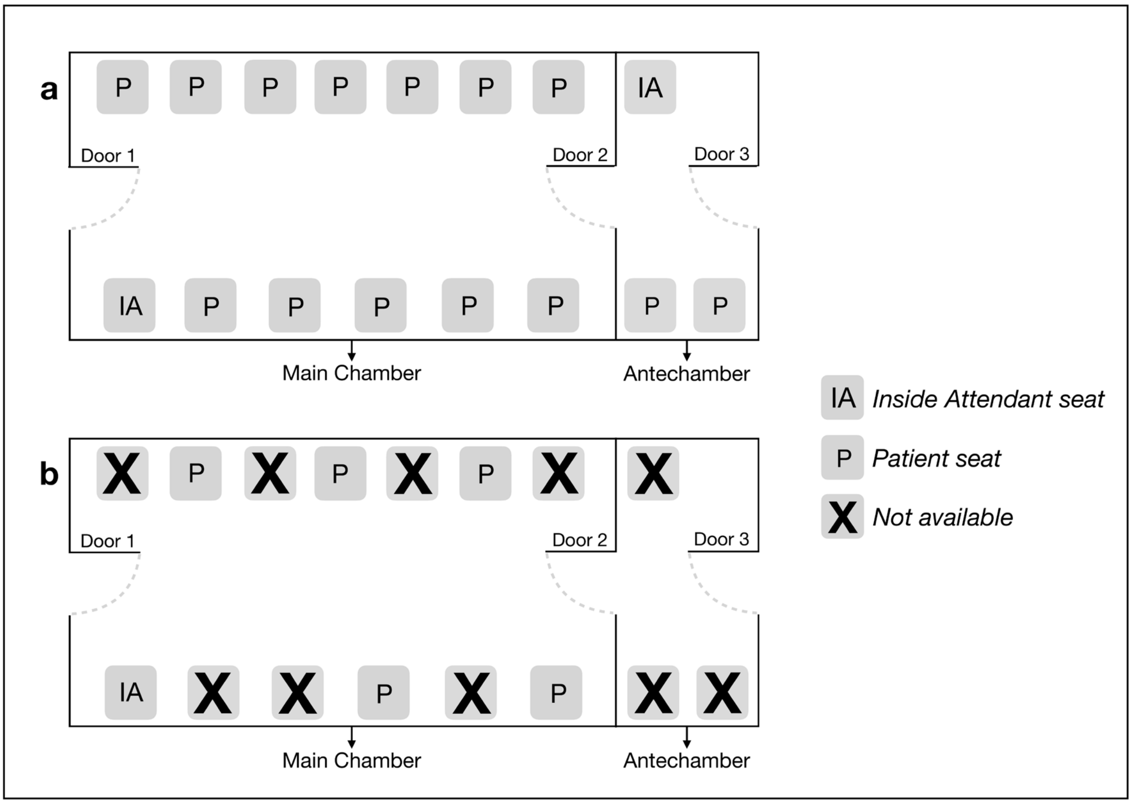
Immediately after the first COVID-19 case was recorded in our country, general safety precautions and regulations were implemented according to the recommendations of the ECHM, UHMS and TMoH. It was made compulsory for every person, patient, and healthcare professional in our clinic to wear a surgical mask. All patients and their companions were assessed with temperature monitoring and Quick Recognition code, a screen that indicates whether a person has COVID-19 or has been in contact with a person diagnosed with COVID-19, before entering the clinic. Non-alcohol-based hand sanitisers were placed at the entrance and exit of the clinic and the chamber. Enough time was allowed to maintain passive chamber ventilation between sessions. In addition, indications for HBOT and treatment sessions were restricted. Patients who did not need urgent HBOT were added to the waiting list and their treatments were postponed. To execute appropriate disinfection procedures, all personal equipment (masks, hoods, hoses, etc.) and all surfaces of the chamber were disinfected using U.S. Environmental Protection Agency (EPA) approved non-alcohol-based solutions after every session.[5] The EPA List N contains all registered disinfectants suitable for use in inactivating the SARS-CoV-2 virus. Active ingredients which are also approved by TMoH and listed in EPA List N are mostly sodium hypochlorite, hydrogen peroxide and quaternary ammonium.

Our HBOT unit is equipped with a Hypertech® Zyron 12 model multiplace chamber which has a capacity of 12 patients and one inside attendant in the main chamber and two patients and one attendant in the antechamber (Figure 1a). Routine sessions are conducted five days a week (excluding weekends) and the duration of a session is 120 minutes. Normally each patient has one HBOT session per day, but sometimes additional sessions are organised for patients who may have required it. A routine HBOT profile includes a 15-min compression to 243 kPa, a total of period of 90 minutes breathing 100% oxygen at pressure with two five-minute air breaks, and a 15-min decompression time. While an average of 12 patients and one attendant were usually placed in the chamber for each of our routine sessions before the pandemic, the number of occupants was limited to a maximum of six (including the attendant) per session during the pandemic. To maintain recommended social distancing (at least 1 m) inside the chamber,[4] one seat was left unoccupied between each patient (Figure 1b). Before each HBOT session, the patients were questioned if they had any suspicious symptoms (fever, shortness of breath, cough, loss of smell/taste, weakness etc.) of COVID-19. To minimise contact, the dressing room was always supplied with fresh air by passive ventilation and each patient used the room alone.

Our multiplace hyperbaric chamber is compressed with air and built-in breathing system masks are used to provide therapeutic oxygen.[6] Each occupant uses a tight-fitting oronasal mask connected to a demand-type regulator which provides 100% oxygen and vents the exhaust gas outside the chamber and the building. The main purpose of using this system is to prevent air from being drawn into the mask so as to ensure a high oxygen concentration while inhaling, and to prevent oxygen leakage into the chamber while exhaling. Normally, the occupants remove their masks and breathe environmental chamber air during the air breaks to reduce the risk of oxygen toxicity. During the pandemic, those tight-fitting masks, each of which was dedicated to a single patient, were donned as soon as the patients were placed in the chamber and not removed till the end of the session. Air was provided via the masks until the chamber reached 243 kPa. During the air breaks, the mask gas was changed from 100% oxygen to air. This ensured that the environmental chamber air was not contaminated with

Figure 1

a. Seating plan in the hyperbaric chamber before the COVID-19 pandemic; b. seating plan during the COVID-19 pandemic



exhaled air and 'respiratory isolation' of individual patients was achieved. Sometimes patients needed to remove their masks to do the Valsalva maneuver effectively, to drink water or for any approved reason. Sufficient spare surgical masks were kept ready in case of temporarily removal of main breathing masks.

Although we prioritised the patients with urgent indications (carbon monoxide poisoning, arterial or venous gas emboli, etc.), we took extra measures for patients with elective indications (diabetic foot ulcer, ischaemic ulcer, etc.) in order not to cause their clinical outcomes to worsen. For example, it has been reported that patients with chronic diseases suffered from the delays and reductions in routine treatments and healthcare services due to the COVID-19 pandemic. In that study, diabetes was found to be the most affected condition.[7] As many patients undergoing HBOT had chronic wound and diabetic foot ulcers, we did additional sessions for these patients each day or over the weekends when needed. Since the beginning of the pandemic, several studies have demonstrated that patients with pre-existing chronic diseases and comorbidities have increased susceptibility to COVID-19, with high severity and mortality rates.[8,9] Most patients who receive HBOT in our clinic are older people with one or more chronic conditions. Therefore, before deciding on HBOT, we made a comprehensive and detailed evaluation of each patient and aimed to maintain the balance between the risk of transmission and the anticipated benefit.

Special attention was also paid to choosing the right mask for inside attendants during the pandemic. In one study, it was shown that wearing a surgical mask reduced the airborne droplet transmission distance to 30 cm from the source, while using an N95 mask reduced it to 15 cm.[10] The attendants are not always in a sitting position throughout the session because of the need to assist the patients (replacing their masks, helping them to do the Valsalva manoeuvre effectively or even performing first aid in case of an emergency). When the patient takes off his or her mask while being assisted, the attendant may come in close contact with the patient. For this reason, attendants always wore N95 masks inside the chamber.

During the pandemic, we also administered HBOT to many intubated patients without knowing if the patient had COVID-19 or not. Although an intubated patient entails a lower risk of aerosol production inside the hyperbaric chamber than a non-intubated patient,[11] the medical staff have worn gowns, double gloves, N95 masks and face shields while providing care to these patients. Normally, these additional items are not routinely used, but they became essential in the pandemic. On the other hand, some of these extra personal protective equipment items could represent an increased fuel load for fire under hyperbaric conditions. Given the protectiveness of these items against COVID-19, we took some measures to minimise the risk of fire inside the chamber: 100% cotton gowns have been used since the beginning of the pandemic. The oxygen level is maintained at around 21% inside the chamber. The manual fire extinguishers and the deluge system were checked more often than usual.

The incubation period of COVID-19 was found to be approximately 5–6 days.[12,13] In our case, our patient's father developed COVID-19 symptoms one day after they travelled together. He went to the hospital two days after the travel and the positive PCR test was taken on that day. Therefore, he was most probably contagious during the travel and our patient probably became infected during their car ride. In many studies, it was found that confined spaces can easily create a suitable environment for increased virus load and transmission. A car cabin is such a confined space in which respiratory droplets carrying coronavirus can easily accumulate inside and pervade its micro-climate.[14–16] In this case, while the patient tested positive, none of the patients nor the inside attendant who occupied the chamber with this patient tested positive. As HBOT is a long-term therapy in which many of the patients are not required to be hospitalised and therefore are in interaction with different people in daily life, especially during the pandemic, those patients should minimise contact with others, even with their households.

There is evidence that spreading of SARS-CoV-2 may begin 5–6 days before the first symptoms appear, but it may be enough to investigate if there has been a close contact up to 3 days before the symptoms develop.[17] Several published reports also declared that pre-symptomatic transmission was found to be possible 1–3 days before the onset of the symptoms.[18,19] In our case, the patient had most likely been contagious for at least three days before the onset of the symptoms. Despite this, the other patients sharing the same chamber tested negative. In a national environment where only close contacts of known cases or symptomatic individuals are tested, the prevention of cross-infection in the chamber environment in this case demonstrates the value (and successful outcome) of treating every patient as a potential asymptomatic carrier.

This report also highlights the importance of taking strict and solution-focused preventive measures in HBOT clinics and maintaining them without compromising on discipline during the COVID-19 pandemic. These measures seem to be permanent in the coming period as the outbreak lingers.

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A diving physician's experience of dental barotrauma during hyperbaric chamber exposure: case report

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Key words
Barodontalgia; Case reports; Hyperbaric oxygen treatment; Pain

Abstract

(Altun BD, Sümen SG, Dumlu A. A diving physician's experience of dental barotrauma during hyperbaric chamber exposure: case report. Diving and Hyperbaric Medicine. 2022 March 31;52(1):63–65. doi: 10.28920/dhm52.1.63-65. PMID: 35313376.)
Previous cases of dental barotrauma have been reported in pilots and divers. We report a case of dental barotrauma and barodontalgia in a diving physician accompanying patients during hyperbaric oxygen treatment, and due to pressure changes in the hyperbaric chamber. The physician developed sharp pain localised to the right maxillary molars but radiating to the face, ear and head during decompression from 243 kPa (2.4 atmospheres absolute). The pain intensified following completion of decompression and was consistent with irreversible pulpitis. Clinical examination and panoramic radiography suggested fracture of a heavily restored tooth due to barotrauma. This was managed by tooth extraction. The physician subsequently discontinued accompanying the patients during their hyperbaric oxygen treatment sessions. Dentists and maxillofacial surgery specialists suggest waiting for a minimum of four weeks or until the tooth socket and/or oral tissue has healed sufficiently to minimise the risk of infection or further trauma before exposure to further pressure change. Although seemingly rare, and despite the comparatively slow pressure changes, dental barotrauma can occur in hyperbaric chamber occupants.

Introduction

Hyperbaric oxygen treatment (HBOT) is defined as inhalation of 100% oxygen at an elevated pressure (most commonly at or above 203 kPa or two atmospheres absolute). It is commonly used for the treatment of decompression sickness, air embolism, carbon monoxide poisoning, problematic wounds such as diabetic foot, ulcers and late effects of radiotherapy.[1–3] HBOT is regarded as a safe treatment modality in which serious side effects (such as pulmonary barotrauma) are rare, and more common side effects (such as hyperoxic myopia or middle ear barotrauma) are usually mild and reversible.[4–6]

Barotrauma may occur due to the changes in volume of gas-containing spaces inside the body, in response to changing atmospheric pressure. If pressure changes happen quickly and pressure equalisation between anatomic gas spaces and changing ambient pressure is not achieved, tissue such as the eardrum may be damaged.[7,8] Head and face barotrauma is especially seen in rigid cavities that cannot expand or contract such as sinuses, middle ear and teeth.[9–11]

Barodontalgia is intraoral pain evoked by a change in barometric pressure.[11] Indirect barodontalgia may occur due to middle ear or sinus barotrauma, with referral of pain to the teeth.[12] Direct barodontalgia is generally assumed to arise from changes in volume of gas pockets trapped or evolved in defective restorations causing fracture of the restoration and/or the tooth itself (odontocrexis), although there is one report of a tooth fracture occurring on an apparently sound tooth in a fighter pilot during flight.[13] Pain is considered a result of the involvement of the innervated dental pulp. Irreversible pulpitis may occur, which is characterised by persistent pain, even if the cause is eliminated and may be exacerbated at night.[14,15]

Barotrauma, barodontalgia and odontocrexis (tooth fracture) are known risks for divers and pilots who are frequently exposed to pressure changes. To prevent these complications, maintaining good clinical oral health practices such as having biannual dental checkups and daily brushing and flossing teeth are recommended.[16,17]

The risk is less well defined for occupants of recompression chambers. A search of Ovid/Medline, PubMed, ScienceDirect and Web of Science databases up to October 2021 using the terms *"hyperbaric oxygen therapy"*, *"dental barotrauma"*, and *"barodontalgia"* found 45 cases all experienced during diving and aviation,[13–16,18–23] with none during hyperbaric chamber exposure.

Case report

The patient consented to the publication of her case history and radiography.

A 49-year-old Turkish woman presented with pain in the right posterior maxillary region. She introduced herself as a hyperbaric physician and stated that she had her right maxillary premolars and molars (tooth numbers: 15, 16, 17 and 18) filled a year previously with no known complications. The pain on the treatment side started when she was accompanying her patients as an inside attendant in the hyperbaric chamber during decompression from 243 kPa. It was described as sharp and radiated to the face, ear and head. It intensified through the subsequent evening in a pattern consistent with irreversible pulpitis. The pain was only partially responsive to strong oral analgesia.

Clinical and radiological examination revealed that there was a fracture in the maxillary right third molar and its restoration (Figure 1). In view of the low probability of successful secondary restoration and the possibility of supraeruption of the tooth over time due to an impacted and ectopic mandibular third molar (Figure 2), an extraction was considered the best treatment. After the extraction she ceased accompanying the patients during their hyperbaric oxygen therapy session in accordance with standard advice to wait for a minimum of four to six weeks or until the tooth socket and/or oral tissue has healed sufficiently to minimise the risk of infection or further trauma before subjecting the wound to pressure change.[17,24,25] Although this recommendation pertains to diving, it was adhered to due to the similarity of the mechanism. During follow-up clinical examination on 15th day post-extraction, the patient reported no complaints.

Discussion

Aviators and divers who encounter substantial atmospheric pressure changes may suffer from barodontalgia and dental barotrauma.[13–16,18–23] The present case represents a seemingly rare example of barodontalgia occurring during pressure change in a hyperbaric chamber, and identifies it as a risk for patients and an occupational risk for hyperbaric chamber attendants.

The mechanism of barodontalgia and odontocrexis during pressure changes is still unclear. Trapped air under the restoration or endodontically treated tooth is one explanation. When pressure decreases, trapped air expands and this may result in the fracture of the tooth or dislodgement of restorations. Moreover, expanding air may trigger pain by compressing dentine tubules and pulp.[26,27] The present case is consistent with this theory. Fracture of the restoration appears to have occurred during a decompression which allowed air trapped in her tooth to expand. The patient had no symptoms prior to this decompression.

In relation to prevention, it has been suggested that diving be avoided for at least one week following oral surgery to prevent air from entering healing tissues, and that the dentist must confirm healing.[11] Some publications recommend a four to six week break after tooth extraction.[17,24,25] It follows that we advised our patient that she should not act as a hyperbaric attendant for four weeks after extraction of her third molar. Although she did not have any complaints 15 days after the extraction, this time was necessary for full wound healing.

Figure 1
Panoramic radiography showing a fracture in the third maxillary molar (white arrow)

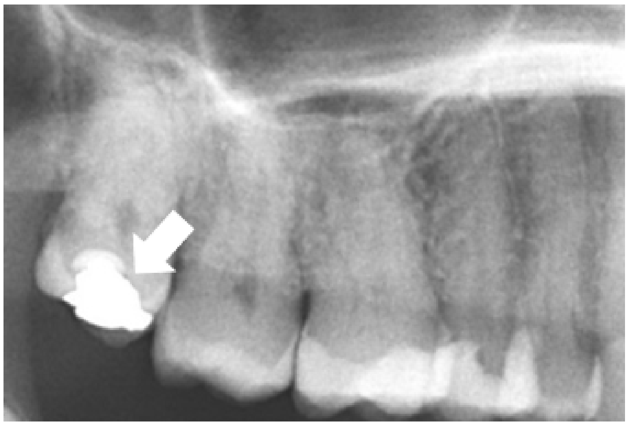
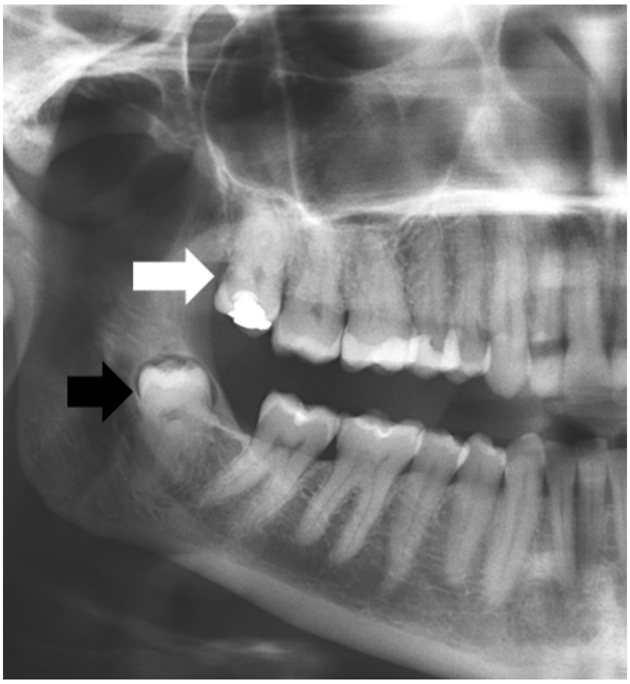


Figure 2
Panoramic radiography showing unopposed maxillary third molar (white arrow) and impacted mandibular third molar (black arrow)



Conclusions

In addition to diving and aviation, this case demonstrates that dental barotrauma and barodontalgia can also be encountered during HBOT. Hyperbaric physicians may consider adding dental barotrauma to lists of potential complications in consent processes, especially in patients with poor dentition. Dentists should also be aware of the possibility of dental barotrauma among divers, pilots, hyperbaric physicians and nurses.

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Letter to the Editor

Diving after COVID-19: an update to fitness to dive assessment and medical guidance

We write to inform the community of an update to our previously published guidelines in Diving and Hyperbaric Medicine regarding evaluation of divers who have recovered from COVID-19.[1] We originally developed these guidelines for the dive clinic at the University of California, San Diego (UCSD).

However, the current landscape of the pandemic has significantly changed since their original development in May 2020, in particular the development of vaccines protecting divers/people from infection, severe disease, and death.[2] We have also witnessed the evolution of a virus into various strains, including some variants that are more contagious, and some that seem to cause both more and less severe disease.[3]

The situation has changed significantly, with the massive surge in cases due to the Omicron variant resulting in many divers who require rapid clearance to return to work. In addition, many only report symptoms like the common cold.[4] In light of these developments, we recognise an amendment of our guidelines is needed.

These modifications to our guidelines were developed in a response to the challenges noted above and from our clinical observations. In our experience, in addition to information gathered from very limited publications, it appears that in cases where the disease causes only upper respiratory symptoms, there are limited long term sequelae or complications.[3] We have also noted the publication of multiple reports suggesting that a percentage of young and otherwise healthy patients who recover from mild or asymptomatic COVID-19 illness, may have surrogate findings of myocardial inflammation or damage on cardiac MRI. These findings are, however, of unclear clinical and prognostic significance. Our recommendations remain centered around the presence of cardiac symptoms or exercise limitations to guide further testing. Consequently, we have adjusted our treatment of such cases to a similar approach as for other uncomplicated seasonal, upper respiratory viruses.

A few things should be noted: first, recommendations for those with moderate or severe disease have not changed; second, as with our original guidelines, we strongly emphasise that these amendments are only applicable to those who have recovered from their acute illness, are completely asymptomatic, and back to their baseline exercise capacity.[1]

Below is a summary of the changes made:

PREVIOUS GUIDELINES WITH REGARDS TO ASYMPTOMATIC OR MILD DISEASE:

Category 0: No history of COVID or asymptomatic positive testing.
Work up: No additional work up required

Category 1: Mild illness, defined as outpatient treatment only without hypoxia or abnormal imaging.
Work up: Spirometry and two view chest X-ray

AMENDED GUIDELINES:

Category 0: No history of COVID or asymptomatic positive testing.
Work up: No additional work up required

Category 0.5: Very mild illness. Those with isolated upper respiratory or systemic symptoms (rhinorrhea/congestion/pharyngitis/loss of taste or smell), fevers, fatigue, or myalgias but WITHOUT lower respiratory or cardiac symptoms.
Work up: No additional work up required

Category 1: Mild illness, defined as outpatient treatment only without hypoxia or abnormal imaging. Any lower respiratory or cardiac symptoms, including chest pain, palpitations, significant* cough, shortness of breath with exertion or at rest.
Work up: Spirometry and two view chest X-ray

*for example, a cough that is productive, prevents sleeping, or requires medication, ultimately defined at the discretion of the evaluating physician.

Other factors may be taken into consideration including vaccination status, as there is evidence that breakthrough infections in those vaccinated against COVID-19 results in milder disease, and regional prevalence of variants (Omicron vs. Delta, etc).[2,5]

We must emphasise that our guidelines have been rewritten and amended out of need for urgent adaptation, from limited data, and our own clinical experience. As with all guidelines, ultimately the discretion of what work up should be obtained lies with the evaluating physician. We anticipate that we will continue to revise as the clinical picture evolves and more information is available.

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Diving medicine; Fitness to dive; Medicals-diving; Occupational health; Pulmonary barotrauma; Recreational diving; Scuba

Obituary

Professor David Hallen Elliott OBE, DPhil, FRCP(Lond), FRCP(Ed), FFOM

David Elliott, the "*Elliott*" of the textbook, Bennett and Elliott's Physiology and Medicine of Diving, died in Haslemere, England on Tuesday 18 January, at age 89.

Professor David Hallen Elliott was born in 1932 and graduated in medicine from St Bartholomew's Hospital Medical College in 1956. After his initial clinical years, he enlisted as a Royal Navy medical officer and founded his incomparable diving medicine experience during service with the Institute of Naval Medicine, the Royal Navy Physiological Laboratory and the Admiralty Experimental Diving Unit through the 1960s and 1970s. He was a key participant in many air and heliox saturation diving operations, as a clinician and researcher, including as Diving Medical Officer on board the Royal Navy's saturation diving vessel the HMS Reclaim. In 1969, he and physiologist Peter Bennett realised their project of publishing a definitive textbook. 'Bennett and Elliott' rapidly became and remains the definitive reference for our specialty. David authored a number of the chapters and co-edited editions one to four. In addition to his human medical research, David contributed three years to advancing our knowledge of the pathophysiology of decompression illness through animal research conducted with Fred Bove and John Hallenbeck at the US Naval Medical Research Institute.

After retiring from Naval service, David became the chief medical officer for Shell Petroleum UK in 1976, embarking upon a civilian career built around the health and safety of offshore industry workers, in particular offshore and saturation divers. David's influence led Shell to support the Advanced Course in Diving Medicine that the University of Aberdeen ran in conjunction with the Aberdeen Medical Centre which introduced many of us to David and to the challenging and fascinating world of saturation diving. In his early civilian life, he was able to continue making contributions to researching the limits of deep diving, collaborating with Professor Bühlmann in Zurich and Professor Bennett and the Atlantis team at Duke University.

When the European Diving Technology Committee established a medical sub-committee in 1973 (EDTCmed) David became the inaugural chair, establishing courses in occupational diving medicine and working with Jurg Wendling and Tor Nome to develop the consensus text Medical Assessment of Working Divers. He also helped found the Diving Medical Advisory Committee of the International Marine Contractors Association (DMAC) in 1978 and was chair of DMAC from 1981 to 1990. He continued to contribute to DMAC and EDTCmed until 2017, leaving us with the farewell email message: *Best Wishes to All, and may sequelae from your own bubbles* ***remain forever silent***. We miss him and his contributions and will forever remember his gracious, insightful and always valuable input.

After retiring from office-based employment in London in 1989, David was appointed Professor of Occupational Medicine at the Robens Institute of Health and Safety at the University of Surrey, a position that enabled him to continue to contribute to our field as an author, educator, mentor, consultant and member of advisory committees.

The recreational diving sector was not denied his expertise. He contributed diving accident management chapters to the British Sub-Aqua Club manuals and held the position of Technical Advisor to the UK National Underwater Instructors Association. He also continued to provide input into Royal Navy policy and operations until 2015, as Civilian Consultant in Diving Medicine and Physiology. In his latter years, he was regularly engaged as an expert witness in medico-legal matters around diving injuries and deaths in the UK and international jurisdictions.

As an educator, David has left a legacy of diving medicine physicians who now practice around the world. Anecdotes and case reports from his personal experience were a critical component of his teaching. His involvement in the early decades of deep diving operations had exposed him to situations that should never be repeated but which remain enormously informative. On occasions he was involved in creating solutions to problems that would appear insolvable to most. Those he subsequently taught and mentored now carry some of this unique experience with them as they contribute to diving safety and accident management and as they, in turn, mentor the next generation on how difficult scenarios may be managed.

As a recreational diver, David proudly declared that he only held an entry-level qualification – "*just enough to get tank fills worldwide*". His naval records reveal that he was trained as a clearance diver, a closed-circuit oxygen diver, a semi-closed nitrox rebreather diver, a deep air diver, and an oxy-helium trials diver (the latter to 150 m depth).

Those with a navy background may salute the Surgeon Commander Elliott who '*crossed the bar*' recently. The rest of us can say *Vale* David: quintessential English gentleman, iconic diving doctor and our teacher, mentor, colleague and friend. Rest in Peace. You will be with us always.

Ian Millar, Jurg Wendling, Maarten van Kets and Olav Sande Eftedal on behalf of the DMAC and the EDTCmed committees

Footnote: Picture – David in Gdansk, 2011

Notices and news

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

EUBS President's message

Jean-Eric Blatteau

The evolution of the COVID pandemic seems to grant us a truce, maybe just temporary, but it will allow us, I hope, to resume our annual scientific meetings and we all hope to meet again next September in Prague, Czech Republic, where we will also have the opportunity to pay tribute to one of the pillars of diving medicine, Professor David Elliott, who died recently at the age of 89.

At the end of February 2022, the world has unfortunately fallen into a logic of planetary war, with terrible consequences for the Ukrainian people, for whom we extend our full support and compassion.

It is obvious that the current events will have repercussions, including in our field, which we are still struggling to assess.

Jean-Eric Blatteau
EUBS President

EUBS Notices and news

Annual Scientific Meeting: 'EUBS2020' will finally happen in 2022

The unpredictable events associated with the spread of the COVID-19 pandemic in recent months have prompted us to change and postpone the date of this scientific event two years in a row, from 2020 to September 2022. As the COVID-19 situation evolves, we believe that with all epidemiological measures and especially vaccination of the general population, we will be able to organize our meeting as planned. The Annual (46th) EUBS Conference will therefore be held for the first time in its nearly 50-year history with an interval of three years.

The conference is currently scheduled for 31 August to 03 September 2022, at the original location, the NH Prague City Hotel. We feel that in our professional community there is major benefit meeting in person, both during lectures and in discussions in and out of the meeting room and, not to be forgotten, during social events. For these reasons, we will prioritise trying to make this a physical meeting. However, we anticipate the possibility we might have to adapt to a mixed (hybrid online) meeting, depending on the COVID-19 situation at the time.

Registrations as well as Abstract submission will be open from 10 March 2022, please visit the dedicated conference website http://www.eubs2020.com to book your EUBS Annual meeting experience. Your colleagues and friends will be waiting for you.

EUBS Executive Committee

Every year, a new Executive Committee member needs to be elected – elections start well before our next General Assembly (during the EUBS Annual Scientific Meeting).

This year, in line with the EUBS Constitution change approved in 2021, we will need a new Member-at-Large, who will be nominated for a period of four years.

Candidates will be presented by the Executive Committee by 15 June 2022, and the voting will be by internet ballot, starting 30 June 2022. If you want to contribute and help our society, please come forward and send a short CV to our secretary secretary@eubs.org before 01 June 2022.

If you do not feel up to presenting yourself, why not nominate someone else. Suggestions are welcome at the same email address.

EUBS Affiliate Society agreements

For 2022, the agreement has been renewed with the following scientific societies in order to promote membership and contact among the hyperbaric and diving scientists and practitioners in Europe and (why not) worldwide. Members of these societies benefit from a 10% reduction on the EUBS membership fees, when providing proof of membership from their other society. Simply indicate the Affiliate Society from the drop-down list on the EUBS Membership Application or Renewal Form.

- Belgian Society for Diving and Hyperbaric Medicine (http://www.sbmhs-bvoog.be)
- Scott Haldane Foundation, The Netherlands (http://www.scotthaldane.org)

- Italian Society for Diving and Hyperbaric Medicine (http://www.simsi.it/)
- German Society for Diving and Underwater Medicine (http://www.gtuem.org)
- French Society for Diving and Hyperbaric Medicine (http://www.medsubhyp.com)
- Swiss Society for Underwater and Hyperbaric Medicine (http://www.suhms.org)
- Undersea and Hyperbaric Medical Society (http://www.uhms.org)
- Spanish Society for Diving and Hyperbaric Medicine (http://www.asemhs.org)
- Austrian Society for Underwater and Hyperbaric Medicine (http://www.asuhm.at)

For 2022, the Dutch Society for Diving Medicine (http://www.duikgeneeskunde.nl) has joined our Affiliate Society list.

We are pleased to announce that in exchange, EUBS members benefit from a substantial reduction to their UHMS membership – simply mention your EUBS membership when enrolling/renewing your UHMS membership.

In addition, we are discussing new agreements and invite other National Societies to contact us in order to further expand these agreements.

EUBS website

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

By popular demand, EUBS Members can also download the complete Abstract Book of previous EUBS Meetings from the Member Area.

While on the EUBS website, make sure you take a look at our Corporate Members' webpage (http://www.eubs.org/?page_id=91). On this page, the logos and links of organizations, societies and companies that support EUBS financially are placed. EUBS is grateful for their continuing support and would suggest that if you contact any of them, please do so by clicking on the link at that page, so they will know that you did so through the EUBS website.

OXYNET Database updated

Since 2004, a public online database of European Hyperbaric Chambers and Centers has been available, started and initially maintained by the OXYNET Working Group of the COST B14 project of the European Commission, later by the European Committee for Hyperbaric Medicine (ECHM). The original database (although not maintained) is still available on http://www.oxynet.org.

However, over the past few years, the list and contact information of the OXYNET database have been updated thanks to the efforts of EUBS ExCom members, and hopefully, by the time you read this, be available online.

If you have updated information or any other request or remark, please send an e-mail to oxynet@eubs.org. If you can collect information for more than one center in your area or country, please do.

Passing of Professor David H Elliott

Just before compiling the news and notices, we received the word that David Elliott passed away at the age of 89, at his home in Haslemere, England. David was, at least for the older part of our community, a landmark and pillar of knowledge of diving medicine, having been active in various committees and working groups until 2017.

While there is an extensive obituary for David in the previous pages of this journal, members of EUBS ExCom express below their personal experience and feelings about this 'distinguished gentleman' of our field.

> "*In my early ears of work in diving medicine research I knew David as an extremely knowledgeable, curious, and inclusive scientist open to new ideas. Back in 1993 I was fortunate to be asked by David to be part of a team of eight colleagues travelling on a 3–4 weeks tour of lectures and scientific presentations visiting both Navy and Hyperbaric hospital departments in Singapore, Perth, Melbourne, Sydney in Australia and New Zealand. With David as host and coordinator on behalf of the citizen ambassador program, I look back on this event as a very special but also educational experience with David as an excellent host, coordinator and always a true gentleman. As we say farewell to you David, your name and legacy in diving medicine will last for many years to come.*"

Ole

> "*While I have only significantly interacted personally with David twice (first time in Malta 2000, second time in Gdansk at the 2011 EUBS conferences), being in the presence of this icon/giant of diving medicine was not intimidating at all - as stated many times, he was a true gentleman and very easy to talk to. Very inspirational.*"

Peter

> "*I have interacted with David several times in Diving Medicine courses and conferences; I remember very well one discussion that we had together about the fact that I was giving my slides away to others to be used for educational purposes and, at the end we agreed that it was useful and to be encouraged. I also remember a sentence*

(a pearl of wisdom) that he used to express his gratitude to his wife: She put a picture of me up in the kitchen and informed my children as follows: 'if you happen to cross this stranger in the house, just be warned: he is your father'. Farewell David, thanks for your legacy."
Tino

"*A great gentleman and colleague – this is a great loss to the scientific community. David Elliott has been a point of reference for years; I knew him as a mentor and in addition to his great experience in the Navy, academic, and industrial diving I must add his desire to share his brilliant expertise. A pioneer and guide in diving medicine.*"
Gerardo

"*Great name, great person – we will miss him.*"
Jacek

"*The very first textbook that I read as I started my training was "Bennett and Elliot's Physiology and Medicine of Diving". This is how I first encountered the name David Elliott. Unfortunately, I never had the privilege to meet Dr. Elliott in person but knew enough to know that he was a pioneer in diving medicine. Prof Elliot will be remembered as an excellent educator with an exemplary career and invaluable contributions to the field.*"
Bengusu

"*David was a great educator doing his best to pass on the lessons he had learnt. The courses he ran with Nick McIver were excellent and often run in wonderful parts of the world. He brought experts from around the world together to share their experiences and learn from each other. A true Gent!*"
Phil

"*I have had the pleasure of meeting David several times throughout my career and remember being slightly in awe of him but still finding him very approachable. My copy of 'Bennett and Elliot's Physiology and Medicine of Diving' remains my diving medicine bible! This is a very sad loss of a great gent who will be sorely missed by the diving community.*"
Lesley

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

Ole Hyldegaard, MD, Ph.D., DMSci, Professor in Clinical Hyperbaric Medicine

Congratulations go to Ole Hyldegaard, MD, Ph.D., DMSci, who has become the first Danish academic to become Professor in Clinical Hyperbaric Medicine. Ole was inaugurated on 01 February 2022 as Clinical Professor in Hyperbaric Medicine at the University of Copenhagen.

He is also the Chief of the Hyperbaric unit, University Hospital Rigshospitlaet, Copenhagen, which holds a new state of the art hyperbaric facility with two separate multiplace chambers and two monoplace chambers which will be ready to function in 2023. The new chambers were donated partly by private funding from the ELLABFONDEN who donated 50.4 million d.kr (=6.8 mill €) and a 5-year research program in HBOT.

Baltic Internation Symposium on Diving and Hyperbaric Medicine (BIS_on_DHM): Advances and up-to-date knowledge for professionals

The second edition of the BIS_on_DHM will be held as a face-to-face meeting on 09–11 June 2022 at the same location as previously, in the Nadmorski Hotel in Gdynia, Poland.

We sincerely hope to meet you all at BIS_on_DHM 2022, in complete health and with ease of mind to do science, update our knowledge and to communicate efficiently when the COVID-19 disaster has finally ended.

Two full days of lectures on both Diving and Hyperbaric Medicine with peri-symposium masterclasses. Only invited lecturers and experts in the field with great experience in their topics. The National Centre for Hyperbaric Medicine in Gdynia is responsible for preparation of the scientific programme.

More info and registering at the website: http://www.bisdhm.events.

The EUBS

website is at

http://www.eubs.org/

Members are encouraged to log in and keep their personal details up to date.

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

Notices and news

SPUMS notices and news and all other society information can be found on:
https://spums.org.au/

SPUMS President's message

Neil Banham

Despite the difficulties caused by COVID-19 over the last 2 years, some normality is starting to return, although many challenges remain.

The 2022 SPUMS Annual Scientific Meeting (ASM) has been confirmed, but will be held entirely virtually:

Theme: *Take a Deep Breath – Diving and Hyperbaric Respiratory Physiology in 2022*

Date: Wednesday 04–06 May 2022, 0900h–1500h AEST

Thanks again to Greg van der Hulst and his team for arranging this. No further details regarding the SPUMS 2023 ASM have been decided at this time.

In person attendance however, will be possible at the Hyperbaric Technicians and Nurses Association 30th ASM which is scheduled to be held at The Henry Jones Art Hotel in Hobart Tasmania from 07–09 September 2022.

The guest speakers are:

Dr Richard "*Harry*" Harris SC, OAM

Mr Chris Lemons (Saturation diver – Last breath documentary) from the United Kingdom

SPUMS will again be supporting this conference, with members being involved in organising and presenting. HTNA ASMs are always of high quality both academically and socially and I encourage you to consider attending. A link with information will be available on the SPUMS website 'Home page' menu in the near future.

The 2022 EUBS ASM, Prague, Czech Republic which was postponed in 2020 and 2021 is finally looking like proceeding this year from 16–18 September 2022. More information is available on the SPUMS Home page.

The 2022 ANZHMG Introductory Course in Diving and Hyperbaric Medicine originally scheduled to be held in Fremantle from 21 February–04 March 2022 has been postponed until June due to ongoing travel restrictions into Western Australia as a result of Omicron, details are on the SPUMS website https://www.spums.org.au/content/approved-courses-doctors.

This course is always fully subscribed, so if you are considering attending, apply soon.

It is hoped that the 2023 course can again occur in late February/early March, again in Fremantle.

Finally, I am saddened to report the passing of Professor David Elliott, a long time SPUMS member, and a keynote speaker at several SPUMS ASMs. David had extensive expertise in occupational and offshore diving and will be greatly missed. On behalf of SPUMS, I send our condolences to his family and friends. An obituary appears in this issue.

Neil Banham
SPUMS President

The Australian and New Zealand Hyperbaric Medicine Group 2022

Introductory Course in Diving and Hyperbaric Medicine

Dates: 13–24 June 2022
Venue: Hougoumont Hotel, Fremantle, Western Australia
Cost: AUD$2,700.00 (inclusive of GST) for two weeks

The course content includes:

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

Contact for information:
Sam Ovens, 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
https://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 Facebook page

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

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 https://www.anzca.edu.au/education-training/anzca-diploma-of-advanced-diving-and-hyperbaric-me.

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 2022

Closing date	May 2022
Withdrawal date	July 2022
Written section:	
short answer questions	August 2022
Viva examination	September 2022

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 enquiries 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 https://spums.org.au/ or at https://www.dhmjournal.com/.

The paper may be submitted to journals other than *Diving and Hyperbaric Medicine*; however, even if published in another journal, the completed paper must be submitted to the Education Officer (EO) for assessment as a diploma paper. If the paper has been accepted for publication or published in another journal, then evidence of this should be provided.

The diploma paper will be assessed, and changes may be requested, before it is regarded to be of the standard required for award of the Diploma. Once completed to the reviewers' satisfaction, papers not already submitted to, or accepted by, other journals should be forwarded to the Editor of *Diving and Hyperbaric Medicine* for consideration. At this point the Diploma will be awarded, provided all other requirements are satisfied. Diploma projects submitted to *Diving and Hyperbaric Medicine* for consideration of publication will be subject to the Journal's own peer review process.

Additional information – prospective approval of projects is required

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

All research reports must clearly test a hypothesis. Original basic and clinical research are acceptable. Case series reports may be acceptable if thoroughly documented, subject to quantitative analysis and if the subject is extensively researched in detail. Reports of a single case are insufficient. Review articles may be acceptable if the world literature is thoroughly analysed and discussed and the subject has not recently been similarly reviewed. Previously published material will not be considered. It is expected that the research project and the written report will be primarily the work of the candidate, and that the candidate is the first author where there are more than one.

It is expected that all research will be conducted in accordance with the joint NHMRC/AVCC statement and guidelines on research practice, available at: https://www.nhmrc.gov.au/about-us/publications/australian-code-responsible-conduct-research-2018, or the equivalent requirement of the country in which the research is conducted. All research involving humans, including case series, or animals must be accompanied by documentary evidence of approval by an appropriate research ethics committee. Human studies must comply with the Declaration of Helsinki (1975, revised 2013). Clinical trials commenced after 2011 must have been registered at a recognised trial registry site such as the Australia and New Zealand Clinical Trials Registry http://www.anzctr.org.au/ and details of the registration provided in the accompanying letter. Studies using animals must comply with National Health and Medical Research Council Guidelines or their equivalent in the country in which the work was conducted.

The SPUMS Diploma will not be awarded until all requirements are completed. The individual components do not necessarily need to be completed in the order outlined above. However, it is mandatory that the research proposal is approved prior to commencing research.

Projects will be deemed to have lapsed if:

- the project is inactive for a period of three years, or
- the candidate fails to renew SPUMS Membership in any year after their Diploma project is registered (but not completed).

For unforeseen delays where the project will exceed three years, candidates must explain to the EO by email why they wish their diploma project to remain active, and a three-year extension may be approved. If there are extenuating circumstances why a candidate is unable to maintain financial membership, then these must be advised by email to the EO for consideration by the SPUMS Executive. If a project has lapsed, and the candidate wishes to continue with their DipDHM, then they must submit a new application as per these guidelines.

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

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

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

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

Courses and meetings

Scott Haldane Foundation

As an institute dedicated to education in diving medicine, the Scott Haldane Foundation has organized more than 300 courses all over the world, over the past 29 years. SHF is targeting on an international audience with courses worldwide.

Due to the COVID-19 Pandemic some courses are re-scheduled. Fortunately, we were able to find new dates for all postponed courses. Below the schedule of upcoming SHF-courses in 2022.

The courses Medical Examiner of Diver (part 1 and 2) and SHF in-depth courses, as modules of the level 2d Diving Medicine Physician course, fully comply with the ECHM/EDTC curriculum for Level 1 and 2d respectively and are accredited by the European College of Baromedicine (ECB).

2022

14–21 May	Medical Examiner of Divers part 2 (level 1), Bonaire, Dutch Caribbean
31 May–01 June	Internship different types of diving (level 2d), Royal Dutch Navy-Den Helder NL
05–12 November	Medical Examiner of Divers part 1 (level 1), Indonesia
12–19 November	In-depth course Diving medicine (level 2d), Indonesia
19–26 November	In-depth course Diving medicine (level 2d), Indonesia
In planning	In-depth course Psyche under pressure (level 2d), tbd In-depth course Diving after (long) Covid, (level 2d), tbd
On request	Internship HBOt (level 2d certification) NL/Belgium

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

Please also check the COVID-19 News update on this website for the latest schedule changes.

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SIMSI Società Italiana di Medicina Subacquea ed Iperbarica

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

Date: 02–04 December 2022, Padua

"*SIMSI XXV Biennial Congress*", University of Padova

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

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

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

Gerardo Bosco and Vincenzo Zanon

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.

Historical Diving Society Australia - Pacific

P O Box 347, Dingley Village Victoria, 3172, Australia
Email: info@historicaldivingsociety.com.au
Website: https://www.historicaldivingsociety.com.au/

DHM Journal Facebook

Find us at:
https://www.facebook.com/divingandhyperbaricmedicine

Diving and Hyperbaric Medicine: Instructions for authors (summary)

(updated August 2021)

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

Address**:** The Editor, Diving and Hyperbaric Medicine, Department of Anaesthesiology, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand
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European Editor**:** euroeditor@dhmjournal.com
Editorial Assistant**:** editorialassist@dhmjournal.com
Journal information**:** info@dhmjournal.com

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

There is on-screen help on the platform to assist authors as they assemble their submission. In order to submit, the corresponding author needs to create an 'account' with a user name and password (keep a record of these for subsequent use). The process of uploading the files related to the submission is simple and well described in the on-screen help provided the instructions are followed carefully. The submitting author must remain the same throughout the peer review process.

Types of articles

DHM welcomes contributions of the following types:

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

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

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

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

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

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

Formatting of manuscripts

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

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

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

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

DIVER EMERGENCY SERVICES PHONE NUMBERS

AUSTRALIA – DAN
1800-088200 (in Australia toll free)
+61-8-8212-9242 User pays
(outside Australia)

NEW ZEALAND – DAN Emergency Service
0800-4DES-111 (in New Zealand toll free)
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+618-8212-9242

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ADSF
AUSTRALASIAN DIVING SAFETY FOUNDATION

Scholarships for Diving Medical Training for Doctors

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

There are two categories of scholarships:

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

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

DISCLAIMER

Opinions expressed in this publication are given in good faith and in all cases represent the views of the authors and are not necessarily representative of the policies or views of SPUMS, EUBS or the Editor and Editorial Board.