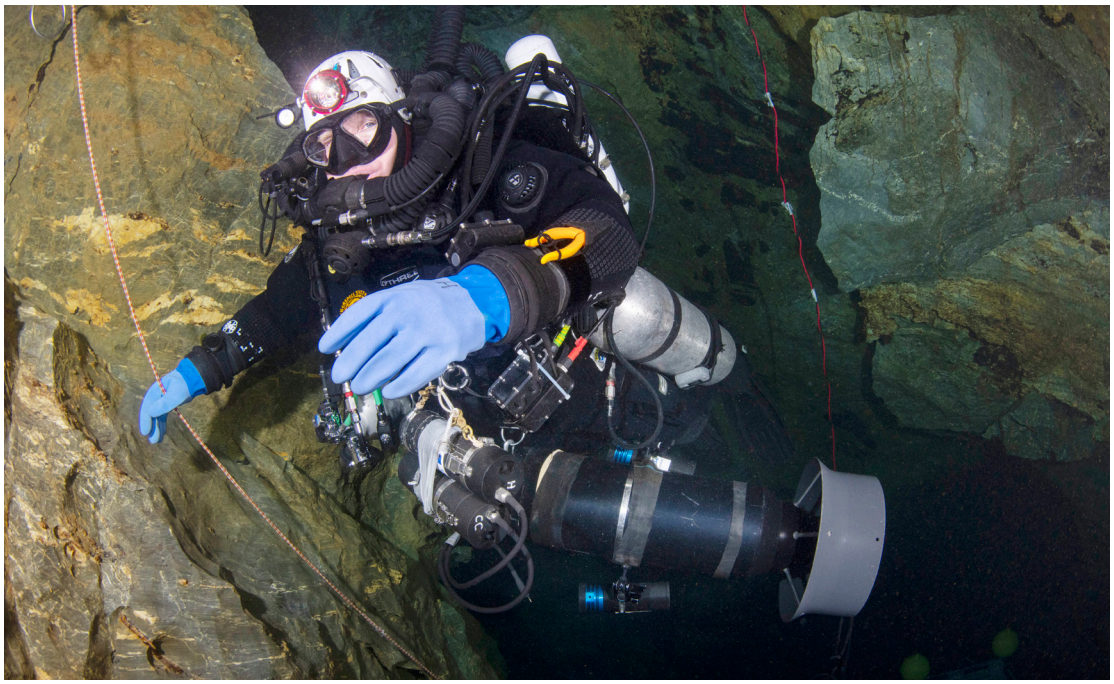
Diving and Hyperbaric Medicine

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

SPUMS

Volume 50 No. 1 March 2020

EUBS



Exhaled breath to measure pulmonary O_2 toxicity?

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HBOT effect on endothelial function in diabetics

Blood viscosity after prolonged cold-water immersion

Occupational diver satisfaction with health surveillance

Efficiency of different first aid oxygen administration devices

Validation of a US Navy air diving decompression profile

Diving with hypertension and antihypertensive drugs

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

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

PURPOSES OF THE SOCIETIES

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

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DIVING AND HYPERBARIC MEDICINE

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Submissions: https://www.manuscriptmanager.net/dhm

Subscriptions and print copies of back issues to 2017:
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Diving and Hyperbaric Medicine **is published online jointly by the South Pacific Underwater Medicine Society and the European Underwater and Baromedical Society**
E-ISSN 2209-1491; ABN 29 299 823 713

The Editor's offering

In this issue we are pleased to publish the final paper in a thematic series that comprises Thijs Wingelaar's PhD dissertation. Dr Wingelaar completes his PhD this month, and such completions within our discipline are a goal that all senior academics in the field should actively strive to support. PhD students not only conduct important work during the course of their studies, but recent history tells us that many remain academically active in diving and hyperbaric medicine even if not working full time in the field. Names like Kate Lambrechts, Frauke Tillmans, Peter Buzzacott who came through the PHYPODE or similar programs offering PhD study continue to be active in the field (including publishing in and/or reviewing for DHM). One benefit of operating in a comparatively under-researched field such as diving and hyperbaric medicine is that there remain many 'low hanging fruit' questions that in other better funded fields would have been answered decades ago. It is thus a fertile field for doctoral degree study. Congratulations to Dr Wingelaar and his supervisors (Professor Rob van Hulst and others).

This issue also contains papers from two senior clinicians who are also doctoral research degree candidates. Denise Blake from Townsville Australia is researching various aspects of early management of decompression sickness (DCS), and in her present paper provides objective evidence that guides the choice of oxygen flow rates when using non-rebreather masks for oxygen administration to a DCS victim. Dr Chris Sames from Auckland New Zealand is researching medical assessment and surveillance systems for occupational divers, and his present paper describes levels of satisfaction among divers in respect of the health assessment and surveillance system that has been the subject of his various studies. This system set important new precedents by being among the first to break away from the traditional 'annual medical' paradigm for occupational divers, to a five-yearly medical system with health surveillance by questionnaire in between.

In other original articles Jean-Eric Blatteau and colleagues identify clinical features and management strategies among DCS cases in fisherman-divers that are predictive of long-term sequelae. Some factors predictive of poor outcome, such as the severity of the initial presentation or deep in-water recompression using air are not surprising, but others, such as over-treatment with hyperbaric oxygen instituted late are perhaps more surprising. The latter may simply reflect an inappropriate focus on futile therapy in unsalvageable cases which delays institution of effective rehabilitation. Kaitlyn Rostomily and colleagues provide evidence that the increase in blood viscosity seen with cold water immersion is caused by haemoconcentration rather than decreased blood temperature. Morten Hedetoft and colleagues used upper limb peripheral arterial tonometry in diabetic patients to evaluate the effect of hyperbaric oxygen treatment (HBOT) on endothelial function. Their finding of minimal effect is interesting but should be interpreted cautiously because baseline endothelial function was borderline normal prior to HBOT in their cohort of subjects, and it is not known how upper and lower limb endothelial function correlate in these patients. Finally, Brian Andrew and David Doolette present the findings of a study to validate a US Navy air bounce dive schedule. This paper is notable in that it presents data that have previously appeared in a US Navy technical report. The journal takes the view that since these reports are not easily available to the general public, not externally peer reviewed and not searchable in the literature indexes, the distillation of related data into a peer reviewed and indexed scientific paper is a legitimate initiative. There are several similar reports of likely high interest to the diving community that we hope to publish in this way.

There are two review articles. Peter Westerweel and colleagues review diving with hypertension and anti-hypertensive drugs. This is of high practical relevance to the many readers of the journal who perform assessments of suitability for diving. There is also a review of wearable sensors in breath-hold diving by Vinetti and colleagues. This paper is likely to interest those performing research in the voluntary apnoea space, and also those interested in breath-hold diving safety.

Finally, there are two case reports. A case of pulmonary barotrauma is reported by Bigeni and Saliba. It is not clinically distinctive, but the authors provide some uniquely illustrative thoracic radiology of this case. Eynan and colleagues report a case of unmistakable premonitory symptoms of cerebral oxygen toxicity during oxygen breathing at one atmosphere absolute while undergoing a carbon dioxide tolerance test. This case will be of immense interest to technical divers because it illustrates the potential for cerebral oxygen toxicity to occur at inspired pressures of oxygen usually considered safe if the subject is concomitantly hypercapnic.

Professor Simon Mitchell
Editor, Diving and Hyperbaric Medicine

Front cover: Dr Richard Harris, during decompression from a deep cave dive in the Pearse Resurgence, New Zealand. **Photo:** Simon Mitchell.

Original articles

Assessment of pulmonary oxygen toxicity in special operations forces divers under operational circumstances using exhaled breath analysis

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Key words
Volatile organic compounds; VOCs; Gas chromatography-mass spectrometry; GC-MS; Methyl alkanes; Oxygen rebreather diving; O_2-CCR

Abstract
(Wingelaar TT, Brinkman P, Hoencamp R, van Ooij PJAM, Maitland-van der Zee AH, Hollmann MW, van Hulst RA. Assessment of pulmonary oxygen toxicity in special operations forces divers under operational circumstances using exhaled breath analysis. Diving and Hyperbaric Medicine. 2020 March 31;50(1):2–8. doi: 10.28920/dhm50.1.2-8. PMID: 32187611.)
Introduction: The Netherlands Maritime Special Operations Forces use closed circuit oxygen rebreathers (O_2-CCR), which can cause pulmonary oxygen toxicity (POT). Recent studies demonstrated that volatile organic compounds (VOCs) can be used to detect POT in laboratory conditions. It is unclear if similar VOCs can be identified outside the laboratory. This study hypothesised that similar VOCs can be identified after O_2-CCR diving in operational settings.
Methods: Scenario one: 4 h O_2-CCR dive to 3 metres' seawater (msw) with rested divers. Scenario two: 3 h O_2-CCR dive to 3 msw following a 5 day physically straining operational scenario. Exhaled breath samples were collected 30 min before and 30 min and 2 h after diving under field conditions and analysed using gas chromatography-mass spectrometry (GC-MS) to reconstruct VOCs, whose levels were tested longitudinally using a Kruskal-Wallis test.
Results: Eleven divers were included: four in scenario one and seven in scenario two. The 2 h post-dive sample could not be obtained in scenario two; therefore, 26 samples were collected. GC-MS analysis identified three relevant VOCs: cyclohexane, 2,4-dimethylhexane and 3-methylnonane. The intensities of 2,4-dimethylhexane and 3-methylnonane were significantly ($P = 0.048$ and $P = 0.016$, respectively) increased post-dive relative to baseline (range: 212–461%) in both scenarios. Cyclohexane was increased not significantly ($P = 0.178$) post-dive (range: 87–433%).
Conclusions: VOCs similar to those associated with POT in laboratory conditions were identified after operational O_2-CCR dives using GC-MS. Post-dive intensities were higher than in previous studies, and it remains to be determined if this is attributable to different dive profiles, diving equipment or other environmental factors.

Introduction

Exposure to a high pressure of oxygen (PO_2) can induce cerebral and pulmonary oxygen toxicity (POT).[1,2] While recreational divers and patients receiving hyperbaric oxygen therapy are at risk, divers using closed circuit oxygen rebreathers (O_2-CCR) may be at increased risk of POT due to the duration and PO_2 of exposure.[2,3] For covert special operations forces (SOF) diving, the beneficial properties of O_2-CCR, such as endurance and stealth, outweigh the potential health hazards associated with these diving systems.[4–7] To limit the risk of POT, oxygen exposure is restricted to a specific dose calculated according to mathematical models (such as units of pulmonary toxicity dose; UPTD).[8–10] However, the foundation of these models has been questioned.[3,11]

The most important flaw of the UPTD concept is the use of vital capacity as a marker of POT, which has substantial inter- and intrapersonal variation.[12,13] In addition, the correlation between UPTD and a decrease in vital capacity has been determined after 'dry dives' (i.e., inside a recompression chamber), which exclude factors related to diving that affect pulmonary function, such as immersion and hypothermia.[14,15]

The authors of the studies that first described the UPTD recognised this and assumed that newer techniques would overcome these limitations in due time.[9,10]

Exhaled breath analysis has recently been utilised to detect POT in 'wet' (i.e., diving) and 'dry' conditions. This technique seems able to distinguish between wet and dry hyperbaric hyperoxia and between oxygen and air diving.[16–18] Two separate groups of volatile organic compounds (VOCs) in exhaled breath have been detected: markers associated with inflammation, such as cyclohexane; and methyl alkanes, which are markers of lipoperoxidation.[17,18] These methyl alkanes originate from the membrane of alveoli in response to lipoperoxidation.[19]

While these markers fit within the pathophysiological framework of POT, the aforementioned studies were conducted in a controlled environment. This strengthens the methodological validity; however, it cannot be assumed that these findings translate to the real working environment of SOF divers. Many internal factors (e.g., continuous physical exertion, sleep deprivation and a very limited amount of food) and external factors (e.g., air contamination, weather conditions and no access to a clean environment during sample collection) can affect exhaled breath profiles and may limit the practical applicability of exhaled breath markers to determine POT in the field.[20,21]

This study aimed to determine exhaled breath profiles after simulated operational dives. We hypothesised that markers associated with inflammation and lipoperoxidation as reported in our previous studies (i.e., cyclohexane and methyl alkanes) can be detected after oxygen dives of practical relevance to military operations.

Methods

SETTING

This observational study was approved by the Ethics Committee of the University of Amsterdam (reference: 2017.183) and the Surgeon General of the Ministry of Defence. In accordance with the Declaration of Helsinki, all participants gave written informed consent on a voluntary basis, which could be retracted at any time without any consequences. According to privacy regulations, no study data were included in the medical files of the participants.

The study consisted of two scenarios, both of which simulated an operational dive of the Royal Netherlands Navy Maritime Special Operations Forces (NLMARSOF). Eligible for inclusion were healthy NLMARSOF divers, who were fit according to the European Diving Technical Committee standards, with the exception that pulmonary function tests were assessed using the reference values of the Global Lung Function Initiative.[22,23] Exclusion criteria were recent respiratory tract infection or use of medication. Participants were not exposed to hyperbaric conditions for at least 72 h prior to the start of the dive.

In the first scenario, no strenuous physical exercise (including sports) was performed on the day before the measurements were taken. In the second scenario, the divers completed a 5-day training exercise, which involved vigorous physical exertion. To avoid affecting the exhaled breath profiles, divers fasted for 1 h before the first measurement and within 1 h of sample collection, with the exception that drinking water was allowed.[24]

The scenarios were carried out in Q4 2018, with different individuals in both scenarios to avoid any carry-over effects.

Scenario one:

Divers were rested and well-fed, and completed a 4 h tactical dive to a maximum depth of 3 metres' seawater (msw) (131.7 kPa) breathing 100% oxygen using Lambertsen Amphibious Respiratory (LAR) 5010 equipment (Dräger, Germany). This dive profile represented a 355 UPTD oxygen exposure. Water temperature was 11°C, with visibility estimated at 2–3 metres.

Scenario two:

Divers completed a 5-day training exercise, which involved vigorous physical effort including, but not limited to, kayaking 140 km, walking and running with approximately 50 kg of equipment and having very little sleep (estimated at 2–3 h per 24 h). After this exercise, a 3 h operational dive breathing 100% oxygen using LAR-5010 equipment up to a maximum depth of 3 msw was performed. This dive profile represented a 266 UPTD exposure. Due to the operational scenario, there were some restrictions regarding sample collection, which are described below. The diving location was the same as that used in scenario one, with a registered water temperature of 10°C and limited visibility due to night-time conditions.

MEASUREMENTS

The procedures for collection and analysis of exhaled breath samples have been published previously.[17,18] Briefly, exhaled breath samples were collected in accordance with European Respiratory Society (ERS) recommendations.[25] The diver breathed for 5 min through a disposable two-way non-rebreathing valve (Carefusion, Utrecht, the Netherlands) combined with an inspiratory VOC filter (Honeywell, USA in scenario one and Dräger, Germany in scenario two) to prevent contamination by exogenous particles. After 5 min, a single expiratory breath was collected in an empty uncoated aluminium balloon (Globos Nordic, Denmark). After collection, 500 mL of exhaled breath was pumped though a stainless-steel tube filled with Tenax™ GR 60/80 sorbent material (Camsco, Houston, USA) using a calibrated

Table 1
Baseline characteristics of the study population. Data are mean (standard deviation)

	Total (n = 11)	Scenario one (n = 4)	Scenario two (n = 7)
Age (years)	28.0 (5.2)	31.0 (7.7)	25.8 (2.2)
Height (cm)	184 (9.7)	180 (4.7)	186.9 (11.3)
Weight (kg)	82 (7.6)	78.8 (4.8)	83.4 (8.7)

automatic air sampler pump (Gastec, Kanagawa, Japan) at a rate of 250 mL·min^{-1}, resulting in entrapment of VOCs. Pre-dive measurements were performed 30 min before diving. Post-dive measurements were performed at 30 min and 2 h after diving.

Exhaled breath samples were analysed using gas chromatography-mass spectrometry (GC-MS) based on standardised procedures.[25] Briefly, the tubes were heated to 250°C for 15 min with a flow rate of 30 mL·min^{-1} using a thermal desorption unit (Markes, Sacramento, USA). VOCs were captured in a cold trap at 10°C, which was then heated rapidly to 300°C for 1 min. Thereafter, molecules were transferred via splitless injection into a 30 m gas chromatography column with a diameter of 0.25 mm (Restek, Bellefonte PA, USA) at a rate of 1.2 mL·min^{-1}. Molecules were ionised using electron ionisation at 70 eV. Fragments were detected using a quadrupole mass spectrometer (GCMS-GP2010, Shimadzu, Japan) with a scan range of 37–300 Da. Ion fragments were used for statistical analysis. The predicted fragment ions were manually checked in the raw chromatograms, and the corresponding metabolites were tentatively identified based on National Institute of Standards and Technology (NIST) library matching, using the OpenChrom software package.[26] Metabolites were considered identified if the first five hits in the library were the same compound and all matching factors were higher than 90%.

STATISTICAL ANALYSIS

Our previous studies investigating VOCs after hyperbaric hyperoxia (PO_2 192 kPa; 1 h) reported a 35% increase in emission of methyl alkanes. A 50% increase in emission was estimated in the present study. Using nQuery 7.0 (Statistical Solutions Ltd, Cork, Ireland) and assuming a power of 80% and a significance level of 0.05, a minimum sample of five participants was needed to detect such an increase.

After GC-MS analysis, an ion fragment peak table was generated with de-noising, alignment and peak detection (signal-to-noise ratio 100:1).[27] Subsequently, data were tested univariately using the Wilcoxon rank-sum test (i.e., pre-dive vs. 30 min post-dive and pre-dive vs. 2 h post-dive) to identify potentially relevant ion fragments. Then, ion fragments with retention times (± 2 s) that correlated (0.98 or higher) were selected. Compounds could be identified from this selection of ion fragments/retention times. As intensities of the GC-MS signal are commonly non normally distributed, the medians of the VOCs were longitudinally tested using a Kruskal-Wallis test with correction for

Figure 1
Overview of data and statistical analysis. GC-MS = gas chromatography-mass spectrometry; NIST = National Institute of Standards and Technology; VOC = volatile organic compound

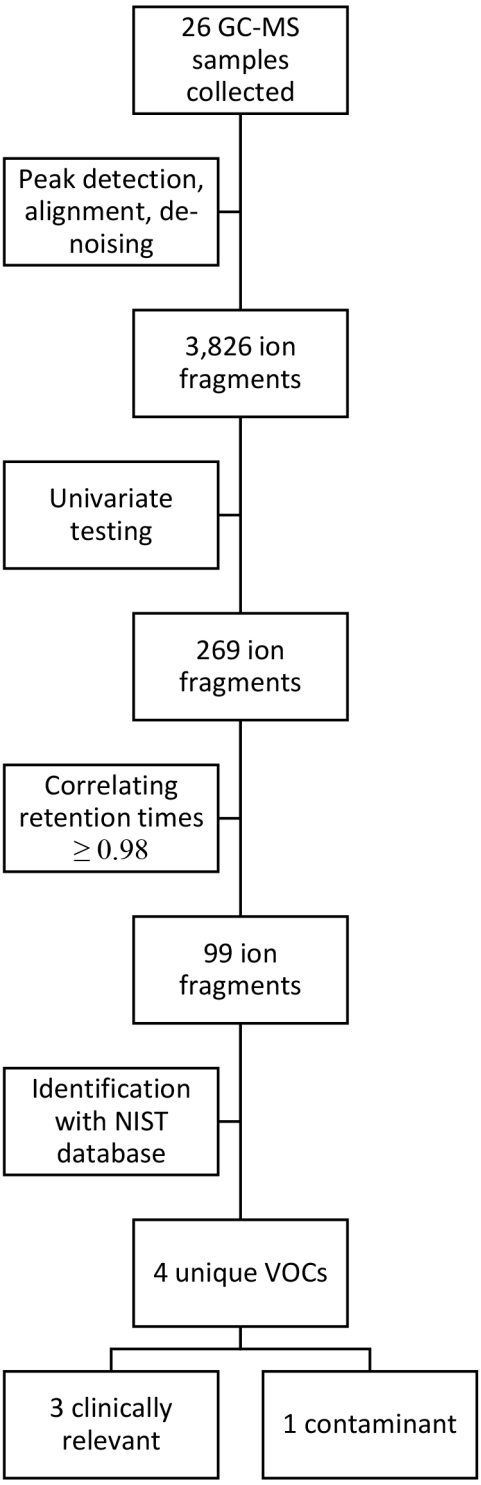


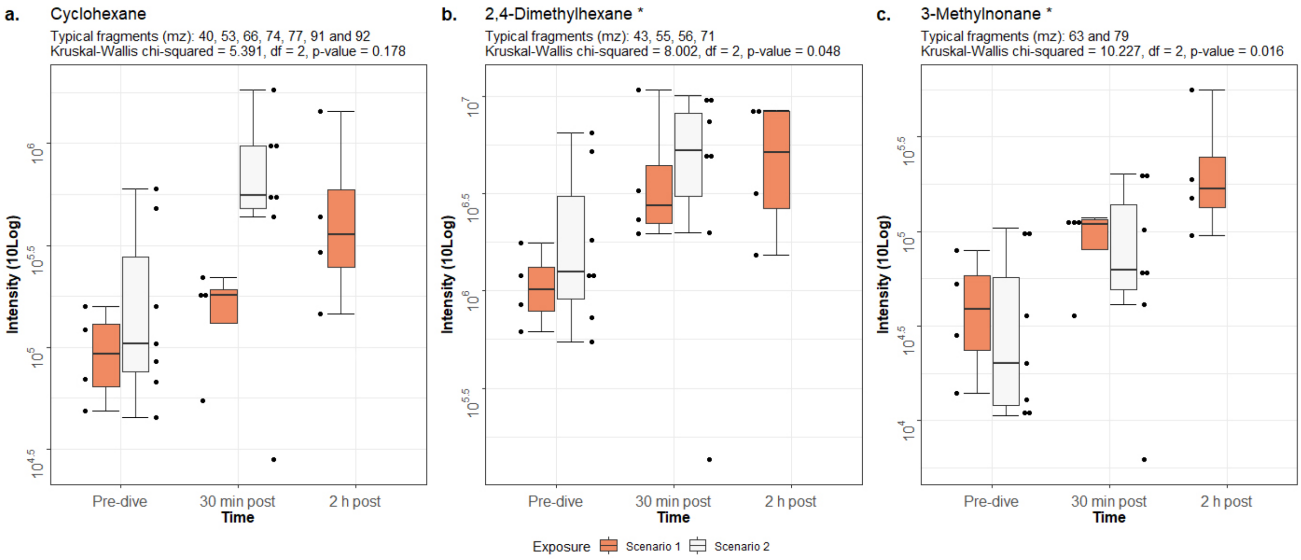
Table 2

Intensities of the identified VOCs. Data are median (IQR) and relative to the baseline in scenario one for each compound. The increase in percentage is relative to its respective baseline. A. Cyclohexane (Kruskal-Wallis chi-squared = 5.391, df = 2, P = 0.178). B. 2,4-Dimethylhexane (Kruskal-Wallis chi-squared = 8.002, df = 2, P = 0.048). C. 3-Methylnonane (Kruskal-Wallis chi-squared = 10.227, df = 2, P = 0.016)

A. Cyclohexane	Pre-dive	30 min post-dive	2 h post-dive
Scenario one	1.00 (0.67–1.37)	1.87 (1.51–2.01) + 87%	3.82 (2.67–7.19) + 282%
Scenario two	1.09 (0.80–3.33)	5.82 (5.04–10.20) + 433%	–
B. 2,4-Dimethylhexane	Pre-dive	30 min post-dive	2 h post-dive
Scenario one	1.00 (0.77–1.31)	2.73 (2.18–5.03) +273%	5.61 (2.69–8.16) + 461%
Scenario two	1.22 (0.91–3.43)	5.12 (4.36–8.06) + 344%	–
C. 3-Methylnonane	Pre-dive	30 min post-dive	2 h post-dive
Scenario one	1.00 (0.60–1.47)	2.70 (2.16–2.83) +270%	4.15 (3.34–6.90) + 415%
Scenario two	0.49 (0.30–1.56)	1.53 (1.23–3.60) + 212%	–

Figure 2

Intensities of the identified VOCs with IQR. Raw data are plotted as dots next to their respective boxplot. Results of the Kruskal-Wallis test are shown above each figure. Significant differences between pre- and post-dive intensities are marked with an asterisk (*). Note that 2 h post-dive measurements were not collected in scenario two



repeated measurements using the FDR-concept as described by Benjamin and Hochberg.[28]

All statistical analyses were performed using the R software package (version 3.6.1, R Foundation for Statistical Computing, Austria), including surrogate variable analysis (SVA version 3.32.1) and Methods for the Behavioural, Educational and Social Sciences (MBESS version 4.6.0). A P-value of < 0.05 was considered statistically significant.

Results

This study included 11 male divers of the NLMARSOF. Their baseline characteristics are shown in Table 1. Two divers in scenario two were smokers. All other divers were non-smokers. The dives were completed without incidents.

In total, 26 GC-MS samples were collected: 12 in scenario one and 14 in scenario two. The 2 h post-dive sample could not be collected in scenario two due to operational limitations, meaning that only pre-dive and 30 min post-dive samples were collected. Analysis of these samples identified 3,826 ion fragments, of which 269 were significant (P < 0.05) after univariate testing. Overall, in contrast with previous studies under controlled (laboratory) conditions, the GC-MS signals contained a moderate amount of noise.

Of the 269 ion fragments, 99 had a retention time (± 2 s) with a correlation of ≥ 0.98. Following grouping of these fragments using the Standard Reference Dataset (NIST), four unique VOCs were identified (Figure 1): cyclohexane; 2,4-dimethylhexane; 3-methylnonane; and toluene.

The intensities of cyclohexane, 2,4-dimethylhexane and 3-methylnonane were significantly higher post-dive than pre-dive in both scenarios ($P < 0.05$) (Figure 2). All values, relative to the baseline of scenario one, are displayed in Table 2. The increase (in percentage) is to the baseline of its respective scenario. Notably, the baselines of cyclohexane and 2,4-dimethylhexane were higher in scenario two than in scenario one, while the baseline of 3-methylnonane is higher in scenario one than in scenario two.

Toluene was only identified in scenario two (both pre- and post-dive) and should be considered a contaminant due to its exogenous origin.[29] To ensure that toluene did not originate from the LAR-5010 diving set or the VOC filter, we conducted an additional test in which a subject breathed pure oxygen for 4 h using the LAR-5010 rebreather at an ambient pressure of 101.3 kPa. Samples were collected pre- and post-exposure as described above. Small amounts of toluene were identified both pre- and post-exposure. In the sample with the highest signal intensity, the signal-to-noise ratio was 45:1 and thus this can be discarded as background noise. We conclude that this contamination is attributable to the nearby generator used to generate electricity, not to use of the LAR-5010 rebreather.

Discussion

This study identified similar VOCs in operational oxygen diving using an O_2-CCR as in laboratory conditions, including markers of inflammation (cyclohexane) and lipoperoxidation of membranes (2,4-dimethylhexane and 3-methylnonane). The relatively low number of VOCs may be attributable to the overall 'noisy' GC-MS signals, which may have masked potential subtle changes. Toluene has not been previously identified in oxygen diving and should be considered a contaminant.

Cyclohexane, 2,4-dimethylhexane and 3-methylnonane were identified as clinically relevant in previous studies analysing exhaled breath after hyperbaric hyperoxic exposure.[16–18] Although a dose-response relationship has not been established, the exhaled concentrations of cyclohexane, 2,4-dimethylhexane and 3-methylnonane were much higher in the present study than in our previous studies, which used shorter and deeper dive profiles in a controlled environment.[16,17] In the present study, the intensities of the identified compounds increased by 87–482% after exposure to an inspired PO_2 of 131.7 kPa for 3 and 4 h (Table 2). By contrast, the intensities of the same compounds only increased by 16–88% after exposure to a PO_2 of 192.5 kPa for 1 h in a previous study.[17] This could indicate that time is more important than inspired PO_2 in the development of POT or that other factors in operational diving affect or accelerate the development of POT.

None of the divers in our study experienced clinical symptoms of POT. It could be argued that this can be attributed to the relatively low hyperbaric hyperoxic exposure; scenario one (355 UPTD) provides 80% of the 'daily limit' of 450 UPTD, while scenario two (266 UPTD) gives 60%. However, clinical symptoms of POT are rarely reported in SOF diving, perhaps due to the covert nature of the operations.[3] Recent data showed several divers having severe symptoms of POT after hyperbaric hyperoxic exposure (560 UPTD, or 125% of the daily limit) and repeated dry and wet hyperbaric hyperoxic exposures.[30,31] Knowledge of the transition from subclinical to clinical symptoms of POT is limited and it seems that clinical symptoms of POT can occur at exposures lower than the daily limit. We feel this further substantiates the need for an alternative parameter to express oxidative damage to the lung.

The baseline intensities of cyclohexane and 2,4-dimethylhexane were 9% and 22% higher in scenario two than in scenario one, respectively, while that of 3-methylnonane was 51% lower. It cannot be concluded with certainty whether this is because the intensities of cyclohexane and 2,4-dimethylhexane are increased in operation settings, possibly due to subclinical infections or other stressors, or whether this reflects individual variation. As there are no reference values for these VOCs, the clinical implication of these variations at baseline are unknown. The intensity of cyclohexane was almost 5-fold higher in scenario two than in scenario one at 30 min post-dive, even though the exposure was 1 h longer in scenario one than in scenario two. Conversely, the intensity of 3-methylnonane increased 212% in scenario two while in scenario one at 30 min post-dive the intensity increased 270%. Perhaps this can be attributed to the lower starting intensity. Although the intensities of the identified compounds were increased post-dive in both scenarios, we cannot explain the difference between scenarios one and two. It is possible that factors in operational diving, such as fatigue and little food, affect the development of POT. This should be investigated in future studies.

The identified VOC toluene is commonly present in working environments.[29,32,33] For clarification: exogenous VOCs may still be present in exhaled breath even after correct use of inspiratory VOC filters, as some particles may still reside in the alveolar space after 5 min of pre breathing through the filters.[29,34] This chemical compound is widely used as a solvent and in fuels, and prolonged exposure to it elicits a wide range of clinical symptoms.[33,35] *In vitro* experiments demonstrated that human epithelial lung cells (A549) are damaged upon exposure to toluene, but this is repaired within 24 h of exposure.[36] The effects of toluene on the pulmonary system *in vivo* are unclear.[35] We attribute the detection of toluene in the present study to exhaust fumes from the nearby diesel generator, not to use of LAR-5010 equipment and/or

VOC filters. It is unclear to what extent toluene or exhaust fumes affected our results.

STRENGTHS AND LIMITATIONS

Caution is needed when comparing the results of this study with those of previous studies that used other dive profiles. However, the same compounds were identified post-dive, which strengthens the hypothesis that these compounds are associated with POT. In addition, the scenario used in the current study (3 or 4 h at an inspired PO_2 of 131.7 kPa) more accurately mimics the circumstances in which SOF divers are deployed, perhaps making these results more relevant than those reported in our previous study (1 h at an inspired PO_2 of 192.5 kPa).[17]

Fewer compounds were identified in the present study than in our previous studies. This may be attributable to the amount of noise in the GC-MS signals, which might have masked subtle changes in compounds. The total number of subjects was low, and the small number of samples was prone to bias. However, according to our sample size analysis, we included enough participants to provide sufficient statistical power at the group level. We must acknowledge that this could be confounded by inter- and intra-subject variability which we did not measure, and which is therefore unknown. Additionally, a Kruskal-Wallis test can be less reliable with small samples. We have performed additional tests with bias corrected and accelerated (BC_a) bootstrap resampled data (n = 1,000) for cyclohexane, 2,4-dimethylhexane and 3-methylnonane, which generated P-values of 0.068, 0.018 and 0.006 respectively. While this increases statistical validity of the Kruskal-Wallis test, we feel that interpreting bootstrapped data should be done carefully and does not necessarily increase clinical validity, therefore, we did not report these values in the results section. We identified cyclohexane, 2,4-dimethylhexane and 3-methylnonane in our previous studies; therefore, despite the small sample size, noisy GC-MS signals, possible influence of toluene and two subjects that were smokers, the associations can be considered robust. Lastly, intensities of measured VOCs are dependent upon concentrations of the substances present in the exhaled breath. Even though the post dive samples were collected 30 min after emerging, we cannot rule out remaining changes in the functional dead space due to immersion or hyperoxia, thus affecting exhaled breath concentrations. Therefore, we cannot be sure that the intensities we have found are an accurate representation of the 'true' concentration. Usage of an internal standard could have overcome this, and we recommend using one in future studies.[29]

This study confirms our hypothesis that markers associated with inflammation and lipoperoxidation (i.e., cyclohexane and methyl alkanes) can be detected in exhaled breath after oxygen dives of practical relevance to military operations using GC-MS. These molecular markers could potentially form the basis of a field test for pulmonary oxygen toxicity. However, further work is required to associate VOC levels with clinically relevant pulmonary change following oxygen exposure, assess the sensitivity and specificity of the test, and to develop a measurement instrument suitable for deployment in the field.

Conclusion

The present study identified cyclohexane, 2,4-dimethylhexane and 3-methylnonane after operational 3 and 4 h dives with O_2-CCR (LAR-5010). These compounds were previously noted after oxygen dives, which strengthens the hypothesis that they are related to POT. However, the signal intensities are higher than in a controlled environment; therefore, it remains to be established if these findings are solely due to oxygen diving or other factors in operational diving. In addition, further studies are required to determine which intensities can be regarded as safe and which risk reversible pulmonary damage when diving with increased oxygen mixtures.

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Conflicts of interest and funding: nil

Submitted: 28 June 2019
Accepted after revision: 12 October 2019

Factors influencing the severity of long-term sequelae in fishermen-divers with neurological decompression sickness

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Key words
Diving; Bubbles; Decompression sickness; Fisherman diver; Neurologic sequelae; Hyperbaric oxygen; In-water recompression

Abstract
(Blatteau JE, Lambrechts K, Ruffez J. Factors influencing the severity of long-term sequelae in fishermen-divers with neurological decompression sickness. Diving and Hyperbaric Medicine. 2020 March 31;50(1):9–16. doi: 10.28920/dhm50.1.9-16. PMID: 32187612.)

Introduction: Numerous studies have been conducted to identify the factors influencing the short-term prognosis for neurological decompression sickness (DCS). However, the long-term sequelae are rarely assessed. The purpose of this study to investigate the factors likely to influence the long-term prognosis.

Methods: Twenty-seven Vietnamese fishermen-divers who on average 9 (SD 6) years beforehand had presented with neurological DCS and ongoing sequelae, were questioned and examined. The severity of the initial clinical profile was quantified using a severity score. The long-term sequelae were clinically evaluated by looking for a motor or sensory deficit or muscular spasticity, and by applying a severity score for the sequelae which focussed on gait and sphincter disorders.

Results: An initial severity score of ≥ 15 is significantly associated with a risk of serious long-term sequelae [OR = 13.7 (95% CI 2.4 to 79.5)]. Furthermore, certain treatment practices such as in-water recompression to depths > 17 metres' seawater breathing air are significantly associated with more serious sequelae. The practice of intensive non-standardised hyperbaric oxygen sessions over prolonged durations (median 30 days [IQR 19.5]) delayed after the initial accident (median 4 days [IQR 6]) also seems unfavourable.

Conclusion: This study establishes a link between the initial DCS severity and the long-term sequelae causing severe gait disorders and sphincter incontinence. Furthermore, this work suggests that certain detrimental treatment practices should be modified. During this field study, we also found that it was possible to reduce sequelae of these divers by offering them an individual programme of self-rehabilitation.

Introduction

Decompression sickness (DCS) in scuba diving is the consequence of bubbles linked to the presence of dissolved gas, especially nitrogen, in the various tissues of the body during exposure in a hyperbaric atmosphere.[1,2] The neurological form of these diving accidents is common and particularly feared because of its prognosis. The initial clinical profile is polymorphous starting with the presence of subjective neurological signs and moving on to the appearance of signs of motor and sensory deficit that could go as far as tetraplegia. Cognitive disorders are also possible if the brain is affected.[3]

In the past, numerous studies have been conducted with the aim of identifying the factors influencing the short-term prognosis for neurological DCS. The initial clinical presentation before treatment,[4–6] the symptom latency after surfacing[3,7,8] and the time elapsed between the first signs and recompression[9–16] are all factors to be taken into consideration. The severity of the initial clinical impairment seems to be one of the dominant factors in the prognosis and the presence of short-term neurological sequelae after the treatment in hyperbaric centre.[16] However, to date there are no studies considering the long-term sequelae of neurological DCS and, in particular, the factors likely to influence the severity of sequelae over the long term, which should be studied.

For many years an NGO, AFEPS [French-Speaking Association for Mutual Aid and the Promotion of Life Sciences], has organised a programme of humanitarian aid for Vietnamese fishermen-divers in order to prevent and treat DCS.[17] However, not all fishermen have access to this training and the populations of fishermen-divers continue to be affected by many cases of DCS. An assignment devoted to the evaluation and treatment of long-term sequelae from neurological DCS was organised in April 2015 in central

Table 1
Characteristics of the 27 injured divers studied

Characteristics of divers (n = 27)	Mean (SD)
Age (years)	38 (8)
Weight (kg)	59.7 (0.6)
Height (cm)	166 (6)
BMI (kg·m^2)	22 (2.5)
Years of diving before the accident	12.7 (7)
Years since the accident	9 (6)

Vietnam, in Quang Ngai province. During this assignment we studied a group of 27 randomly recruited Vietnamese fishermen-divers, by attempting to retrace the clinical history of the initial DCS until the fixation of long-term sequelae.

This work pursued several objectives. Firstly, we questioned the divers about the initial symptoms and the methods of therapeutic management. We then sought to identify the main clinical and functional sequelae responsible for a change in the quality of life of injured divers. Finally, we sought to individualise the factors that could influence the severity of these sequelae in the long term. Ultimately, a self-rehabilitation programme was proposed for each patient, under the guidance of a team made up of French and Vietnamese practitioners, doctors, physiotherapists, occupational therapists, and orthotists. The aim of this programme was to enable former fishermen-divers to regain, over the long term, a certain amount of independence, a place in society and optimum standard of living, particularly due to pain reduction.

Methods

POPULATION STUDIED

The study was approved by the institutional review board of the health department from Qhang Ngai province.

The medical observations for 27 fishermen-divers who presented a neurological DCS (diver characteristics in Table 1) were performed after random recruitment organised by the local people's committees on the island of Ly Son (n = 13) and in the village of Binh Chau (n = 14). It is a community of fishermen-divers in Central Vietnam, homogeneous both geographically and for lifestyle or diving operating methods. Participation was voluntary without commander involvement, and all provided informed consent prior to participation.

Dives are organised from 10 to 15-metre-long boats, capable of embarking eight to 10 divers, and equipped for open sea navigation (Figure 1). Fishing seasons are mostly spent around the Paracel Archipelago, several days sailing from the Vietnamese coast.

The divers' equipment is rudimentary, with some clothing, a lead belt and, very rarely, a neoprene wetsuit and fins (Figure 2). The water temperature varies from 22 to 30°C, depending on the season. The divers breathe compressed air from a hose placed directly in the mouth (Figure 3). The boat is equipped with a compressor, the drive belt of which is coupled to that of the boat's engine. The compressed air is sent to a small buffer tank from which four 60 to 70-metre hoses exit and are placed in the diver's mouth with a pressure of 6–8 bars.

During these fishing seasons dives are carried out at a depth between 40 and 60 metres' sea water (msw). The diving depth is known through use of a boat depth sounder. The divers carry out two to four dives a day with two to three-hour intervals between each dive. The dive time is in the order of 30 to 40 minutes. The return to the surface takes place slowly, between 10 and 15 minutes. Decompression stops are carried out completely empirically with inadequate depths and durations.

INITIAL CLINICAL PROFILE

All the fishermen-divers presented initial clinical signs suggesting neurological DCS with spinal and/or cerebral topography. The presence of a motor and sensory deficit of the upper and/or lower limbs has been reported in all the study subjects. Back pain that appeared early and of severe intensity occurred in 45% of cases. The appearance of urinary retention was reported in 70% of cases. There was initial loss of consciousness in 27.5% of cases, with spontaneous regaining of consciousness. The initial clinical severity was assessed by a severity score validated for neurological DCS,[6] especially the spinal forms (Table 2). The scores were calculated retrospectively by the investigators based on interviews with the divers. In this study, the calculated score took into consideration the development of symptoms during the six hours after the appearance of the first signs. None of the divers received normobaric oxygen after surfacing, but many divers carried out in-water recompression (breathing air) at variable depths. The final score took into account the evolution of symptoms after in-water recompression.

LONG-TERM SEQUELAE

Long-term sequelae were evaluated clinically by quantifying the extent of the actual deficit (motor and sensory) by an ASIA score,[18] looking for spasticity, tone disorders, the presence of tendon retraction, and by evaluating gait disorders. For these evaluations, the investigating doctors performed neurological exams. Injured divers were also questioned about functional aspects, trying to determine the level of change in the activities of daily life and the extent of sphincter disorders.

The severity of the long-term sequelae was evaluated based on the Rankin score,[18] modified and adapted to the population studied, by taking into account gait disorders and/or sphincter disorders; sequelae that are particularly frequent in divers suffering neurological DCS (Table 3).

Figure 1
Typical boats of the Vietnamese fisherman diver fleet

Figure 2
Diver about to enter the water. Note the rudimentary equipment and lack of fins

Different clinical factors such as the severity of the initial clinical presentation, the presence of motor and sensory deficits, spasticity, or factors linked to the initial management, such as in-water recompression or delayed hyperbaric oxygen treatment (HBOT) were analysed to study their relationship with the extent of the long-term sequelae.

Figure 3
Diver with air supply hose. Note the lack of a demand valve

STATISTICS

The statistical analysis was done with the Sigmastat 3.0 software program (SYSTAT Inc, Richmond CA, USA). Parametric data are presented as mean (standard deviation [SD]) and non-parametric data as median (interquartile range [IQR] or range). Receiver operating characteristic (ROC) curves were used to find the optimal cut-off levels. Chi-square or Fisher tests were used to identify significant predictive variables for intermediate or high grades of long-term sequelae. Additional analysis with the Mann-Whitney U-test or the unpaired *t*-test were also carried out to compare continuous variables. Odds ratios (OR) with 95% confidence intervals (95% CI) were calculated to estimate the relative risks between groups. We also used the Spearman correlation for the initial severity score and the long-term sequelae score. Alpha for statistical significance was set at $P < 0.05$.

Results

DESCRIPTION OF LONG-TERM SEQUELAE

Of the 27 subjects examined, 70.4% exhibited a motor deficit. The deficit remained moderate with an average ASIA score of 91.5/100. Eighty-nine percent of subjects presented a sensory deficit for all modes, with an average ASIA score of 184/224. Muscular spasticity in the lower limbs was objectively present in 52% of subjects. Eighty-nine percent of injured divers had gait disorders to a greater or less extent compatible with proprioceptive ataxia i.e. spinal cord lesions affecting deep sensitivity. Twenty subjects (74%) exhibited gait changes that did not need external aid, but which were augmented when subjects closed their eyes. Seven subjects (26%) exhibited severe gait impairment necessitating external aid, related to the presence of spasticity, hypertonia, tendon retraction or motor and sensory deficit in the lower limbs. Finally, 70% of subjects had urinary sphincter

Table 2
Initial clinical severity scoring system for neurologic DCS

Clinical parameter	Descriptor	Score						
		0	1	2	3	4	5	6
Age ≥ 42 y	no yes	*	*					
Back pain	no yes	*	*					
Evolution before recompression	better stable worsen	*			*		*	
Sensory deficit	no yes	*				*		
Motor deficit	no paresis paraplegia	*				*	*	
Bladder dysfunction	no yes	*						*

Table 3
Adapted Rankin Score for long-term sequelae for neurologic DCS

Score	Activities of daily life	Gait disorders	Sphincter disorders
1	No limitation, minor symptoms	No alteration at rest, tiredness during physical activities	No
2	Slightly limited, restrictions of certain past activities	Altered, but possible without external assistance	Forced urination possible, partial control of intestinal transit
3	Limited	Limited, but possible with crutches	Partial urinary or anal incontinence
4	Requiring frequent external assistance	Significantly limited, requiring walking frame or external assistance	Permanent urinary or anal incontinence
5	Bedridden, requiring permanent external assistance	Impossible to get out of bed without external assistance	Permanent urinary or anal incontinence requiring external assistance

disorders and 48% anal sphincter disorders, with problems of partial incontinence in the majority of cases.

INITIAL TREATMENT METHODS

Seventy-eight percent of divers underwent early in-water recompression (breathing air) after the appearance of the first symptoms: the injured divers were sent back under the water for a median duration of 50 min (range 10–480) and to a median depth of 20 msw (range 8–50). Thirty-eight percent of divers were sent to a remotely located hyperbaric centre. The median time for access to a hyperbaric centre was four days (range 3 h–30 d). The HBOT sessions were particularly intensive with a median 30 days of HBOT (range 8 d–6 months) with daily sessions lasting 3 h (SD 1.2) on 100% oxygen at 283.6 kPa (2.8 atmospheres absolute [atm abs]). Treatment with rehabilitation, often combined with acupuncture, was only performed in 48% of cases over a period from several weeks to several months after the accident.

FACTORS DETERMINING SEVERITY OF SEQUELAE

Clinical factors

The median modified Rankin score for sequelae was 2 (range 1–4). For the statistical analysis, two groups were distinguished taking into account the extent of the change in activities of daily life and the need for an external aid: intermediate grade sequelae being scores of 1 to 2; high grade sequelae being scores of 3 to 4 (no subjects achieved a score of 5).

Table 4

Clinical parameter association with the severity of long-term sequelae based on the adapted Rankin score (Intermediate grade = scores 1–2; High grade = scores 3–4). Data are number of subjects unless otherwise specified. M-W = Mann-Whitney U test

Clinical parameter	Intermediate *n* = 15	High grade *n* = 12	*P*-value (statistical test)
Initial severity score Median (IQR)	10 (5.7)	16 (1.5)	*P* = 0.023 (M-W)
Initial severity score ≥ 15	4	10	*P* = 0.011 (Chi-square)
Presence of a motor deficit	10	8	*P* = 1 (Fisher)
ASIA motor score Mean (SD)	95.5 (5.4)	92.5 (6.7)	*P* = 0.2 (*t*-test)
Bilateral motor deficit	3	5	*P* = 0.4 (Fisher)
Presence of a sensory deficit	13	11	*P* = 1 (Fisher)
ASIA sensory score Mean (SD)	186.3 (28.6)	189.3 (29.3)	*P* = 0.8 (*t*-test)
Bilateral sensory deficit	7	8	*P* = 0.5 (Fisher)
Presence of spasticity	7	8	*P* = 0.5 (Fisher)
Bilateral Spasticity	2	8	*P* = 0.007 (Fisher)

Table 5

Treatment parameters significantly associated with the severity of long-term sequelae based on the adapted Rankin score (Intermediate grade = scores 1–2; High grade = scores 3–4). M-W = Mann-Whitney U test

Treatment parameter	Intermediate *n* = 15	High grade *n* = 12	*P*-values (statistical test)
In-water recompression (Number of subjects)	9	12	0.02 (Fisher)
Depth (msw) of IWR (Median (IQR))	10 (13.7)	22.5 (16)	0.004 (M-W)
HBOT (Number of subjects)	2	9	0.002 (Fisher)

Table 4 shows the results concerning the association between the various clinical parameters and the severity of the sequelae, split into intermediate and high-grade sequelae.

Furthermore, the presence of a sensory deficit was significantly associated with the presence of proprioceptive ataxia revealed by a gait disorder that was increased when divers closed their eyes ($P = 0.025$, Chi-square test).

An initial clinical severity score of ≥ 15 (threshold identified by ROC analysis) was significantly associated with a risk of serious long-term sequelae (OR 13.7 [95% CI 2.4 to 79.5]). We also found a positive correlation (Spearman correlation coefficient 0.4, $P = 0.02$) between the initial severity score and the long-term sequelae score (Figure 4).

Factors linked to the initial treatment

Table 5 shows the analysis of the association between the different methods of treating the initial DCS and the severity of the sequelae. With an ROC analysis, we identified that an in-water recompression depth threshold of ≥ 17 msw was significantly associated with a higher number of high grade long-term sequelae (OR 20 [95% CI 3.3 to 120.3]). A higher number of serious long-term sequelae for subjects who received HBOT was found (OR 19.5 (95% CI 3.2 to 117.6); HBOT sessions over prolonged periods greater than or equal to 30 days were performed in 72.7% of the cases.

Furthermore, the data given in Table 6 shows the absence of a significant relationship between the severity of the initial clinical profile and the performance of recompression in water or HBOT sessions.

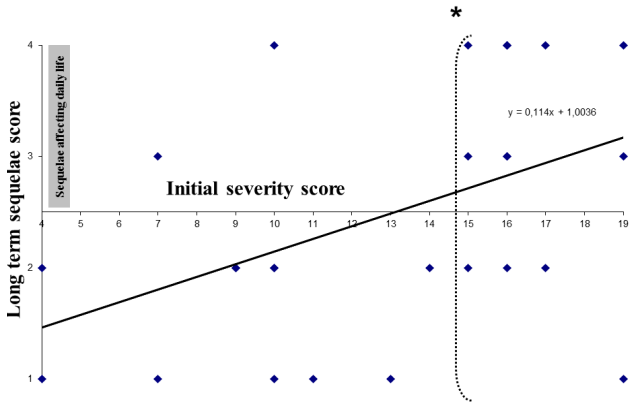
Discussion

Due to the use of specific scores this study has made it possible to establish a link between the initial clinical presentation and the severity of the long-term neurological sequelae. The score for the initial clinical profile has been validated in the framework of a multi-centre study.[6] That study showed that patients with an initial severity score higher than eight presented a higher risk of neurological sequelae at one month (positive predictive value of 87%). However, only the presence or absence of sequelae were considered without quantification of the impairment. On the other hand, clinical recovery was taken into account at one month after the accident without necessarily assessing the level of the impairment at one year or more. So, the present study using a ROC analysis is the first to demonstrate a significant link between an initial clinical score higher than 15 and the risk of developing sequelae with a major effect on the patient's quality of life several years after the accident. According to the Rankin classification we used and adapted for the sequelae observed in the divers, the main sequelae affecting the daily life of the divers are the loss of independence in walking with the need to use a technical

Table 6
Relation between the initial severity score and the number of subjects receiving in-water recompression and hyperbaric oxygen treatment

Treatment parameter	Score < 15 *n* = 13	Score ≥ 15 *n* = 14	*P*-value
Number receiving in-water recompression *n* (%)	8 (61.5)	13 (92.8)	*P* = 0.08
Number receiving HBOT *n* (%)	4 (30.7)	7 (50.0%)	*P* = 0.53

Figure 4
Relationship between the initial severity score and the long-term sequelae score. There is a positive correlation between initial severity score (especially when greater than or equal to 15) and a risk of severe sequelae affecting daily life (score > 2), especially when the *$P < 0.05$



aid (crutches or walking frame), recurrent pain in the lower limbs and back, and the problems of urinary and faecal incontinence.

For gait disorders we have shown that these were mainly linked to proprioceptive ataxia of variable extent observed in 89% of cases, and routinely associated with the presence of a deficit in the deep sensitivity of the lower limbs. For subjects with severe gait disorders requiring an external aid we observed that the change in gait did not seem to be influenced by the extent of the motor and/or sensory deficit, moderate in most cases, but rather by the presence of lower limb spasticity, particularly when this was bilateral.

We have been able to put in place a rehabilitation programme targeted at gait disorders and improvement in living standards: pain reduction, increase in joint suppleness and amplitude, stabilisation of deformations, etc. For subjects who retained some independence in walking (n = 20), the programme included learning specific exercises, in the form of laminated sheets with demonstration photos and explanation translated into Vietnamese. The exercises involved muscle strengthening and stretching, and exercises for proprioception and posture. Collective learning sessions were organised as well as individual sessions, depending on the specific needs of each patient.

For the most severely affected fishermen-divers with major limitations in walking (n = 7), treatment was concentrated on the use of and training in distributed technical aids (walking frame, crutches). Exercises for rebalancing the pelvis, lumbar relaxation and active or passive mobilisation of the lower limbs, associated with specific muscle strengthening, have been proposed. Finally, the advice of an occupational therapy specialist has made it possible to promote lifestyle and living environment and optimisation of movements in particular.

An important aspect of this study concerns the assessment of the traditional practice of in-water recompression on air after the appearance of the first symptoms of DCS. The practice of recompression is quite frequent in the communities of fishermen-divers in emerging countries, which do not have hyperbaric installations. However, the non-standardised practice of in-water recompression is debatable, because a number of complications are possible like drowning, hypothermia or dehydration, and also its efficacy is difficult to establish if there is no reproducible, uniform protocol.[19–21] Although some studies performed in different isolated communities of fishermen-divers are in favour of in-water recompression,[22,23] the results of our study demonstrate a factor that aggravates and increases the risks of long-term neurological sequelae. In fact, the practice of recompression in very deep water breathing air over a long duration contributes to an increase in dissolved gas (nitrogen) and the formation of bubbles during decompression. Our study shows a significant relationship between the in-water recompression depth and the severity of the long-term neurological sequelae. The number of high-grade sequelae is greater for recompression depths ≥ 17 msw.

These results are consistent with the prevention programme initiated several years ago in these fishermen-diver communities, proposing to perform in-water recompressions with oxygen breathing at a shallow depth instead of deep air recompressions for neurological DCS.[17,19,24]

An unexpected result concerns the practice of HBOT sessions. Our study seems to show a potentially detrimental effect of these HBOT sessions if they are delayed after the initial accident (median time to HBOT of 4 ± 6 days), without a standardised protocol. In fact, a higher number of serious long-term sequelae for subjects who received HBOT are observed, and this result seems minimally influenced by the degree of severity in the initial clinical profile. There are very few studies, which have evaluated the efficacy of HBOT

sessions performed late after a DCS (median four days in our study). Some studies seem inclined towards a worse clinical recovery when the delay is more than 24 hours.[10–12,14] However, other studies show a definite benefit in performing late recompressions after more than 48 hours.[25–27] In these studies the HBOT was short with an average total number of one to two sessions,[25,26] or more if residual symptoms existed.[27] It involved a majority of Type 2 accidents with about only 20% to 40% of severe forms and a cure rate greater than 60%. Thus, it is difficult to compare these results with our series, which only concerns neurological DCS with high initial clinical severity and sequelae. However, the benefit of repeated HBOT sessions over an extended period may be questioned. In our study the HBOT was continued over prolonged periods greater than or equal to 30 days in 72.7% of the cases with daily sessions of 3 ± 1.2 hours with 100% O_2 at 2.8 atm abs. This intense, prolonged practice does not correspond to western standards, which generally recommend no more than ten additional HBOT sessions after DCS, with the implementation of early rehabilitation by physiotherapy. In our study the repeated sessions probably caused tiredness and lower efficacy of rehabilitation, often considered to be optional or forgotten.

Seriously injured fishermen-divers should be subjected to an early, adapted rehabilitation programme with physiotherapy and occupational therapy. We think that it is also possible to improve the sequelae of DCS in these patients later by offering them a personalised programme of self-rehabilitation. To be effective this programme should target exercises adapted to each subject by combining muscle strengthening and stretching with proprioception exercises.

We acknowledge that the results should be interpreted with caution. Indeed, the number of subjects included is small and does not allow for a multivariate analysis. Moreover, it is a retrospective study, which consequently may be a source of selection bias. The in-water recompression depths and times were obtained by interviewing the divers and thus subject to memory error. Because the outcome of serious DCS is highly variable even in the absence of treatment, it is possible there is a significant population of previously injured divers who resolved completely, which were not captured by this study. We hope that the analysis performed on two different sites, using standardised clinical scores has reduced these potential biases a little.

Conclusion

For the first time this study has made it possible to establish a link between the initial DCS clinical severity and the presence of long-term neurological sequelae, which have an impact on the patients' quality of life. The most frequent long-term sequelae are gait disorders related to proprioceptive ataxia. The change in the quality of daily life is linked to the presence of urinary or faecal incontinence and severe walking impairment often linked to bilateral spasticity.

Furthermore, our study suggests changing certain practices, which could aggravate the prognosis for these diving accidents, in early and later treatment. We support the firm and definitive abandonment of deep in-water recompressions in favour of shallow in-water recompressions with oxygen.[17,20,21]

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Acknowledgements

We thank Corentin Boucher, Brian Charbel, Émilie and Marie Hofman, Jean-Michel Pontier for their active participation and unconditional support during this mission. We thank Dr Nguyen Van Mui for the preparation of this mission and also our interpreter, Phan Thanh, and our colleague's Dr Sang, Nguyen Tien Dung and Tran Dung Ahn. Our thanks also go to Dr Pierre Nguyen, founder of AFEPS, and Dr Georges Michel, current president of the AFEPS.

Conflicts of interest and funding: nil

Submitted: 09 August 2019
Accepted after revision: 24 September 2019

Measurement of peripheral arterial tonometry in patients with diabetic foot ulcers during courses of hyperbaric oxygen treatment

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Key words
Endothelium; Diabetes; Hyperbaric Research; Wounds

Abstract
(Hedetoft M, Olsen NV, Smidt-Nielsen IG, Wahl AM, Bergström A, Juul A, Hyldegaard O. Measurement of peripheral arterial tonometry in patients with diabetic foot ulcers during courses of hyperbaric oxygen treatment. Diving and Hyperbaric Medicine. 2020 March 31;50(1):17–23. doi: 10.28920/dhm50.1.17-23. PMID: 32187613.)
Introduction: Treatment of diabetic foot ulcers is complex and often protracted. Hyperbaric oxygen treatment (HBOT) improves wound healing in diabetic ulcers and serves as an important adjunct to regular diabetic wound care. Endothelial dysfunction plays a central role in diabetes-related vascular complications and may be evaluated by a non-invasive technique called peripheral arterial tonometry which measures a reactive hyperaemia index (RHI). We hypothesized that endothelial function measured by peripheral arterial tonometry is impaired in diabetic foot ulcer patients and that HBOT might improve endothelial function.
Methods: Endothelial function was prospectively assessed by peripheral arterial tonometry in 22 subjects with diabetic foot ulcers and 17 subjects without diabetes during courses of HBOT. Endothelial function was evaluated before first (baseline) and 30th treatments, and at 90-day follow-up. Serum insulin growth factor-I (IGF-I) concentrations were determined by immunoassay. Results were compared to 23 healthy subjects.
Results: No baseline differences were found in endothelial function between subjects with diabetes, HBOT patients without-diabetes and healthy control subjects (RHI; 1.26, 1.61 and 1.81, respectively). No significant changes in RHI were found in patients with ($P = 0.17$) or without ($P = 0.30$) diabetes during courses of HBOT. At 90-day follow-up IGF-I was significantly reduced in the subjects with diabetes ($P = 0.001$) and unchanged in the group without diabetes ($P = 0.99$).
Conclusions: We found no significant differences in RHI between subjects with diabetic foot ulcers and patients without diabetes, nor improvement in endothelial function assessed by peripheral arterial tonometry during courses of HBOT.

Introduction

The incidence and prevalence of type 2 diabetes have quadrupled between 1980 to 2004 mainly due to rise in sedentary lifestyles, obesity and an ageing population.[1] Diabetes is predicted to affect more than 300 million people by 2025[2] and 642 million by 2040[1] which has brought increased attention to serious complications such as diabetic foot ulcers. Treatment of diabetic foot ulcers is often protracted and ulcers are reported as non-healing in 19–34%.[3] Diabetic foot ulcers account for more than 60% of all non-traumatic lower limb amputations in the United States[4] and the five year mortality rate for amputated persons with diabetes is 60%.[4]

The pathophysiology of diabetic foot ulcers is well described including autonomic neuropathy, arterial flow insufficiency and microangiopathy,[5] and in general the lower extremities are more prone to the development of peripheral arterial disease (PAD)[6] causing diabetic foot ulcers. The complex sequence in successful wound healing includes "*removal of necrotic debris, resolution of inflammation, repair of the connective tissue matrix, angiogenesis and resurfacing*".[5] The dependency of these processes on oxygen has been well established.[7,8] However, chronic diabetic foot ulcers have failed to follow this orderly sequence and treatment often requires regular outpatient wound care, antibiotics and sometimes long-term hospitalization.

Hyperbaric oxygen treatment (HBOT) has been demonstrated to improve wound healing in chronic diabetic foot ulcers in several double-blinded randomized controlled trials[3,9] and

meta-analyses have shown that HBOT reduces the risk of major amputations.[10,11]

HBOT has been shown to enhance leukocyte function, stimulate angiogenesis, improve fibroblast function and promote granulation; all central processes in wound healing.[12–15] HBOT-mediated angiogenesis seems partly to be explained by increased vascular endothelial growth factor (VEGF)[16] which is among the most specific growth factors for neovascularization.[17] Insulin-like growth factor I (IGF-I) has also been shown to increase with HBOT and promotes wound healing in patients with diabetic foot ulcer.[18]

Diabetes-induced endothelial dysfunction plays a central role in diabetes related vascular complications.[19] Endothelial dysfunction may be evaluated by peripheral arterial tonometry (PAT), which in several clinical studies have demonstrated impaired endothelial function in persons with diabetes.[20–24]

It is plausible that the beneficial effect of HBOT on angiogenesis and neovascularization might be reflected in improved endothelial function. However, to date, this has never been investigated in persons with diabetic foot ulcers. The aim of this study was to evaluate endothelial function by peripheral arterial tonometry in persons with diabetic foot ulcers and to determine whether HBOT would have an impact on peripheral vascular function. We hypothesized that endothelial function is impaired in persons with diabetic foot ulcers compared to both healthy controls and to persons without diabetes also undergoing HBOT for various other indications such as bony- or soft tissue radiation injuries and non-diabetic ischemic wounds. We also hypothesized that courses of HBOT would improve endothelial function measured by peripheral arterial tonometry. Furthermore, we tested for correlations between endothelial function and IGF-I.

Methods

The study was designed as a prospective longitudinal single-centre study.

ETHICS

The study was approved by the Regional Ethical Committee of Copenhagen Region (H-3-2013-208) and the Data-Protection agencies in Denmark (30-1181). The study was registered at: https://clinicaltrials.gov/ (ID: NCT02221466). The study abided by the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from each patient.

SUBJECTS

Twenty-two subjects with type 1 and type 2 diabetes admitted to The Hyperbaric Oxygen Treatment Unit at Copenhagen University Hospital for chronic diabetic foot ulcers were prospectively included in this study. Subjects without diabetes (n = 17) who received hyperbaric oxygen treatment in our ward were recruited as controls. Historical data from 23 healthy individuals earlier published in a stroke study were included as normal values for endothelial function.[25] Study treatment was given as an adjunct to regular diabetic wound care treatment and as part of the clinical routine for persons with diabetic foot ulcers.

Blood samples were collected and assessments of peripheral endothelial function were performed before the first (baseline) and 30th HBOT sessions. Additionally, all patients were invited for a 90-day follow-up examination.

HYPERBARIC OXYGEN THERAPY

All subjects received HBOT in a multiplace hyperbaric chamber (Drass Galeazzi S.p.A., Type HPO4000/HPE50.2.A, 1998). Oxygen (100%) was administered by hood (Amron International, Aspen, Canada). All sessions were performed in ambulatory settings. The subjects received HBOT five days per week for six weeks (30 sessions). All subjects were treated with Table RH14 (treatment pressure: 245 kPa (~14 metres' seawater equivalent), compression / decompression rate: 3 $m \cdot min^{-1}$, treatment duration: 90 min, no air breaks).

ASSESSMENT OF PERIPHERAL ENDOTHELIAL FUNCTION

Peripheral endothelial function was assessed by peripheral arterial tonometry (EndoPAT 2000, Itamar Medical Ltd, Caesarea, Israel). The apparatus consists of a two finger-mounted plethysmograph probe capable of sensing volume changes in the vessels in relation to arterial pulsation. The examination includes three phases: a 5-minute equilibration period; a 5-minute period where a blood pressure cuff on one arm is inflated to supra-systolic pressure to occlude blood flow; and once released, a 5-minute period of reactive hyperaemia.

The system collects data digitally and performs operator-independent analysis of the endothelial function including a post-occlusion/pre-occlusion ratio called the reactive hyperaemia index (RHI). An alternative method when calculating the vascular response, but with improved association with cardiovascular risk factors (called the Framingham reactive hyperaemia index (fRHI)) was included in the analysis. Moreover, the system provides two other outcomes called augmentation index (AI) and AI standardized to a heart rate of 75 bpm (AI@75bpm) that measures arterial stiffness derived from the morphology of the arterial pulse waveform. For ease of comparison between individuals the result is related to the heart rate with adjusting to standard heart rate of 75 bpm. We have earlier reviewed the method including reproducibility, advantages and limitations of the apparatus.[26]

LABORATORY BLOOD ASSAYS

Blood samples were collected immediately before assessment with the peripheral arterial tonometer and stored at -80°C until analysis. IGF-I was measured by a chemiluminescence immunoassay on the IDS-iSYS automated platform (Immuno Diagnostic Systems, East Boldon, UK) at the Hormone Laboratory of the Department of Growth and Reproduction, Rigshospitalet, Copenhagen University, Denmark. Interassay coefficient of variation was < 8% and the limit of detection was 10 $\mu g \cdot L^{-1}$.

ENDPOINTS AND STATISTICAL ANALYSIS

The primary endpoint was the RHI. Secondary endpoints were the fRHI, AI, AI@75bpm, and IGF-I assays.

Statistical analyses were performed using R 3.0.2 software for Mac (The R Foundation for Statistical Computing Platform) with additional RStudio 0.98.507 (RStudio, Inc.) software attached. Tests for normality were conducted using the Shapiro-Wilks test. Groups were compared using the Welch two sample *t*-test or Wilcoxon rank-sum test at baseline. A paired *t*-test or the Wilcoxon signed-rank test was used to analyze the effect of HBOT courses. Correlations between variables were analyzed with Kendall's rank correlation tau. Categorical variables were analysed using Fisher's exact test.

Values are given as mean (SD), unless otherwise indicated. *P*-values are reported as exact values, unless less than 0.001. Statistical significance was assumed at $P < 0.05$.

Results

Data from 22 subjects with diabetic foot ulcers, 17 subjects without diabetes and 23 healthy individuals entered the analysis. Subject characteristics and notable differences among study groups are presented in Table 1. The group with diabetes consisted of more men, were older and had in general higher systolic blood pressure, higher body mass index (BMI) and lower cholesterol levels compared to the group without diabetes. Twelve (54%) subjects with diabetes and five (29%) subjects without diabetes were examined at day 90.

Peripheral arterial tonometry was feasible in almost all subjects. There was a significant drop-out during the entire courses of treatments due variously to: amputation and thereby end of therapy (n = 3, all with diabetes); drop-out due to other sickness (n = 3, two without diabetes, one with diabetes); inability to cooperate (n = 1, without diabetes); and lack of response to 90-day follow-up invitation (n = 22, 12 without diabetes, 10 with diabetes). Results obtained from the peripheral arterial tonometry and IGF-I analyses are presented in Table 2. Data from the historical healthy controls[25] are presented in the first column of Table 2.

RHI AND fRHI

The Shapiro-Wilk test showed non-normally distributed values in the diabetic and non-diabetic groups (P = 0.02 and 0.01, respectively). No significant baseline differences were found between the latter groups (P = 0.20) or between the diabetic group and healthy controls (P = 0.09) (see data in Table 2). Moreover, no baseline differences were found between the patient group without diabetes and healthy controls (P = 0.29). The same results were found for the fRHI variables where no baseline differences were found between the group with diabetes and without diabetes (P = 0.59) or the healthy controls (P = 0.36). Likewise, no differences were found between the group without diabetes and healthy controls (P = 0.29). In the group of subjects with diabetes the Wilcoxon signed-rank test showed no statistically significant differences from baseline to 30th treatment or to 90-day follow-up (P = 0.17 and P = 0.95, respectively). Neither differences were found in fRHI in the same group (P = 0.14 and 0.76, respectively). Likewise, in the group without diabetes no differences were found between baseline and 30th treatment or 90-day follow up (P = 0.30 and 0.31, respectively). The same non-significant differences were found concerning fRHI in this group (P = 0.95 and P = 0.19). No correlations were found between RHI and the other measured variables in either groups.

AI AND AI@75BPM

Shapiro-Wilk test showed normally distributed values in both the group with diabetes and the group without diabetes (P = 0.75 and P = 0.54, respectively). No baseline differences in AI were found between the group with diabetes and the group without (P = 0.62) or the healthy controls (P = 0.1) (see data in Table 2). A significant baseline difference was found when comparing the group without diabetes to the healthy controls (P = 0.03). Evaluating AI@75bpm, significant differences were found between persons with diabetes and healthy controls (P = 0.01) and between the persons without diabetes and healthy controls (P < 0.001). No baseline differences in AI@75bpm were found between the group with diabetes and without (P = 0.44).

In the subjects with diabetes a paired *t*-test showed no statistical differences in AI from baseline to either 30th treatment or 90-day follow up (P = 0.28 and P = 0.14, respectively). In the group without diabetes significant differences were found between baseline and the 30th treatment and 90-day follow up (P = 0.02 and P = 0.02, respectively). Regarding AI@75bpm no differences were found in the group with diabetes from baseline to either 30th treatment or 90-day follow-up (P = 0.31 and P = 0.28). No significant differences were found in the group without diabetes from baseline to either 30th treatment or follow-up (P = 0.13 and P = 0.06)

Table 1
Baseline characteristics of the study groups. Tabulated values are mean (SD), unless otherwise is indicated in the table

Parameter	Diabetic (*n* = 22)	Non-diabetic (*n* = 17)	*P*-value	Parameter	Diabetic (*n* = 22)	Non-diabetic (*n* = 17)	*P*-value
Male gender, *n* (%)	19 (86%)	3 (18%)	< 0.001	Current smoking, *n* (%)	2 (9%)	3 (18%)	0.64
Age, years	68 (8)	56 (14)	0.002	Diabetes duration, years	21 (14)		
Height, cm	177 (9)	167 (7)	< 0.001	HbA1c, $mmol \cdot mol^{-1}$	54 (11)	34 (4)	< 0.001
Weight, kg	82 (16)	59 (12)	< 0.001	Glucose, $mmol \cdot L^{-1}$	8.7 (1.6)	5.9 (0.6)	< 0.001
Body mass index, $kg \cdot m^2$	26 (4)	21 (4)	< 0.001	Total cholesterol $mmol \cdot L^{-1}$	3.6 (0.9)	5.3 (0.9)	< 0.001
Systolic BP, mmHg	144 (23)	129 (27)	0.038	HDL cholesterol $mmol \cdot L^{-1}$	1.1 (0.4)	1.6 (0.6)	0.004
Diastolic BP, mmHg	81 (11)	84 (14)	0.60	HDL/total cholesterol ratio	3.6 (1.5)	3.7 (1.2)	0.71
Heart rate, $beats \cdot min^{-1}$	77 (13)	78 (11)	0.84				

Table 2
Outcome measures obtained by peripheral arterial tonometry during courses of hyperbaric oxygen therapy. Values from historical healthy control persons published in a previous stroke study are presented in first column.[24] Tabulated values for RHI and fRHI are median (IQR). Values for AI, AI@75bpm and IGF-I are mean (SD)

Outcome measure	Group	Baseline Diabetic *n* = 22 Non-diabetic *n* = 17	After 30 HBOT Diabetic *n* = 16 Non-diabetic *n* = 15	90-day follow-up Diabetic *n* = 12 Non-diabetic *n* = 5
RHI	Diabetic Non-diabetic Healthy control	1.26 (1.0) 1.61 (0.82) 1.81 (0.52)	1.63 (0.96) 1.60 (0.42)	1.29 (0.67) 2.9 (0.51)
fRHI	Diabetic Non-diabetic Healthy control	0.14 (0.73) 0.26 (0.60) 0.34 (0.36)	0.48 (0.62) 0.29 (0.41)	0.07 (0.44) 0.94 (0.19)
AI	Diabetic Non-diabetic Healthy control	7.55 (22.2) 10.88 (19.2) -3.07 (20.6)	15.25 (18.0) 25.31 (24.7)	17.57 (22.0) 40.29 (28.8)
AI@75bpm	Diabetic Non-diabetic Healthy control	9.33 (22.2) 13.93 (19.2) -7.25 (21.2)	15.33 (18.0) 22.72 (24.7)	16.89 (22.0) 33.67 (28.8)
IGF-I	Diabetic Non-diabetic	118.6 (37.0) 89.4 (25.9)	110.8 (37.1) 90.1 (24.6)	106 (27.3) 94.8 (21.4)

At baseline a significant correlation was found between AI and systolic blood pressure (tau = 0.33 , $P = 0.04$) in the group with diabetes. A significant correlation between AI and heart rate was found in the group without diabetes (tau = -0.38, $P = 0.04$). No other correlations were found.

IGF-I

Shapiro-Wilk test showed normally distributed IGF-I values in both groups ($P = 0.65$ and $P = 0.62$). Significant baseline differences were found in IGF-I between the group with and without diabetes ($P = 0.01$) (see data in Table 2). A paired *t*-test showed no significant difference in the group with diabetes from baseline to the 30th treatment ($P = 0.24$). However, highly significant difference was observed from baseline to 90-day follow up ($P = 0.001$). No changes were found from baseline to the 30th treatment or 90-day follow-up in the group without diabetes ($P = 0.44$ and $P = 0.79$ respectively). No correlations were found between IGF-I and the other measured variables in either groups.

Discussion

We used the non-invasive peripheral arterial tonometry for measurements of endothelial function in patients undergoing sessions of HBOT.

In contrast to our hypothesis, we did not find any significant differences in endothelial function at baseline between the group with diabetes, the group without diabetes or the healthy controls. This surprising result might be a consequence of small sample sizes and high variabilities in RHI. Moreover, some regional anatomic disparities in PAD might exist. The lower extremities are more vulnerable to

the development of PAD[6] and a direct correlation to upper extremity RHI remains unproven. Even though several of the persons with diabetic foot ulcers in this cohort were likely suffering from severe PAD of their lower extremities, this was not mirrored by the measured RHI of the upper extremities (i.e., fingers) in this patient cohort as several patients had near normal RHI values at inclusion.

The baseline RHI values in the group with diabetes were on the threshold for classification as abnormal and this might complicate the evaluation of our second hypothesis – that courses of HBOT might improve RHI in persons with diabetes. The lack of significant baseline abnormality might help explain why no significant changes in RHI were observed. Although not registered in our trial files, the current cohort also consisted of some type 2 diabetes patients, whereas previous reports have described RHI index changes primarily in type 1 diabetes patients. Although PAD is a well-established complication for both groups, the predictive value of RHI index may vary between type 1 and type 2 patients.[27]

Peripheral arterial tonometry is well evaluated especially in relation to cardiovascular risk-factors and the prediction of adverse effects.[28,29] In patients with type 2 diabetes and microalbuminuria the method has been shown to be an independent predictor of coronary artherosclerosis.[30]

In a cohort of persons with diabetes (n = 123) the non-invasive test used here showed good reproducibility without significantly variations in RHI when assessed twice a day.[31] Furthermore, in 20 metabolic patients the technique has shown good test-retest reliability in a setup of five examinations separated by a minimum one-week period.[32]

It is well known that type 2 diabetes is associated with an increased risk of hypertension[33] and antihypertensive treatment in persons with diabetes significantly reduces cardiovascular risk.[34] We found elevated systolic blood pressure in the group with diabetes compared to the group without, however mean systolic blood pressure in the group with diabetes was almost 140 mmHg which is borderline normal and might be a result of rigorous antihypertensive treatment.

As alluded to above, the mean RHI values in the present cohort of persons with diabetes may be interpreted as representing borderline endothelial dysfunction; the tonometer manufacturer suggests that this state is defined by an index below 1.68.[35] In contrast to our study, others have shown significantly impaired endothelial function comparing to healthy individuals.[21,22] RHI values among persons with diabetes in those studies were not substantially different to values in the present study. However, due to lower RHI-values in the present cohort of healthy individuals and greater RHI variability among the persons with diabetes no significant differences were found in this study.

The diabetes and non-diabetes groups were different in other ways. The diabetes group consisted of more men, were older and had (on average) higher systolic blood pressure and increased BMI compared to the group without diabetes; all significant risk factors for impaired endothelial function. Therefore, it was unexpected that no difference in endothelial function was found between these groups at baseline.

Contrary to a study evaluating endothelial function by peripheral arterial tonometry in patients with diabetes undergoing coronary angiography[36] and in adolescents with uncontrolled type 1 diabetes,[37] we did not find any correlation between RHI and HbA1c in our cohort of persons with diabetic foot ulcers.

AI has shown to be associated with cardiac risk factors and coronary artery disease and may be a useful instrument to evaluate the overall risk for coronary artery disease.[38] A study evaluating microvascular endothelial function in persons with type 1 and type 2 diabetes showed significantly lower AI in persons with type 1 diabetes than healthy controls, while persons with type 2 diabetes were comparable to controls.[21] We did not observe any significant differences in AI between our cohort of subjects with diabetes (both type 1 + 2) and healthy controls. However, after standardizing AI to a heart rate of 75 bpm we did find differences between the persons with diabetes and the healthy controls. Perhaps surprisingly, the patient group without diabetes also varied significantly from healthy controls, which might draw attention to this group's overall morbidity; a group primary comprised of subjects with delayed radiation injury following cancer therapy including the use of chemotherapy. Unexpectedly, we observed a significant increase in AI among the subjects without diabetes over the course of HBOT, however after adjustment to AI@75bpm the difference became non-significant.

IGF-I, a pro-insulin like growth factor, is related to insulin resistance[39] and has shown to stimulate keratinocyte proliferation in the basal layer of epidermis.[40] A lack of IGF-I expression may be important in the delayed wound healing in diabetic foot ulcers. In a cohort of subjects with diabetes, IGF-I was shown to increase with sessions of hyperbaric oxygen therapy and to be a predictive factor of wound healing.[18] However, the present study demonstrated decreasing IGF-I levels over a course of HBOT which was statistically significant at the 90-day follow up.

To our knowledge, this is the first study to monitor endothelial function by peripheral arterial tonometry in subjects with diabetes undergoing a course of HBOT. Some certain limitations to this study consist. First, the combination of small sample sizes and high variability in RHI might have prevented finding any correlations and significant differences between groups. Second, the ulcers were not scored using acknowledged methods such as PEDIS or Wagner ulcer grading[41,42] which preclude assessment of the association between ulcer severity and endothelial function. Third, we

did not measure transcutaneous oxygen tension (TCOM), a quantitative assessment of oxygen availability and indirect measure of periwound microcirculatory bloodflow. The TCOM test is generally accepted as one of the most useful for prediction of failure to respond to HBOT. A comparison and evaluation of the linkage between peripheral endothelial function and periwound microcirculatory blood flow are needed. Finally, the subjects with diabetes treated with HBOT at our centre represents a group of patients with significant wound healing delay, often previous and multiple minor- and/or major amputations as well as a high degree of comorbidities with a median Charlson comorbidity index value of 5.[43]

Future studies should aim to evaluate the relationship between endothelial function in subjects with diabetic foot ulcer assessed by peripheral arterial tonometry and specific growth factors for neovascularization, such as VEGF. Future studies could aim to investigate the correlation between TCOM and peripheral arterial tonometry. Furthermore, studies investigating the association between endothelial dysfunction and the prediction of wound healing in subjects with diabetic foot ulcer are wanted.

Conclusions

This study demonstrated borderline impaired endothelial function measured by peripheral arterial tonometry among subjects with diabetic foot ulcers, however, no significant differences were found when compared to either a patient group without diabetes undergoing HBOT or healthy controls. There was no significant improvement in endothelial function during courses of HBOT in either patient cohort. However, given the baseline lack of substantial endothelial dysfunction (and therefore reduced scope for improvement) and the possibility that tonometry in the upper limb may not accurately reflect endothelial function in the lower limb, we cannot confidently exclude a positive effect of HBOT on lower limb endothelial dysfunction in subjects with diabetes.

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Conflict of interest and funding

No conflicts of interest are declared. This work was supported by a grant from the 'Direktør Jacob Madsen and Hustru Olga Madsens Fond'.

Submitted: 24 June 2019
Accepted after revision: 22 November 2019

Haemoconcentration, not decreased blood temperature, increases blood viscosity during cold water immersion

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Key words
Blood viscosity; Cold; Hemoconcentration; Hypothermia; Ice; Physiology; Stress

Abstract
(Rostomily KA, Jones DM, Pautz CM, Ito DW, Buono MJ. Haemoconcentration, not decreased blood temperature, increases blood viscosity during cold water immersion. Diving and Hyperbaric Medicine. 2020 March 31;50(1):24–27. doi: 10.28920/dhm50.1.24-27. PMID: 32187614.)

Introduction: Prolonged cold-water immersion (CWI) has the potential to cause significant hypothermia and haemoconcentration; both of which have previously been shown to independently increase blood viscosity *in vitro*. The purpose of this study was to determine the effect of CWI on blood viscosity and examine the relative contribution of decreased blood temperature and haemoconcentration.

Methods: Ten healthy volunteers were immersed to mid-sternum in 10°C water for 90 minutes. Gastrointestinal (GI) temperature, haematocrit (Hct), and blood viscosity were measured pre- and post-CWI.

Results: CWI caused mean (SD) GI temperature to decrease from 37.5 (0.3)°C to 36.2 (0.7)°C ($P < 0.05$). CWI also caused mean Hct to increase from 40.0 (3.5)% to 45.0 (2.9)% ($P < 0.05$). As a result of the haemoconcentration and decreased GI temperature during CWI the mean blood viscosity increased by 19% from 2.80 (0.28) mPa·s^{-1} to 3.33 (0.42) mPa·s^{-1} ($P < 0.05$). However, when the pre-CWI blood sample was measured at the post-CWI GI temperature (36.2°C) there was no significant difference in the blood viscosity when compared to the pre-CWI (37.5°C) blood sample (2.82 (0.20) mPa·s^{-1} and 2.80 (0.28) mPa·s^{-1} respectively). Furthermore, the changes in Hct and blood viscosity during CWI were significantly correlated with an r = 0.84.

Conclusion: The results of the current study show that prolonged, severe CWI causes a significant 19% increase in blood viscosity. In addition, the results strongly suggest that almost all of the increased blood viscosity seen following CWI is the result of haemoconcentration, not decreased blood temperature.

Introduction

Prolonged cold-water immersion (CWI) is frequently encountered by recreational athletes (e.g., open ocean swimmers and divers, triathletes), military personnel during training (e.g., Special Forces) and is routinely used during recovery from exercise to attenuate inflammation and delayed-onset muscle soreness. It is well known that CWI results in haemoconcentration[1] and hypothermia;[2] both of which have been shown to independently increase blood viscosity, *in vitro*.[3–5] This is clinically important as increased blood viscosity has been shown to be associated with an increased risk for thrombo-emboli formation and thus the incidence of ischemic stroke, myocardial infarction, and pulmonary embolism.[6–8] It has been shown that cold air exposure can increase blood viscosity,[7] however, the effect of CWI on blood viscosity in humans is unknown. Likewise, the relative importance of decreased blood temperature and haemoconcentration on increasing blood viscosity during CWI has not been explored. Thus, the purpose of the current study was to address these two questions. It was hypothesized that CWI would significantly increase blood viscosity and that both haemoconcentration and decreased blood temperature would contribute to the increase.

Methods

PARTICIPANTS AND ETHICAL APPROVAL

Six male and four female participants (n = 10) with mean (SD) age 26 (6) years, height 1.70 (0.12) m, weight 73.4 (13.3) kg, and body mass index (BMI) 24.9 (3.0) kg·m^2, volunteered for the investigation. All volunteers initially provided a urine sample on the day of testing and hydration status was assessed using urine specific gravity (USG) via a clinical refractometer (Model 5711-2021; Schuco®, Williston Park, NY). USG values below 1.018 indicated euhydration and were required prior to the CWI. Pregnant females were excluded from the study. The study was conducted in accordance with the ethical standards of the San Diego State University Institutional Review Board for the protection of human subjects and with the 1964 Helsinki declaration and its later amendments. Informed written consent was obtained from all individual participants.

Figure 1
Mean (SD) GI temperature (°C) during 90 min of CWI. * indicates significantly different than the pre-CWI value

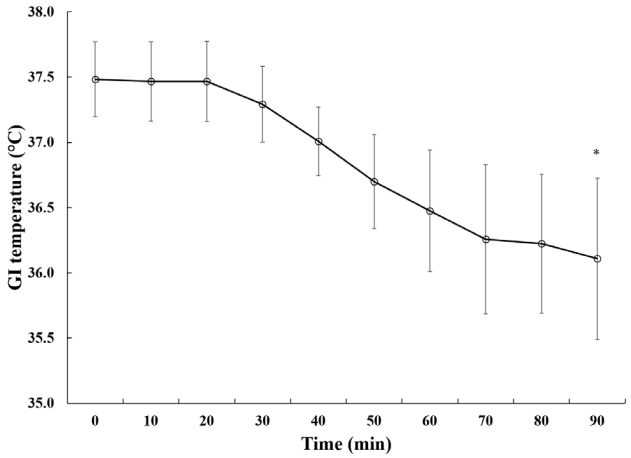
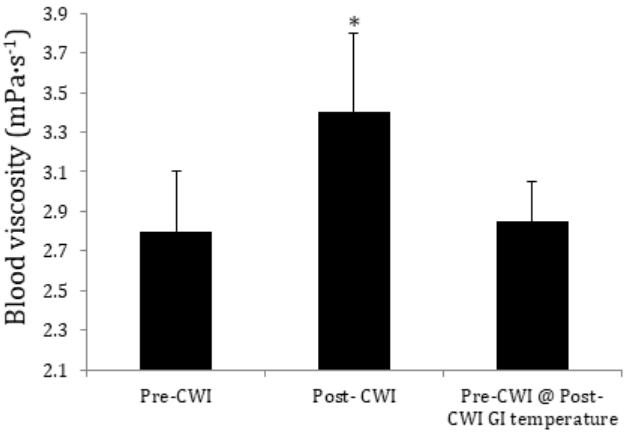


Figure 2
Blood viscosity values (mPa·s^{-1}) pre- and post-CWI. First bar represents the pre-CWI blood sample (40%, 37.5°C). Second bar represents the post-CWI blood sample (45%, 36.2°C). Third bar represents the pre-CWI blood sample measured at the post-CWI GI temperature (40%, 36.2°C). * indicates significantly different than the pre-CWI value



EXPERIMENTAL DESIGN

Each trial included 90 minutes of CWI (10°C) up to the participant's mid-sternum with the subject in the seated position in a large plastic tank with the right forearm and hand resting outside the tank not immersed. The subjects were clothed in shorts or a one-piece swimsuit. The water was not stirred during the CWI. Data were collected every five minutes throughout the trial and included gastro-intestinal (GI) temperature via an ingested pill (HQ Inc., Palmetto FL, USA) taken 3–6 hours before immersion and heart rate (Model RS400; Polar®, Lake Success NY, USA). The ambient laboratory temperature was 23°C.

Blood samples were collected, with the subject in the seated position, pre- and immediately post-CWI in order to determine haematocrit and blood viscosity. Approximately 300 µl of capillary blood was collected into a microtainer EDTA tube via a free-flowing fingertip stick from the non-immersed right hand. The tube was capped and inverted several times to prevent clotting. Blood was transferred to capillary tubes, centrifuged at 10,000 rpm, and measured in duplicate in order to determine pre- and post-CWI haematocrit (Hct). The mean was the recorded value.

BLOOD VISCOSITY ANALYSIS

To measure blood viscosity, 100 µl of the blood sample was transferred into a glass capillary tube along with a steel ball. The capillary tube was then capped and secured in the rotating arm of a Lovis 2000M microviscometer (Anton Paar, Graz, Austria) that was temperature controlled. Blood viscosity was determined three times: 1) pre-CWI blood sample at the pre-CWI GI temperature (37.5°C); 2) post-CWI blood sample at the post CWI GI temperature (36.2°C); and 3) pre-CWI blood sample at the post-CWI GI temperature (36.2°C). In order to determine the third blood viscosity measure, 100 µl of the pre-CWI blood sample was refrigerated until the CWI trial was completed when the post-CWI GI temperature was known. Blood viscosity was measured in mPa·s^{-1} and the shear rate was approximately 200 s^{-1}, which is well above the threshold (i.e., 100 s^{-1}) where whole blood is considered a Newtonian fluid.[9]

STATISTICAL ANALYSIS

Dependent *t*-tests were used to measure the changes between pre- and post-CWI GI temperature, Hct, and blood viscosity. The Bonferoni correction was performed to account for the multiple *t*-tests. Significance was set at the $P < 0.05$ level. Kolmogorov-Smirnov tests were used to ensure that the data did not differ significantly from normality. Pearson correlations were calculated between the change in blood viscosity and the change in Hct as well as with the change in GI temperature in order to determine if there was a relationship between the two variables. Statistical analysis was performed using VassarStats (http://vassarstats.net/).

Results

As shown in Figure 1, CWI caused mean GI temperature to decrease from 37.5 (SD 0.3)°C to 36.2 (0.7)°C ($P < 0.05$). CWI also caused mean haematocrit to increase from 40.0 (3.5)% to 45.0 (2.9)% ($P < 0.05$). As a result of the haemoconcentration and decreased blood temperature during CWI the mean blood viscosity increased by 19% from 2.80 (0.28) mPa·s^{-1} to 3.33 (0.42) mPa·s^{-1} ($P < 0.05$) (Figure 2). To determine the relative importance of decreased blood temperature and haemoconcentration on increasing blood viscosity during CWI, the pre-CWI blood sample was measured at both the pre-CWI and post-CWI GI temperature. This allowed for the determination of the effect of decreased blood temperature on blood viscosity, independent of

haemoconcentration. As seen in Figure 2, when the pre-CWI blood sample was measured at the post-CWI GI temperature (36.2°C) there was no significant difference in the blood viscosity when compared to the pre-CWI (37.5°C) blood sample (2.82 (0.20) mPa·s^{-1} and 2.80 (0.28) mPa·s^{-1} respectively). The change in GI temperature and change in blood viscosity during CWI were not significantly correlated with an r = 0.31. However, change in Hct and change in blood viscosity during CWI were significantly correlated with an r = 0.84.

Discussion

The most important new finding of the current study was the significant 19% increase in blood viscosity following 90 min of CWI. To our knowledge this is the first time such a finding has been reported in the literature. Although not previously reported, such a finding was not totally unexpected. Several previous studies[10–12] have reported a significant decrease in plasma volume following CWI. For example, Gordon et al.[10] using the Evans Blue direct-tracer dilution technique, reported that plasma volume decreased by 16% during one hour of CWI. As it has been shown that CWI does not alter red blood cell mass,[12] decreases in plasma volume must increase Hct. This is consistent with several past studies[1,13] that have reported increases in Hct of 4.3 to 4.6 units following CWI and are in agreement with the current finding of a 5.0 unit increase following CWI. It has been hypothesized that CWI decreases plasma volume via several mechanisms including increased blood pressure from cold induced vasoconstriction and hormonal induced diuresis.[10–12]

Numerous studies have examined the relationship between blood viscosity and Hct both *in vitro*[4,14] and *in vivo*.[15] In the normal physiologic Hct range (30–50%) the relationship is fairly linear, and the two variables are strongly correlated (r = 0.84). Within this range, blood viscosity increases about 4% for each one-unit increase in Hct.[16] Therefore, the five unit increase in Hct in our subjects following CWI would be predicted to increase blood viscosity by 20%, which is in close agreement to the 19% increase reported in Figure 2.

The relative contribution of decreased blood temperature and haemoconcentration was determined by measuring the pre-CWI blood sample at both the pre-and post CWI GI temperature. This allowed for the determination of the effect of decreased blood temperature on blood viscosity, independent of haemoconcentration. As seen in Figure 2, when the pre-CWI blood sample was measured at the post-CWI GI temperature (36.2°C) there was no significant difference in the blood viscosity when compared to the pre-CWI (37.5°C) blood sample (2.82 (0.20) and 2.80 (0.28) mPa·s^{-1} respectively). Furthermore, the change in blood viscosity was not significantly correlated (r = 0.31) with the change in GI temperature during CWI. However, the change in Hct and the change in blood viscosity during CWI were significantly correlated (r = 0.84). Such results strongly suggest that the increase in blood viscosity during CWI is primarily the result of haemoconcentration and not decreased blood temperature. Such a conclusion is supported by the findings of Azzopardi et al.[17] who used surface cooling to purposely cause hypothermia in newborn infants with birth asphyxia. The cooling resulted in an increase in blood viscosity that was not related to body temperature but was significantly correlated to Hct.

The major limitations of the current study are twofold. First, it was assumed that blood temperature during CWI would be equal to GI temperature. Thus, the effect of temperature on blood viscosity in the central circulation during CWI may be underestimated in the current study. Second, we did not re-warm the post-CWI blood samples back to 37.5°C as a positive control.

Conclusion

In conclusion, the results of the current study show that prolonged, severe CWI causes a significant 19% increase in blood viscosity. In addition, the results strongly suggest that almost all the increased blood viscosity seen following CWI is the result of haemoconcentration, not decreased blood temperature.

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Conflicts of interest and funding: nil

Submitted: 15 April 2019
Accepted after revision: 01 November 2019

Professional diver routine health surveillance and certification: an internet-based satisfaction survey of New Zealand divers

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Key words
Diving industry; Fitness to dive; Health surveillance; Medicals – diving; Occupational diving; Occupational health; Survey

Abstract
(Sames C, Gorman DF, Mitchell SJ, Zhou L. Professional diver routine health surveillance and certification: an internet-based satisfaction survey of New Zealand divers. Diving and Hyperbaric Medicine. 2020 March 31;50(1):28–33. doi: 10.28920/dhm50.1.28-33. PMID: 32187615.)

Introduction: Professional divers, like many other specialised occupational groups, are subject to regulatory constraints that include mandatory initial medical certification and routine recertification. The New Zealand system of diver certification and health surveillance has undergone modifications in recent years, but its acceptance among end-users has never been formally assessed. Because of the wide variety of tasks, circumstances and personalities encountered in the diving industry, unanimous satisfaction is an unrealistic expectation, but establishing the current mood of divers in this regard and canvassing opinions on possible improvements is an important step towards optimising the certification process.

Method: A multi-choice satisfaction questionnaire was added, as a quality assurance measure, to the on-line health questionnaire completed annually by all New Zealand professional divers. A complete 12-month dataset was analysed to determine levels of satisfaction, areas of dissatisfaction and suggestions for improvement. Comparison of the opinions of various diver groups was achieved by stratification into employment-type sub-groups and those working locally, overseas or both.

Results: The responses of 914 divers who completed the survey established an 85% satisfaction rate with the existing diver certification system. Dissatisfaction was independent of diving locality. Compliance cost was the most common area of dissatisfaction, particularly among recreational diving instructors.

Conclusions: Most New Zealand professional divers consider the current certification system satisfactory. Effective communication between the regulating authority and divers was identified as an important area for further development.

Introduction

Professional divers comprise a specialised group of workers whose occupation is regulated in most countries by government authorities responsible for workplace health and safety standards. For involved divers, this means mandatory compliance with a set of regulations regarding fitness for work and level of experience and/or training in order to achieve or maintain certification. Each jurisdiction is responsible for developing its own set of regulations and has authority to demand compliance from any diver entering its zone for work purposes. Many New Zealand divers seek employment in other countries to supplement their local work and, because there is no globally accepted set of regulations for this industry, there may be additional cost and duplication of certification processes such as medical examinations.

The New Zealand professional diver certification system has adopted changes over the past 15 years aimed at providing an efficient, cost-effective and evidence-based process.

First, and probably most notably, there was relaxation of the typical requirement for a full medical examination from annually to five-yearly. To clarify, the default position regarding the requirement for a full medical examination remains annual but, without a compelling health reason, divers are deemed exempt and only require the examination five-yearly. Although this evolution was based on sound evidence, it placed the New Zealand system at odds with most other countries that have retained the traditional annual requirement with no exemptions,[1] though there is some global variability in the frequency of mandated medical examinations, dependent on type of diving and/or diver age.

Second, in addition to the full five-yearly medical examination, the New Zealand system requires completion of an on-line health questionnaire in each of the four intervening years. The questionnaire has been modified from the original Standard (AS/NZS 2299) version which was shown to be unfit for purpose, and it may be modified again pending the outcome of an ongoing study investigating the utility and wording of the component questions.[1,2] Responses to the questionnaire are centrally audited by diving medicine experts.

Finally, routine chest and long bone X-rays were abandoned for lack of evidence of utility. Routine spirometry and audiometry may soon follow, based, in part, on the evidence of recent studies on the New Zealand professional diving population.[3–5]

However, the above changes were instigated in the context of a centrally audited system, so they may not be generalizable to systems that do not operate as such. Central audit involves review by a diving medicine expert of each diver's health questionnaire and medical examination before certification is issued. The advantage of central auditing is that it provides objective, consistent and expert advice on fitness to dive, but some divers have criticised administrative delay and cost, and also, such a system simply may not be feasible in some countries.

In New Zealand, in addition to the medical requirements, full certification for professional diving work requires successful application for a Certificate of Competence (CoC) on a five-yearly basis. This is assessed and awarded by the regulating authority, WorkSafe New Zealand, a department of the Ministry of Business Innovation and Employment, previously known as Occupational Safety and Health, a branch of the then Department of Labour. Application for the CoC involves submitting proof of training qualifications appropriate for a particular branch of diving and also evidence of a specified minimum level of recent diving activity.

The aim of this study was to canvass opinions of the end-users, New Zealand professional divers, regarding satisfaction with each of the above components of the current evaluation and certification system, to determine the prevailing sentiment and inform future modifications.

Method

The determination of the Health and Disability Ethics Committee was that review was not required for this survey. A brief multi-choice survey was added to the on-line, routine health questionnaire completed annually by all registered divers. The original intention of this addition was to conduct a regular 'user satisfaction' audit as a quality control measure. Apart from type and area of diving, no personal, demographic or health data were collected, and only anonymised, collated data were provided for this study.

The eight-question survey was designed to determine the level of satisfaction and areas of dissatisfaction with the current system of certification and health surveillance of New Zealand professional divers. Questions one and two sought information about principal category of diving and whether work was conducted exclusively in New Zealand, overseas or a mixture of both. The purpose of these questions was to determine any differences in level of satisfaction between the various groups of divers. Question three enquired about general satisfaction with the current certification system. A positive response meant that no further questions needed to be answered. However, it was anticipated that some divers who were satisfied with the system 'in general', but still felt a minor level of dissatisfaction, might respond to the remaining questions. Question four asked which aspect(s) of the certification system was/were thought to be unsatisfactory, with various options given. Questions five to seven expanded on aspects of the three main components of the system, namely; the five-yearly full medical examination, the annual on-line health questionnaire and the CoC requirement. Finally, question eight invited divers to proffer suggestions for any improvements they considered necessary or desirable. Divers completed the survey on a diver-dedicated secure website, and a de-identified dataset comprising all of the data covering a 12-month period was collated.

STATISTICS

Statistical analysis was performed using SAS® v9.4 software (SAS Institute Inc., Cary NC, USA). Frequency and proportion (%) were used for describing the categorical variables of the questionnaire, such as type of diving, main place of work and satisfaction. 95% confidence intervals (95% CI) were estimated for the key categorical variables.

Results

The responses from 914 divers over the 12-month period to April 2019 represented a survey of all New Zealand professional divers completing their registration over that period.

A summary of the non-free-text response rates to questions one to four, and question eight, from the 914 divers, is presented in Table 1. A small group of divers (20) responded to questions five, six and seven, despite having expressed that they were satisfied with the system. The response rates for questions five to seven, from only the 137 divers who claimed to be dissatisfied with the current system, are presented in Table 2. The primary finding was that 85% (95% CI: 83–87%) of divers were satisfied with the current certification system. There was no significant difference in

Table 1
Responses of 914 New Zealand professional divers to Questions 1–4 and Question 8 of an on-line, eight-question survey to assess satisfaction with the current health surveillance and certification system

Questions	Category / response	*n*	%
Q1. Type of diving?	Construction	210	23.0
	Recreation/Instructor	243	26.6
	Scientific/Photography	177	19.4
	Aquaculture	45	4.9
	Military/Police/Customs	103	11.3
	Other (Commercial)	43	4.7
	Multiple types	93	10.2
Q2. Main place of work?	In NZ	708	77.5
	Overseas	54	5.9
	Both	152	16.6
Q3. Satisfied with current diver certification system in NZ?	Yes	777	85.0
	No	137	15.0
Q4. Main problem if not satisfied?	The 5-yearly full medical	14	1.5
	The annual on-line questionnaire	39	4.3
	The 5-yearly CoC requirement	34	3.7
	More than one of the above	40	4.4
	Other (see Q8)	23	2.5
Q8. Comments	Comment made	228	24.9
	No comment made	686	75.1

Table 2
Responses to questions 5, 6 and 7 of the eight-question on-line survey from 137 New Zealand professional divers who reported dissatisfaction with the health surveillance and certification processes; these responses include: * 38; ** 40, and *** 39 divers from the 40 who answered Question 4 "*More than one of the above*" (see Table 1) positively

Issue of concern	Problem area		
	5-yearly full medical	Annual questionnaire	5-yearly CoC
	n = 47*	*n* = 76**	*n* = 67***
Cost	25	35	8
Delay in processing	3	–	8
Not accepted by other jurisdictions	9	9	–
Can't see need for it	–	–	16
Easy to forget	–	6	–
More than one of above	7	17	22
Other	3	9	13

the level of dissatisfaction among those who worked in New Zealand or overseas or a mixture of both (15.4%, 14.8%, 13.2% respectively). However, compared with other types of divers, a larger proportion of recreational diving instructors and divers who engaged in multiple diving roles comprised the 'dissatisfied' group (18.1%, 20.4% respectively).

Free-text comments were contributed by 24.9% of the total group. Of those who identified themselves as being dissatisfied (137) with the overall registration process, 75.2% contributed comments, compared with only 16.1% of satisfied (777) divers. Nevertheless, most comments (54.8%) were from satisfied divers. Of the comments from dissatisfied divers, 34% concerned the cost of the overall process, particularly the annual questionnaire. Some of those who counted themselves among the 'satisfied' also complained about the cost, although a predictably smaller proportion (12%). A reduction in overall cost was requested by 21.9% of all those who commented.

Positive comments such as: 'it works well', 'it's a good system', 'no changes are needed', etc. comprised 25%, while the remaining 75%, representing 18.7% of all respondents, provided comments that were constructively critical, and generally helpful suggestions for improvement (such as: 'send reminder texts or emails'). Recreational dive instructors accounted for 26.6% of respondents but they represented 69%, 43.9% and 61.5% of answers to questions 5, 6 and 7 relating to the costs of the full medical, the questionnaire and the CoC respectively.

Discussion

This 12-month survey of the currently registered New Zealand professional divers showed that a large majority was satisfied with the current certification system. The following discussion is in the context of a 15% dissatisfaction rate and focuses on the main themes raised by the survey, but comments may be applicable to the entire group and, possibly, to other occupational groups required to

undertake routine re-certification, including medical fitness examination.

The most reported area of dissatisfaction was 'cost'. Some comments on cost were simply that the overall compliance costs were too high for a group of workers described by some as 'relatively poorly-paid'. Others questioned the 'value for money' aspect, particularly in regard to the annual on-line health questionnaire, which some suggested should cost nothing to complete. Such comments indicate a discrepancy between the perception of some divers, and the reality of both the logistic challenges and the role of the central auditing process in the questionnaire system. The perception appears to be that, because the annual health questionnaire is completed on-line, analysis of diver responses and issuing of certificates must be an automated function. Automation would only be possible if the process were entirely prescriptive. In reality, each completed annual questionnaire, together with the additional documentation of a full dive medical on a five-yearly basis, is examined by a diving medicine expert and compared with previous responses or results before a determination of medical fitness is made.

If the perceived automation were possible and implemented, it would obviate the need for any involvement of an expert whose principal role is discretionary in determining fitness, based on knowledge of the diver's medical record and of the tasks involved in the diving industry. Cost savings could result, but the process would not be robust. For example, purely prescriptive systems are at risk of reduced veracity because of manipulation (such as withholding of important health information) in order to achieve the desired outcome (certification). As well as putting divers at risk, such systems are likely to increase the exposure of other principal risk acceptors such as the employer or insurance company (or the Accident Compensation Corporation (ACC) in New Zealand). Because of the discretionary nature of the current system, divers are not unfairly denied certification if they admit to a health condition that is not incompatible with diving safely, possibly in a modified version of their particular diving role. In such cases, an accommodation can usually be reached with all involved risk acceptors at a face-to-face meeting, where, if limitations are deemed necessary, a modified job description can be negotiated. This approach, involving facilitation of informed choice by all interested parties, is consistent with the principles of occupational health surveillance.[6,7] No additional cost is incurred by the diver for the conduct of such meetings.

Internationally comparative costs for diver certification are not easy to ascertain, as they are not published, and are likely to vary within any country. However, we believe current costs to New Zealand divers are reasonable, and likely to be lower than in many, if not most, jurisdictions, particularly in those countries where a full dive medical is required annually.

Some divers suggested that the central auditing component of the process should be abandoned in favour of devolving certification authority to 'designated diving doctors' who are usually general practitioners (GPs) with additional training in diving medicine. The perceived advantage for the diver is a reduction in both cost and delay to certification. This system prevails globally (apart from in New Zealand), and is consequently accepted as the 'norm', especially by those divers who live in New Zealand but work overseas. It is a popular system, not least because the diver can be issued with a fitness certificate 'on the spot'. However, weaknesses in such a 'devolved' system have been exposed by studies on certification processes for pilots and professional divers.[8–11] The former demonstrated potentially dangerous deterioration in the quality of unaudited pilot fitness certifications partly because of practice drift as a result of loss of physician objectivity (or possibly corrupt or 'inappropriate advocacy behaviour'). The latter two studies showed that even GPs with additional training in diving medicine were poor at discriminating between fit and unfit divers based on diver applicant scenarios.[10,11] Therefore, it appears that a central auditing system, where feasible, is likely to be safer for divers and associated risk acceptors. It also has the advantage of providing a repository of divers' medical records from which useful material can be retrieved to inform policy on diver certification and health surveillance.

The two issues, certification and health surveillance, are essentially separate matters. The former is confirmation that the diver's health/medical status has been determined to be compatible with safe conduct of his/her stated diving duties for a period of one year, provided there are no intervening changes in health, until the next routine review. The latter involves a broader assessment of the diver's health, including chronic conditions that may have little or no bearing on current 'fitness-to-dive', but may, if not addressed, have long-term adverse consequences (conditions such as hypertension, hyperlipidaemia, obesity, smoking, etc.). Collection of health data, including diving exposure and specific diving-related hazards, is integral to the surveillance process.

As previously stated, we believe that a health surveillance programme should not need to be conducted 'completely separately from annual fitness assessments' for fear of divers concealing health issues that could lead to denial of certification, as proposed by the Diving Medical Advisory Committee (DMAC) in their 2008 statement.[12,13] Designated diving doctors (and their international equivalents) are ideally placed to assist in collection of such data at the time of routine diving medical assessments, complemented by data contributed on-line by divers, and stored on an internet-based database. If privacy and other legal issues could be resolved, and there was sufficient international co-operation, as other authors have suggested, such a database (as currently exists in New Zealand) could be useful globally for this often quite mobile group of workers.[14]

Physical capacity and diving competence remain issues that are appropriately determined in the workplace setting, or a suitable surrogate, rather than by medical practitioners.

Finally, various aspects of the CoC process were common reasons for complaint, particularly from the largest group, the recreational dive instructors. A frequent theme of their comments questioned the role of a government department (WorkSafe New Zealand) in monitoring divers' levels of competence and training when this responsibility usually is, or should be, assumed by the employer. One of the key principles of the Health and Safety at Work Act 2015, and its equivalent in other jurisdictions, is employers' primary duty of care, to ensure the health and safety of employees.[15] Consequently, it is not surprising to find that employers may wish to verify the validity of claims of training and experience. However, WorkSafe has a governance role in ensuring compliance with health and safety regulations. Thus, even though some divers may see verification of their training and experience as an annoying duplication of what has already been audited by the employer, it should be a source of comfort.

To address the obvious discrepancies between diver perceptions and reality and facilitate communication between the regulator and working divers in New Zealand, the Diving Industry Advisory Group (DIAG) was recently established. This group comprises diving medical experts as well as representatives of the regulating authority and of each of the various branches of occupational diving (e.g., scientific, construction, commercial, aquaculture, recreational instructors, etc.). Issues raised by the current survey, such as the perceived inappropriateness of requirements of the CoC for some branches of diving, are being investigated for possible modification. Because of the wide variety of tasks and expertise prevalent in this industry, a global standard of competence is inappropriate, but individual diver subgroup standards mean those divers working in multiple disciplines of professional diving will need to prove competence in each area.

The effect of any procedural changes to the certification system in response to the current survey will be measured by repeating a similar satisfaction survey after a suitable interval.

Conclusions

The current certification system is considered satisfactory by most New Zealand divers. Aspects of the process highlighted by the current survey, for modification, include refinement of the CoC requirements to be more task-appropriate, and improvement in communication with divers about costs and justification for various aspects of the process.

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Acknowledgements

We wish to thank Mr Murray Polson (CEO, Erudite Software Ltd) for developing and maintaining the electronic database for New Zealand professional divers, and for retrieving the data used in this study.

Conflicts of interest and funding

The lead author (CS) and two of the co-authors of this study (DFG, SJM) are on the directorate of Diving and Hyperbaric Medical Services Ltd, which is contracted by WorkSafe New Zealand to provide advice on, and oversight of, the medical component of professional diver certification and health surveillance. SJM's role is that of consultant on matters of policy and procedure rather than conducting diver medical examinations. In addition, SJM is the Editor of *Diving and Hyperbaric Medicine* Journal, but was not involved in the review and decision-making process to publish this study, which was managed entirely by the European Editor, Dr Lesley Blogg.

Submitted: 24 June 2019
Accepted after revision: 09 October 2019

Comparison of tissue oxygenation achieved breathing oxygen using different delivery devices and flow rates

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Key words
Decompression sickness; Decompression illness; First aid; Masks; Medical kits; Oxygen; Transcutaneous oximetry; Scuba diving

Abstract
(Blake DF, Crowe M, Lindsay D, Brouff A, Mitchell SJ, Leggat PA, Pollock NW. Comparison of tissue oxygenation achieved breathing oxygen using different delivery devices and flow rates. Diving and Hyperbaric Medicine. 2020 March 31;50(1):34–42. doi: 10.28920/dhm50.1.34-42. PMID: 32187616.)

Introduction: Divers with suspected decompression illness require high concentration oxygen (O_2). There are many different O_2 delivery devices, with few data comparing their performance. This study evaluated O_2 delivery, using tissue O_2 partial pressure ($P_{tc}O_2$), in healthy divers breathing O_2 via three different delivery devices.

Methods: Twelve divers had $P_{tc}O_2$ measured at six limb sites. Participants breathed O_2 from: a demand valve using an intraoral mask with a nose clip (NC); a medical O_2 rebreathing system (MORS) with an oronasal mask and with an intraoral mask; and a non-rebreather mask (NRB) at 15 or 10 L·min^{-1} O_2 flow. In-line inspired O_2 (F_IO_2) and nasopharyngeal F_IO_2 were measured. Participants provided subjective ratings of device comfort, ease of breathing, and overall ease of use.

Results: $P_{tc}O_2$ values and nasopharyngeal F_IO_2 were similar with the demand valve with intraoral mask, MORS with both masks and the NRB at 15 L·min^{-1}. $P_{tc}O_2$ and nasopharyngeal F_IO_2 values were significantly lower with the NRB at 10 L·min^{-1}. The NRB was rated as the most comfortable to wear, easiest to breathe with, and overall the easiest to use.

Conclusion: Of the commonly available devices promoted for O_2 delivery to injured divers, similar $P_{tc}O_2$ and nasopharyngeal F_IO_2 values were obtained with the three devices tested: MORS with an oronasal or intraoral mask, demand valve with an intraoral mask and NRB at a flow rate of 15 L·min^{-1}. $P_{tc}O_2$ and nasopharyngeal F_IO_2 values were significantly lower when the flow rate using the NRB was decreased to 10 L·min^{-1}.

Introduction

High concentration oxygen (O_2) therapy is an important early first aid treatment for injured divers. Complete relief or improvement of the symptoms of decompression illness (DCI) has been seen in divers receiving pre-hospital normobaric O_2 therapy.[1] The current pre-hospital care recommendation for divers with symptoms and signs of DCI is for O_2 delivery at the highest possible inspired fraction (close to 100%).[2] However, there are many factors that need to be considered when choosing the most appropriate O_2 delivery system for a dive operation.[3,4]

A variety of portable O_2 delivery units have been designed to provide divers with pre-hospital O_2.[3,5] These units incorporate one of two basic operating configurations: (1) a constant O_2 flow configuration used with a non-rebreather mask (NRB), medical O_2 rebreathing system (MORS) or other constant flow delivery devices; and (2) a patient triggered demand valve configuration. The recommended initial O_2 flow rate with the NRB mask for divers with suspected DCI has long been 15 L·min^{-1}.[6] Divers Alert Network (DAN) America reduced its recommended O_2 flow rate to between 10 to 15 L·min^{-1}, to extend the duration of often limited O_2 supplies in the field, while still providing high levels of oxygenation.[7] However, the effect of lower

flow rates on tissue oxygenation is unknown. A previous study comparing tissue oxygenation found that the NRB at 15 L·min^{-1} performed better than the demand valve with an oronasal mask.[8] However, a subsequent study showed that the demand valve provided the best tissue oxygenation when used with an intraoral mask and nose clip (NC);[9] almost certainly because the intraoral mask eliminated leaks that were occurring with the oronasal mask.

The present study used transcutaneous oximetry measurement (TCOM) to determine tissue oxygenation at multiple standardised sites in participants breathing O_2 from a demand valve using an intraoral mask with a NC; a MORS with an oronasal mask and with an intraoral mask; and a NRB at 15 and 10 L·min^{-1}. The primary null hypothesis was that there would be no clinically significant difference in the partial pressure of transcutaneous tissue O_2 ($P_{tc}O_2$) achieved after 10 min of breathing O_2 with any of the different O_2 delivery devices or flow rates.

Methods

Ethics approval was granted from The Townsville Health Service District Human Research Ethics Committee (HREC16/QTHS/196). Healthy, non-smoking, adult certified scuba divers of both sexes were recruited for the study. Facial hair or anatomical abnormality that may impair mask seal, any medical condition or medication that may affect tissue oxygenation, or an allergy to topical anaesthetic were exclusion criteria. Written informed consent was provided by all participants prior to their participation.

Participants refrained from consuming food or caffeine or performing heavy exercise for six hours prior to participating in the study. Demographic data, anthropometric measurements, and resting baseline measurements were collected. Tidal volume (VT) was measured at rest using the EasyOne Spirometer (ndd Medical Technologies, Andover MA, USA) according to the manufacturer's instructions (average over 3–5 breaths). The participants rested in a supine position with their head on one pillow for the duration of the study. The test-room temperature was maintained between 22.4 and 22.9°C; to limit any vasoconstrictive effects of being cold, participants were covered with a blanket.

An 8 French paediatric feeding tube (ConvaTec Ltd., Deeside, UK) was inserted into the right nares after application of topical lignocaine (5%) and phenylephrine (0.5%) (Co-Phenylcaine™ forte spray, ENT Technologies Pty Ltd., Hawthorne East, Australia). Tube position was visually verified with the tip just proximal to the soft palate.[9] The tube was then attached to the E-sCO-OO module of a bedside monitor (GE Carescape Monitor B650, GE Healthcare Finland OY, Helsinki, Finland) allowing for both inspired O_2 (F_IO_2, paramagnetic) and end-tidal carbon dioxide (E_TCO_2, infrared) measurements via a water trap (D-fend Pro+ Water Trap™, GE Healthcare Finland OY, Helsinki, Finland). Room air gas calibration was completed before each breathing system was used. The gas sampling rate was 120 ml·min^{-1}.

TCOM is a non-invasive technique that uses heated electrodes on the skin to measure the $P_{tc}O_2$[10] and was thought to provide a relevant measurement of tissue O_2 delivery in a study drawing an inference about tissue inert gas elimination. $P_{tc}O_2$ was measured using the TCM400 transcutaneous (tc) PO_2 Monitoring System (Radiometer, Copenhagen, Denmark) with tc Sensor E5250. Zero current calibration of the $P_{tc}O_2$ electrode was performed using CAL2 gas (10% CO_2 with N_2 as balance) prior to commencement of the study, and calibration with atmospheric air occurred prior to each monitoring period. A 'humidity correction factor' was entered into the machine prior to each monitoring period. All assessments were performed by the same technician. The TCM400 displayed $P_{tc}O_2$ values in units of mmHg (average of previous monitoring intervals).

Six sensors were used: three on the left arm and three on the left leg.[9] Arm sensors were placed on the upper arm, lateral aspect of the lower arm, and the palm of the hand. Leg sensors were placed on the lateral leg, lateral ankle, and dorsum of the foot. Participants rested quietly while the sensors were placed. They were requested to minimise talking during the study as a method of control but were not allowed to sleep. Initial normobaric room air readings from all sensors were recorded after a minimum 20-min equilibration period that allowed all sensors to stabilize.

The participants were then asked to breathe O_2 for 10 min from the following devices in randomized order determined using the random number generator in Microsoft® Excel (Microsoft Corporation, Redmond Washington, USA):

- Demand valve (L324-020, Life Support Products, Allied Healthcare Products, St. Louis, MO, USA) with intraoral mask and NC held in place by the participant (NuMask® Inc., Woodlands Hills, CA, USA) (Figure 1);
- MORS (Wenoll-System, EMS GmbH, Möhrendorf, Germany) (Figure 2) with intraoral mask and NC held in place by the participant;
- MORS with air-cushion oronasal mask and a 4-strap mask holder (Figure 3);
- NRB mask at 15 L·min^{-1} with elastic strap (Sturdy Industrial Co. Ltd, New Taipei City, Taiwan);
- NRB mask at 10 L·min^{-1} with elastic strap.

The demand inhalator valve provided in portable DAN O_2 units was used for this study. A flexible high-pressure O_2 hose was used to connect the demand valve to the hospital wall medical grade O_2 outlet (415 kPa delivery pressure). The demand valve was attached to a spacer with a side port allowing pressure and gas measurements (Figure 1). A pressure line was attached to the side port and then to the bedside monitor via a BD DTXPlus™ pressure transducer (Argon Medical Devices Inc., Frisco, TX, USA). The monitor was configured to settings used for central venous

Figure 1
Configuration of demand valve, spacer with side port (allowing pressure and gas measurements), and intraoral mask

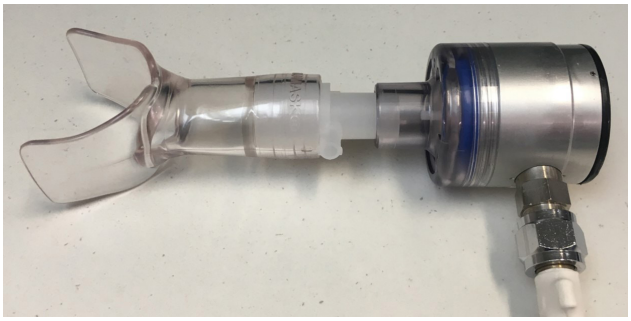


Figure 2
Medical oxygen rebreathing system (Wenoll-System)

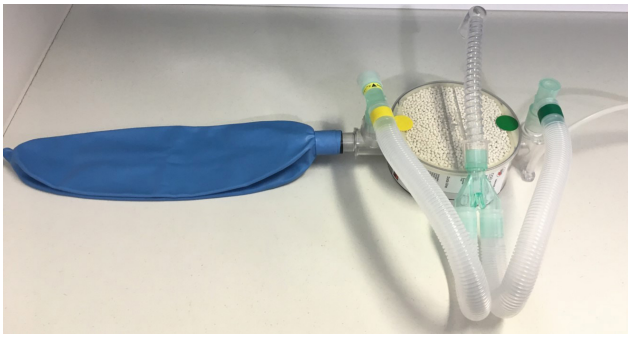


Figure 3
Oronasal mask provided with the Wenoll-System and four-strap holder; oronasal mask secured in position on participant's face

pressure monitoring to give a high sensitivity in the lower range and zeroed before each participant. A single, new demand valve was used in the study and verification of inspiratory opening pressure required to trigger the valve and the expiratory resistance pressure was made prior to the commencement of each new participant. The demand valve configuration with intraoral mask and NC, from previous optimization trials, was used in this current research.[9] Mask and circuit dead space was determined by measuring the amount of water required to fill each device. Mask fill levels were estimated by filling the masks with water and then placing a mannequin's face into the mask.

The NRB was examined to ensure there were three one-way valves in place and then primed with O_2 to inflate the reservoir bag. The NRB was positioned and adjusted to obtain the best seal possible. Participants were asked to breathe normally, and the reservoir bag was monitored for persistent inflation during the breathing periods.

When using the demand valve participants were asked to breathe deeply enough to trigger the valve as outlined in DAN educational material.[6,7]

The Wenoll MORS system was primed with 40 $L \cdot min^{-1}$ of O_2 until the rebreathing bag was completely filled, and the oronasal mask was attached with a four-strap holder. The O_2 flow was 1.5 $L \cdot min^{-1}$ during the 10-min breathing periods as outlined in the Wenoll-System operation manual.

In-line F_IO_2, nasopharyngeal F_IO_2, $P_{tc}O_2$, and other respiratory measures were recorded at the end of the 10-min breathing period, once $P_{tc}O_2$ had stabilized. In-line and nasopharyngeal F_IO_2 measurements were performed to determine if there is a difference between O_2 delivered by a device (in-line) and the O_2 reaching the upper airway (nasopharyngeal). Nasopharyngeal gas sampling was intermittent (every two min) throughout the O_2 breathing periods to prevent clogging of the catheter and to capture peak values. After each 10-min O_2 breathing period, participants breathed room air for 10 min, allowing all $P_{tc}O_2$ levels to return to baseline before the next device was trialled.[11] At the end of the data collection period all participants used a five-point Likert scale to rate each configuration on mask comfort, ease of breathing, and overall ease of use of each device. A final open-ended question asked about any adverse effects while breathing O_2.

ANALYSIS

All collected data were de-identified and entered into an Excel worksheet, and subsequently exported into Statistical Package for the Social Sciences version 25.0.0 (SPSS, IBM® Corporation, Armonk, New York, USA) for analysis.

Based on previous research when participants breathed 100% O_2, mean $P_{tc}O_2$ values between 199 mmHg (26 kPa) (dorsum of foot) and 454 mmHg (60 kPa) (upper arm) were expected.[12] Each sensor site generally has slightly different values, however, a decrease of 75 mmHg (10 kPa) across any of these sites was assumed to be clinically significant. Based on the values above and allowing for substantial correlation ($r = 0.90$) between the repeated measures, a sample size of 12 participants would provide a power of 90% (with $\alpha = 0.05$) to detect clinically significant reductions in tissue oxygenation. In this context, 'clinically significant' was intended to mean a reduction in tissue O_2 delivery sufficient to indicate a potentially important corresponding reduction in the diffusion gradient for inert gas from tissues into blood. There are no published data which demonstrate how such gradients can be inferred from changes in tissue oxygenation, so a threshold tissue oxygenation change of 75 mmHg (10 kPa) (smallest increase in $P_{tc}O_2$ at one sensor site breathing 100% O_2 with a hood[12]) was agreed by consensus of the physiologists and clinicians involved in the study.

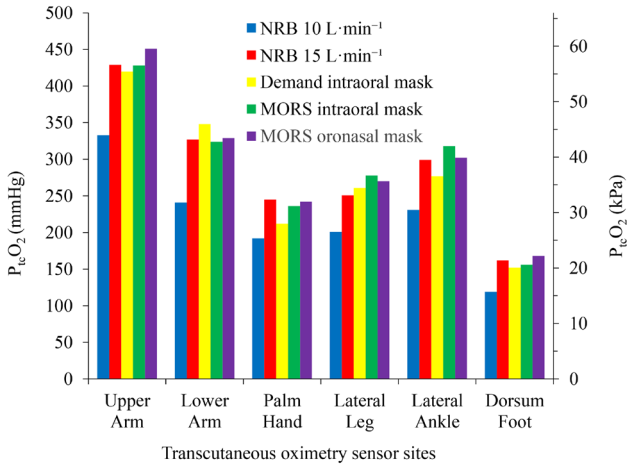
Table 1

Demographic and baseline measurements for the 12 participants breathing air. Optimal waist-to-hip ratios are < 0.82 for males and < 0.71 for females. BP = blood pressure. IQR = inter-quartile range

Characteristic	Median (IQR)	Range
Age (years)	30 (28, 32)	21–34
Body mass index ($kg \cdot m^2$)	19 (15, 22)	15–24
Waist-to-hip ratio Males Females	 0.86 (0.82, 0.87) 0.74 (0.72, 0.80)	 0.82–0.87 0.67–0.93
Heart rate ($beats \cdot min^{-1}$)	67 (59, 70)	50–94
Systolic BP (mmHg)	112 (111, 119)	100–128
Diastolic BP (mmHg)	66 (57, 73)	54–82
Respiratory rate ($breaths \cdot min^{-1}$)	14 (12, 16)	12–16
Tidal volume (ml)	745 (533, 913)	470–1130
Oxygen saturation (%)	97 (96, 98)	96–99
End-tidal CO_2 (mmHg)	39 (37, 45)	36–46

Figure 4

Median transcutaneous oxygen partial pressures (mmHg) after breathing oxygen for 10 min with different devices and flow rates; NRB = non-rebreather mask; MORS = medical oxygen rebreathing system



The Shapiro-Wilk test was used to evaluate normality of data distribution. None of the data were normally distributed. Differences between median $P_{tc}O_2$, E_TCO_2, in-line, and peak and across device over time nasopharyngeal F_IO_2 readings using the various devices and flow rates were analysed using the Friedman test with *post hoc* paired analyses completed using the Wilcoxon signed-rank test with Bonferroni correction. For the *post hoc* tests, a corrected *P*-value of 0.005 (0.05/10) was considered significant for the $P_{tc}O_2$ values and a corrected *P*-value of 0.01 (0.05/4) for the 2-min nasopharyngeal F_IO_2 values.

The primary outcome measure was a comparison of the median $P_{tc}O_2$ measurements recorded across the six sensor sites after breathing O_2 for 10 min using each device and flow rate. Secondary outcome measures included in-line and nasopharyngeal F_IO_2, E_TCO_2, and participant-rated mask comfort, ease of breathing and overall use of each device.

Results

Twelve healthy volunteers, nine females and three males, met all inclusion criteria and completed the study protocol. Their demographic and baseline measures breathing room air are shown in Table 1.

Figure 4 displays the median $P_{tc}O_2$ readings across all sensor sites and breathing devices and flow rates. Baseline $P_{tc}O_2$ values, median and IQR for each sensor site after breathing O_2 for 10 min are presented in Table 2. $P_{tc}O_2$ values were statistically different across each breathing device and flow rate for each sensor site (Table 2). *Post hoc* analysis showed there were no significant differences in $P_{tc}O_2$ values between the NRB 15 $L \cdot min^{-1}$, demand valve and MORS with intraoral or oronasal mask. Some differences in median $P_{tc}O_2$ readings between devices at the same sites met the 75-mmHg (10 kPa) threshold for clinical significance, but only in comparisons between the NRB 10 $L \cdot min^{-1}$ with other devices. The median $P_{tc}O_2$ readings achieved using the NRB 10 $L \cdot min^{-1}$ were more than 75 mmHg (10 kPa) less than all other devices (including the NRB 15 $L \cdot min^{-1}$) at the upper and lower arm sites, and at the lateral leg and ankle sites in comparison to the MORS with intraoral mask. No comparisons of the median $P_{tc}O_2$ between other devices met the threshold for clinical significance.

Peak nasopharyngeal F_IO_2 was highest breathing O_2 at 15 $L \cdot min^{-1}$ with the NRB and lowest when breathing O_2 at 10 $L \cdot min^{-1}$ with the NRB (Table 3). One participant's nasopharyngeal F_IO_2 value at 10 min while breathing using the demand valve was unattainable due to catheter clogging. There was a significant effect of time on nasopharyngeal F_IO_2 for the MORS (Figure 5). It was shown that for the MORS with intraoral mask, nasopharyngeal F_IO_2 was

Table 2

Transcutaneous oxygen partial pressures (median and inter-quartile range shown in mmHg) while breathing oxygen using the different devices and flow rates; * statistically significantly greater than NRB 10 L·min^{-1} based on Wilcoxon signed-rank test with Bonferroni correction; # *P*-values based on the Friedman test; NRB = non-rebreather mask; MORS = medical oxygen rebreathing system

Site	Baseline (room air)	10 L·min^{-1} NRB	15 L·min^{-1} NRB	Demand with intraoral mask	MORS with intraoral mask	MORS with oronasal mask	*P*-value#
Upper arm	70 (61,77)	333 (285, 382)	429 (408, 464)*	420 (373, 465)	428 (385, 476)*	451 (375, 480)*	0.002
Lower arm	65 (58,70)	241 (217, 304)	327 (296, 405)*	348 (264, 370)	324 (286, 405)*	329 (313, 370)*	0.004
Palm hand	66 (63,74)	192 (151, 266)	245 (202, 275)	212 (179, 239)	236 (190, 293)*	242 (163, 289)	0.008
Lateral leg	57 (49,64)	201 (172, 233)	251 (217, 335)*	261 (208, 353)	278 (224, 350)*	270 (219, 330)*	0.004
Lateral ankle	62 (48, 67)	231 (152, 260)	299 (228, 336)*	277 (235, 342)	318 (221, 361)	302 (246, 319)*	0.002
Dorsum foot	54 (50, 65)	119 (88, 149)	162 (133, 226)*	152 (118, 220)	156 (93, 205)	168 (125, 198)*	0.008

Table 3

Inspired oxygen and respiratory measures while breathing oxygen using different devices and flow rates (median and inter-quartile range) and estimated mask and circuit dead space; NRB = non-rebreather mask; MORS = medical oxygen rebreathing system; n/a = not applicable; E_TCO_2 = end-tidal carbon dioxide; F_IO_2 = fraction of inspired oxygen; **P*-values based on the Friedman test

Parameter	10 L·min^{-1} NRB	15 L·min^{-1} NRB	Demand with intraoral mask	MORS with intraoral mask	MORS with oronasal mask	**P*-value
In-line F_IO_2 (%)	n/a	n/a	95 (92, 95)	93 (89, 95)	91 (88, 93)	0.045
Peak nasopharyngeal F_IO_2 (%)	89 (75, 93)	97 (94, 98)	92 (88, 94)	91 (88, 95)	90 (88, 92)	0.013
E_TCO_2 (mmHg)	39 (35, 43)	38 (34, 43)	38 (33, 41)	38 (32, 44)	39 (36, 43)	0.743
Respiratory rate (breaths·min^{-1})	12 (10, 15)	12 (10, 16)	10 (8, 12)	11 (8, 12)	12 (8, 14)	0.055
Mask + circuit dead space (ml)	95	95	14	14 + 350	136 + 350	n/a

significantly higher at time points 3, 4 and 5 (6, 8 and 10 min) compared to time 1 ($P < 0.01$). Nasopharyngeal F_IO_2 at all time points (4, 6, 8 and 10 min) was significantly higher than time point 1 breathing with the MORS and oronasal mask ($P < 0.01$). Both sets of results reflect a roughly linear increase in F_IO_2 over O_2 administration time. There was no statistical difference between the nasopharyngeal F_IO_2 values at each time point for any of the other breathing devices. Figure 6 illustrates the rise in $P_{tc}O_2$ values over the 10-min O_2 breathing periods, mirroring the rise in F_IO_2 values for the MORS.

E_TCO_2 was similar for all devices and flow rates. In-line F_IO_2 did not exceed 97% with any of the devices and was lowest using the MORS with oronasal mask (80%; Table 3). Estimated mask assembly and circuit dead space is presented in Table 3. Actual individual NRB and oronasal mask volumes would vary slightly depending on each participant's facial features.

Participant ratings for mask comfort are presented in Table 4. Ease of breathing rating for each device is listed in Table 5. The NRB was rated as overall easiest to use (Table 6). On *post hoc* analysis no statistical difference was found between each device.

Discussion

High concentration O_2 is the primary first aid treatment for divers suspected of having DCI.[2,3,13] O_2 has been shown in retrospective reviews to improve symptoms and decrease the subsequent number of hyperbaric treatments required.[1] Of the tested commercially available O_2 delivery systems designed for diver first aid, our study has shown that all systems can provide similar levels of tissue oxygenation and nasopharyngeal F_IO_2. However, when breathing with the NRB, an O_2 flow rate of 15 L·min^{-1} is required to reach these levels.

Peak nasopharyngeal F_IO_2 was highest with the NRB with a flow rate of 15 L·min^{-1} (Table 3) though 10-min $P_{tc}O_2$ values were similar for each device. This probably reflects the variability in breathing patterns of each participant and flow direction of the O_2. Nose breathing during use of the NRB

Figure 5

Median (IQR) nasopharyngeal inspired oxygen percentage recorded every two min for each delivery device and flow rate; NRB = non-rebreather mask; MORS = medical oxygen rebreathing system

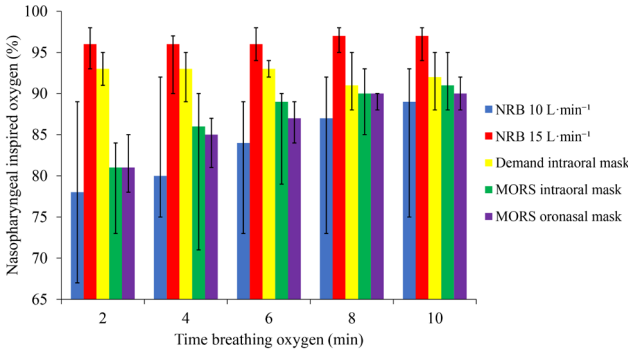
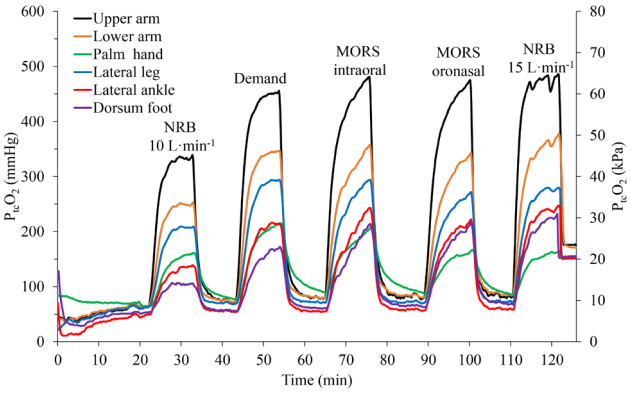


Figure 6

Transcutaneous oxygen partial pressures (mmHg) for one participant while breathing O_2 using different devices and flow rates over a complete iteration of the study. First 20-min equilibration period, followed by alternating 10-min O_2 and air breathing periods on different devices in randomized order. NRB = non-rebreather mask; MORS = medical oxygen rebreathing system



may explain the favourable nasopharyngeal F_IO_2 results. When breathing with the MORS on the oronasal mask, some participants stated that they kept their mouths slightly open to ensure good fit of the mask, potentially bypassing the nasopharyngeal catheter through mouth breathing. Using the intraoral mask, the O_2 flow may have been directed slightly below the nasopharyngeal catheter through obligatory mouth breathing. This illustrates the importance of clearly describing the position of sampling ports in a research protocol and the potential variability in results if O_2 is measured at different sites. $P_{tc}O_2$ better reflects actual O_2 delivery to the body tissues whereas the nasopharyngeal F_IO_2 is subject to the above possible confounders.

Portable O_2 delivery units can provide a constant flow capability or operate as a pressure-triggered demand valve. The demand valve only delivers O_2 when the diver inhales and therefore allows for conservation of O_2, dependent on the respiratory minute volume of the user. The ease of use, familiarity for divers, potential to deliver high inspired O_2 concentrations,[14] as well as the potential for O_2 supply conservation, has led to the recommendation of the demand valve as the O_2 delivery method of choice in the prehospital treatment of DCI.[3] However, previous research unexpectedly showed that the demand valve with oronasal mask provided less tissue O_2 than a constant flow NRB.[8] In the present study, $P_{tc}O_2$ readings whilst breathing O_2 via the demand valve with an intraoral mask and NC were similar to those achieved with a NRB at 15 L·min^{-1}. The previous contradictory findings[8] were almost certainly explained by poor fit of the oronasal mask and subsequent entrainment of ambient air.[9]

The MORS provided similar oxygen levels regardless of the mask used. The oronasal mask provided with the system has an adjustable air-filled cushion to optimize mask fit and seal. The 4-point mask strap held the mask onto the face to aid with the seal. Fitting of the mask onto the participants' face prior to the study allowed for a good seal to limit if not eliminate any entrainment of ambient air. Oronasal masks supplied with a demand valve system do not have the mask strap system, and the diver or first aider must therefore apply pressure to the mask to ensure an adequate seal. The technical difficulty of this almost certainly leads to breaks in the mask seal and entrainment of ambient air, especially because the user must generate negative pressure inside the mask to trigger the demand valve. While both oronasal or intraoral masks provide good O_2 delivery with the MORS, an intraoral mask may provide the highest levels of oxygenation with a demand valve.[9]

The NRB functions as a variable performance device with better oxygenation at a higher flow rate.[15] Unfortunately, this means a greater consumption of O_2. Demand regulators using an intraoral mask and NC behave as fixed performance devices,[9] with O_2 consumption based on minute ventilation. The NRB and demand valve are both open systems with exhaled gas lost into the environment. A closed system is most beneficial for O_2 conservation as only low flow O_2 is required.[5,16] MORS for first aid O_2 delivery are not commonly used by recreational divers, largely due to increased complexity and operational requirements[3,17] and generally limited availability. However, it is possible that the growing popularity of closed-circuit rebreathers for diving will drive an increased interest in MORS systems for first aid use.

The Wenoll System MORS comes with an air-cushion mask (like a pocket face mask) held tightly in place with a 4-strap holder and a regulator mouthpiece. In this study an intraoral mask rather than the regulator mouthpiece was used with the MORS for better comparison with the demand system. Both masks provided good peak O_2 levels at 10 min, but the MORS took longer to reach peak inspired O_2 than the NRB and demand valve (Figure 5). This is consistent with previous research showing a seven-minute time frame to reach 98–100% inspired O_2.[16] It is possible that the MORS

Table 4
Mask comfort rating for each delivery device (*n* (%)). MORS = medical oxygen rebreathing system; **P*-value = 0.052, Friedman test

Comfort assessment	Non-rebreather mask	Demand: intraoral mask	MORS: intraoral mask	MORS: oronasal mask
1. Very uncomfortable	0	0	0	0
2. Uncomfortable	0	4 (33.3)	3 (25.0)	3 (25.0)
3. Neither	2 (16.7)	2 (16.7)	1 (8.3)	3 (25.0)
4. Comfortable	3 (25.0)	4 (33.3)	6 (50.0)	5 (41.7)
5. Very comfortable	7 (58.3)	2 (16.7)	2 (16.7)	1 (8.3)
Median score (IQR)*	5.0 (4.0–5.0)	3.5 (2.0–4.0)	4.0 (2.3–4.0)	3.5 (2.3–4.0)

Table 5
Ease of breathing rating for each delivery device (*n* (%)); MORS = medical oxygen rebreathing system; **P*-value = 0.061, Friedman test

Breathing assessment	Non-rebreather mask	Demand: intraoral mask	MORS: intraoral mask	MORS: oronasal mask
1. Very difficult	0	0	0	0
2. Difficult	0	3 (25.0)	2 (16.7)	1 (8.3)
3. Neither	0	2 (16.7)	1 (8.3)	4 (33.3)
4. Easy	3 (25.0)	1 (8.3)	5 (41.7)	3 (25.0)
5. Very easy	9 (75.0)	6 (50.0)	4 (33.3)	4 (33.3)
Median score (IQR)*	5.0 (4.3–5.0)	4.5 (2.3–5.0)	4.0 (3.3–5.0)	4.0 (3.0–5.0)

Table 6
Overall ease of use for each delivery device (*n* (%)); MORS = medical oxygen rebreathing system; * *P*-value = 0.009, Friedman test

Overall ease of use assessment	Non-rebreather mask	Demand: intraoral mask	MORS: intraoral mask	MORS: oronasal mask
1. Very difficult	0	0	0	0
2. Difficult	0	3 (25.0)	1 (8.3)	1 (8.3)
3. Neither	0	3 (25.0)	1 (8.3)	2 (16.7)
4. Easy	3 (25.0)	2 (16.7)	4 (33.3)	6 (50.0)
5. Very easy	9 (75.0)	4 (33.3)	6 (50.0)	3 (25.0)
Median score (IQR)*	5.0 (4.3–5.0)	3.5 (2.3–5.0)	4.5 (4.0–5.0)	4.0 (3.3–4.8)

may have delivered greater fractions of O_2 more quickly if a procedure to remove nitrogen (N_2) from the participants' lungs had been employed at the start of breathing on the MORS (typically, by exhaling to atmosphere completely, then inhaling O_2 from the system and exhaling it to the atmosphere for several breaths before breathing exclusively on the MORS). Examination of the $P_{tc}O_2$ values while breathing O_2 with the MORS showed a plateau at eight to 10 min and therefore the data reported here probably accurately reflect peak values.

Breathing high concentration O_2 eliminates N_2 from the inspired gas and enhances N_2 elimination from the body.[3] Open circuit systems release exhaled gas into the environment, allowing for the elimination of N_2. In MORS, the higher O_2 flow rate in the first hour not only improves oxygenation[16] but allows for excess gas in the breathing circuit to be automatically vented through the over-pressure valve, which serves to purge accumulated N_2 into the environment.[5] Other suggestions for purging excess N_2 from the MORS circuit when used in injured divers include: periodic increase in O_2 flow rates and periodic use of a purge button, if equipped.[5,16] Monitoring for colour change of the carbon dioxide (CO_2) absorber and spontaneous increase in tidal volume are ways to evaluate scrubber function.[5] Limiting the usage time of the absorber can prevent CO_2 intoxication.[5] Formal training in the use of a MORS for O_2 delivery is recommended.

The NRB was rated as the overall easiest to use (Table 6), even though divers are accustomed to breathing from a demand valve with a mouthpiece. Some participants commented on the change in their breathing patterns when using the demand valve, they used their 'diving breathing pattern' of slower deeper breaths. Although not statistically significant, there was a trend towards a slower respiratory rate when breathing with the demand valve ($P = 0.055$) (Table 3).

Three commonly available pre-hospital O_2 delivery systems were evaluated for O_2 delivery, comfort, ease of breathing, and overall use. There are many other factors that need to be considered when selecting the most appropriate O_2 delivery system for a dive operation.[3,15] Remoteness of diving operations, and therefore a protracted time to arrive at medical care, may increase the need for a system that is more comfortable for the diver but also a system that provides a longer duration of O_2 delivery and CO_2 elimination. Cost, availability and O_2 supplies in different countries may also play an important part in the decision-making process.

Knowledge of individual country guidelines and training requirements are necessary to make educated decisions about appropriate O_2 delivery system selection.

LIMITATIONS

There was a low number of male participants in this study due to a predominance of facial hair. Facial hair was an exclusion factor, as it was thought it could contribute to mask leak.[18] In real world use, facial hair in males may reduce the efficacy of O_2 delivery by a NRB in comparison to a device that does not rely on a facial seal, such as the demand valve or MORS used with an intraoral mask and NC. Previous research shows no significant difference in $P_{tc}O_2$ results by sex.[12]

Even though a higher $P_{tc}O_2$ value likely indicates a greater drive for tissue inert gas elimination, bubble resolution and oxygenation of hypoxic tissues,[3,19,20] this study did not address the clinical efficacy of these O_2 devices in treating DCI or achieving bubble resolution.[21] Similarly, the arbitrary nature of the consensus decision to use a 75 mmHg (10 kPa) $P_{tc}O_2$ threshold to power the study and to indicate a meaningful difference in O_2 delivery / outgassing gradient between devices is acknowledged. Therefore, although perhaps indicative, these data do not prove that one device will be associated with greater clinical efficacy than another.

The nasopharyngeal catheter provided valuable information on the oxygenation provided by each delivery system but may have compromised the seal of both the NRB and oronasal mask. The catheter was secured to the nares and laid against the face, passing under the edge of the masks. The oronasal mask has an air-filled cushion which can easily mould around irregular facial features. The NRB has a more rigid edge and may have been more affected by the presence of the catheter.

The oxygen breathing period was limited to 10 min based on previous research[8,11] where $P_{tc}O_2$ values had stabilized at that time point. The TCM400 machine has a built-in arrow indicator that depicts upward or downward trends to help clinicians to identify stable peak values (when the arrows disappear). However, in visualizing the nasopharyngeal F_IO_2 values it seems that the values were still rising for the MORS and NRB at 10 L·min^{-1}. Although there was no statistical difference in the values at eight and 10 min, extending the monitoring time beyond the 10 min O_2 breathing period could provide additional information.

Conclusion

The three tested O_2 delivery systems used to treat injured divers (MORS with an oronasal or intraoral mask, demand valve with an intraoral mask and NRB at a flow rate of 15 L·min^{-1}) delivered similar $P_{tc}O_2$ and nasopharyngeal F_IO_2 values. $P_{tc}O_2$ and nasopharyngeal F_IO_2 values were lower when the flow rate using the NRB was decreased from 15 to 10 L·min^{-1}. O_2 delivery and supply conservation are important factors to be considered when selecting an O_2 delivery system for a dive operation.

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Acknowledgements

The authors gratefully acknowledge the financial assistance received from the Emergency Medicine Foundation (EMF), Queensland and the in-kind support from Divers Alert Network Asia-Pacific. We also thank our participants, especially those who shaved their facial hair.

Conflicts of interest and funding

Professor Mitchell and Associate Professor Pollock are members of the editorial board of Diving and Hyperbaric Medicine but were not involved in the peer review or publication decision-making process for this article. This process was managed by the European Editor Dr Lesley Blogg.

Submitted: 14 May 2019
Accepted after revision: 07 November 2019

Manned validation of a US Navy Diving Manual, Revision 7, VVal-79 schedule for short bottom time, deep air decompression diving

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Key words
Military diving; Decompression sickness; Decompression illness; Decompression tables; Diving research; Echocardiography; Venous gas emboli

Abstract
(Andrew BT, Doolette DJ. Manned validation of a US Navy Diving Manual, Revision 7, VVal-79 schedule for short bottom time, deep air decompression diving. Diving and Hyperbaric Medicine. 2020 March 31;50(1):43–48. doi: 10.28920/dhm50.1.43-48. PMID: 32187617.)

Introduction: The US Navy air decompression table was promulgated in 2008, and a revised version, calculated with the VVal-79 Thalmann algorithm, was promulgated in 2016. The Swedish Armed Forces conducted a laboratory dive trial using the 2008 air decompression table and 32 dives to 40 metres' seawater for 20 minutes bottom time resulted in two cases of decompression sickness (DCS) and high venous gas emboli (VGE) grades. These results motivated an examination of current US Navy air decompression schedules.

Methods: An air decompression schedule to 132 feet seawater (fsw; 506 kPa) for 20 minutes bottom time with a 9-minute stop at 20 fsw was computed with the VVal-79 Thalmann algorithm. Dives were conducted in 29°C water in the ocean simulation facility at the Navy Experimental Diving Unit. Divers dressed in shorts and t-shirts performed approximately 90 watts cycle ergometer work on the bottom and rested during decompression. VGE were monitored with 2-D echocardiography at 20-minute intervals for two hours post-dive.

Results: Ninety-six man-dives were completed, resulting in no cases of DCS. The median (IQR) peak VGE grades were 3 (2–3) at rest and 3 (3–3) with limb flexion. VGE grades remained elevated two hours post-dive with median grades 1 (1–3) at rest and 3 (1–3) with movement.

Conclusions: Testing of a short, deep air decompression schedule computed with the VVal-79 Thalmann algorithm, tested under diving conditions similar to earlier US Navy dive trials, resulted in a low incidence of DCS.

Introduction

The US Navy air decompression tables have been widely used in military and commercial diving. The standard air tables (USN57) that had been in the US Navy Diving Manual since 1959 were replaced by the air decompression table that first appeared in the US Navy Diving Manual, Revision 6 (2008).[1] This table (USN-Rev6) integrates air decompression, in-water air/oxygen decompression, and surface decompression with oxygen into a single table, and introduces a 20 feet of seawater (fsw) last stop in place of the traditional 10 fsw last stop. USN-Rev6 was computed with the Thalmann algorithm and VVal-18M parameter set, which produced no-stop limits for dives deeper than 80 fsw that were longer than the USN57 no-stop limits. Testing of some of these longer no-stop limits resulted in cases of severe decompression sickness (DCS).[2] The longer USN-Rev6 no-stop limits were edited to the corresponding no-stop limits from USN57.[1,2] A slightly modified version of the air decompression table (USN-Rev7), computed with the Thalmann algorithm and VVal-79 parameter set, was promulgated in the US Navy Diving Manual, Revision 7 (2016). The reason for this latter change was that the VVal-79 Thalmann algorithm computes no-stop limits in accord with those in USN57, and therefore could be implemented in the navy dive computer (NDC).[3] In USN-

Footnote: The US Navy air decompression table measures depth in feet seawater (fsw) and this paper describes test dives conducted using fsw. Where fsw were the original unit, conversions to kPa use 1 fsw = 3.0643 kPa (Naval Sea Systems Command. US Navy Diving Manual, Revision 7, Change A. Washington (DC): Naval Sea Systems Command; 2018, Chapter 2, Underwater Physics, Table 2-10). This paper converts metres of seawater (msw) to fsw using the US Navy convention for calculation of decompression schedules that 1 fsw = 0.3048 msw, as a result 40 msw = 132 fsw (Gerth WA, Doolette DJ. VVal-79 Thalmann algorithm metric and imperial air decompression tables. Research Report NEDU TR 16-05. Panama City (FL): Navy Experimental Diving Unit; 2016). This US Navy conversion differs from the conventional definition that 10 msw = 100 kPa. For clarity, conversions of msw to kPa are not given.

Rev7, a few decompression schedules for bottom times just exceeding the no-stop limit have longer stop times than in USN-Rev6, but most decompression schedules are unchanged.[3]

In 2010, the Swedish Armed Forces adopted USN-Rev6, using a metric version based on the approximate conversion of 10 fsw to 3 metres' seawater (msw). Recently, the Swedish Armed Forces Diving and Naval Medicine Center (DNC) conducted a small series of laboratory man-dives using the 2008 air decompression table.[4,5] Twenty dives to 40 msw for 20-minute bottom times were conducted using the USN-Rev6 140 fsw (530 kPa) / 20-minute bottom time air decompression schedule, which prescribes a 7-minute decompression stop at 20 fsw (6 msw; 163 kPa). An additional 12 dives to 40 msw for 20-minute bottom times were conducted on a modified schedule with a 7-minute decompression stop at 6 msw and an additional 3-minute stop at 3 msw for a total stop time of 10 minutes. These 40 msw dives resulted in high grade venous gas emboli (VGE) and two resulted in mild DCS (shoulder pain and skin marbling) treated with recompression. One DCS followed each of the original and modified schedules.

This DNC trial was the first laboratory man-dive testing of air decompression schedules, other than the no-stop limits, from these tables. The air decompression table was promulgated on the basis that the air decompression times were longer than in the standard air tables being replaced, and on the basis of evaluation of the schedules with probabilistic models of DCS. The DNC result did not conclusively establish a problem with the air decompression tables but motivated a large-scale laboratory test of the USN-Rev7 schedules for short bottom time, deep air decompression dives. This study was first reported in Navy Experimental Diving Unit (NEDU) technical report 19-06.[6]

Methods

This study protocol was approved by the NEDU Institutional Review Board (Department of the Navy human research protection program approved protocol 18-17, DoN-HRPP Number NEDU.2018.0006) in accord with the Declaration of Helsinki.

DECOMPRESSION SCHEDULE SELECTION

In USN-Rev7, the 140 fsw for 20 minutes air decompression schedule prescribes a longer stop time (13 minutes) than the 7-minute stop time schedule in USN-Rev6 tested at DNC. However, because the DNC test of the 140 fsw schedule was conducted at 40 msw (132 fsw), the results remained relevant to current US Navy air decompression prescriptions. Table 1 shows relevant schedules and their estimated probability of DCS (P_{DCS}).[7] For instance, the 130 fsw (500 kPa) / 20-minute bottom time schedule in USN-Rev7 requires an 8-minute air decompression stop at 20 fsw, and a 132 fsw (506 kPa) / 20-minute bottom time dive that could be conducted using the NDC requires a 9-minute air decompression stop at 20 fsw. Both of these currently approved US Navy schedules are very similar to the dive profile tested at DNC, and the 132 fsw / 20-minute bottom time schedule was selected for testing.

EXPERIMENTAL DESIGN

The principal objective was testing of the VVal-79 schedule for 132 fsw / 20-minute bottom time with a 20 fsw last stop, under dive conditions typical of previous US Navy dive trials. The primary endpoint was DCS and the experimental unit was the man-dive not the diver-subject. The cumulative incidence of DCS in this study was predicted to be low (Table 1), and as is usual for validation of decompression schedules, the trial was designed to reject a decompression schedule with a high cumulative incidence of DCS, but otherwise accept the schedule. The specific hypothesis (H_0) was that the VVal-79 schedule for 132 fsw / 20 min bottom time with a 20 fsw last stop would result in P_{DCS} not higher than 5%, estimated from the observed cumulative incidence of DCS. The trial design had 84% power to detect 5% P_{DCS}.

The experiment was designed as an adaptive group sequential trial with a planned 96 man-dives. Had the cumulative incidence of DCS on the 20 fsw last decompression stop schedule reached pre-planned interim stopping criteria, the trial was planned to switch to testing of an equivalent schedule but with a traditional 10 fsw (132 kPa) last decompression stop. These stopping criteria were not met and the switch did not occur. VGE would have been used as an auxiliary endpoint to compare the two schedules if the trial had proceeded to test the alternative schedule. Details of the trial design and calculation of power are given in the technical report.[6] Although there was not a practicable difference in estimated P_{DCS} between the 10 fsw and 20 fsw last stop schedules (see Table 1), the change from a 10 fsw to 20 fsw last stop was a substantive change to US Navy air decompression procedures introduced with USN-Rev6 and USN-Rev7 that had not been subject to extensive testing.

DIVING AND INSTRUMENTATION

Sixty-one qualified military-trained divers gave written informed consent. Four divers did not participate in diving. Of the 57 participating divers, all but two were male. At the time of their first dive in this study, the 55 male divers who completed experimental dives had mean (SD) age of 36 (7) years, body weight of 91.6 (12.5) kg, height of 1.81 (0.06) m, and BMI of 28 (3). The two female divers were: age 37 and 30 years; body weight 74 and 55 kg, height 1.60 and 1.52 m; and BMI 29 and 23.

Subjects were required to avoid hyperbaric or hypobaric exposure for a minimum of 48 hours before and following any experimental dive. Subjects were restricted to one

Table 1
NMRI-98 estimated P_{DCS} of some relevant schedules. TST = total stop time

Profile	Schedule	20 fsw (min)	10 fsw (min)	TST (min)	P_{DCS}% (NMRI98)	P_{DCS} 95% pred. limits
132 fsw / 20	USN-Rev 6 140/20	7	–	7	1.91	1.41–2.53
132 fsw / 20	USN-Rev 6 + safety stop	7	3	10	1.81	1.32–2.43
140 fsw / 20	USN-Rev 6 140/20	7	–	7	2.25	1.66–2.95
140 fsw / 20	USN-Rev 7 (VVal-79)	13	–	13	2.15	1.58–2.86
132 fsw / 20	AIR III-79 NDC (VVal-79)	9	–	9	1.94	1.43–2.58
132 fsw / 20	10 fsw last stop (VVal-79)	1	9	10	1.99	1.46–2.65

alcoholic drink for 24 hours pre- and post-dive, and were instructed to be well-hydrated prior to the dive. Otherwise divers were allowed to follow their normal routine since this study was a test of operational procedures. Subjects were allowed to participate in multiple experimental dives in this trial. Subjects participated in one to four experimental dives (median = 2).

All experimental dives were completed in the wet pot of the ocean simulation facility at NEDU. The wet pot was set up to accommodate four divers at a time. Divers' breathing gas (79% N_2 / 21% O_2) was surface-supplied to full face masks. Divers wore t-shirts and shorts and the wet pot water temperature was actively controlled to a target of 29 ± 2°C. In the wet pot, subjects assumed a semi-prone position (approximately 15° head-up inclination to mimic fin-swimming) on custom-built, hysteresis-braked, underwater cycle ergometers (model HB210, Magtrol; Buffalo, NY). Divers were fully submerged with mid-chest approximately two feet below the wet pot water surface. The wet pot air space was compressed by the introduction of compressed air at a target descent rate of 60 fsw·min^{-1}, until the pressure at diver mid-chest level (chamber air pressure plus 2 fsw hydrostatic pressure) was equivalent to 132 fsw.

Immediately on reaching bottom, subjects began exercising on the cycle ergometers. Subjects pedaled at a target cadence of 60 rpm at a work rate of approximately 90 watts. This results in a diver oxygen consumption of about 1.6 L·min^{-1}, similar to previous US Navy decompression trials.[8,9] Subjects exercised continuously until three minutes before the end of bottom time. They then rested on the cycle ergometers until the end of bottom time and throughout decompression. The wet pot was decompressed at 30 fsw·min^{-1} to the first decompression stop and to the surface.

VENOUS GAS EMBOLI (VGE) DETECTION

For up to two hours during the post-dive observation period, subjects were monitored at approximately 20-minute intervals for VGE. The actual examination times were at mean (range) 16 (10–25), 35 (27–45), 56 (48–67), 76 (69–87), 96 (87–107), and 115 (104–127) minutes post-dive.

For each examination, the subject reclined in the left decubital position while the heart chambers were imaged (apical long-axis four-chamber view) with a trans-thoracic two-dimensional (2-D) echocardiogram. VGE in the right heart chambers were graded according to an ordinal scale adapted from Eftedal and Brubakk[10,11] and defined in Table 2. At each examination, VGE in the right heart chambers were graded three times: after the subject had been at rest for approximately one minute and then after forceful limb flexions of the right elbow and the right knee. For the flexion conditions, the grades were the maximum sustained for the following periods: grades 2 and 3 for at least four cardiac cycles; and grades 4a, 4b, and 5 for at least 0.5 s. The four cardiac cycle period follows from the grade 2 definition and the 0.5 s period was arbitrary. The resting grade and the maximum grade of all conditions (rest, arm movement, and leg movement) were used for analysis; the latter will hereafter be referred to as 'movement' VGE.

Results

Ninety-six man-dives were completed with no diagnosed incidents of DCS. Since stopping criteria were not reached, all dives were conducted on the 20 fsw last stop schedule. The observed cumulative incidence of DCS on the 132 fsw / 20-minute bottom time schedule with a 20 fsw last decompression stop was 0% (95% exact binomial confidence interval: 0%, 3%), and the observed proportions did not differ significantly (2-sided exact binomial test $P > 0.05$) from the NMRI-98 model-estimated P_{DCS} (Table 1).

It is conventional to express VGE as the peak grade of any examination time. The median (interquartile range) peak VGE grade at rest was 3 (2, 3), and the median peak VGE grade with movement was 3 (3, 3). Figure 1 illustrates the VGE grades at each examination time and shows that the highest VGE measurements at rest typically occurred at the 56-minute post-dive examination. VGE typically were detected throughout the two-hour post-dive observation period. At the end of the two-hour post-dive observation period, the median VGE grades remained elevated at grade 1 with rest and grade 3 with movement. Figure 1 illustrates the significant inter-subject variability in VGE grades.

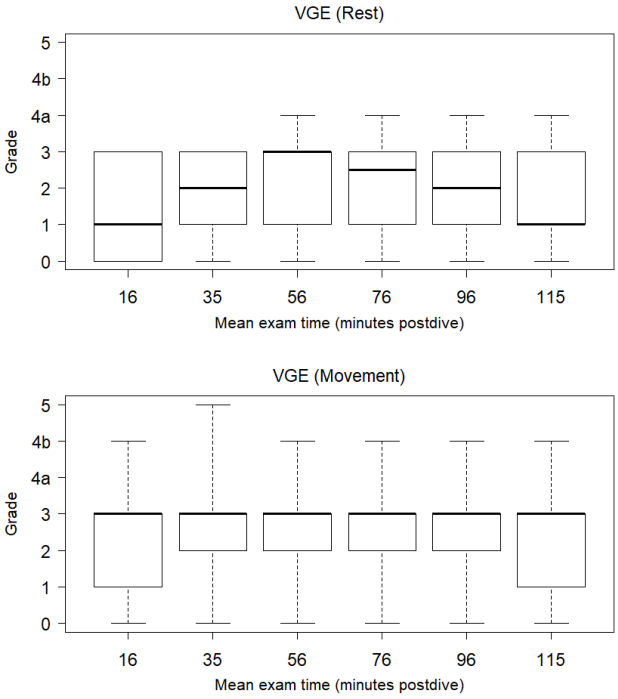
Five subjects had no observable VGE at the 56- and 76-minute examination times, therefore, in accord with the study protocol, they were not examined at the 96- and

Table 2
VGE grading scale. For the flexion conditions, the grades were the maximum sustained for the following durations: grades 2 and 3 for at least 4 cardiac cycles; and grades 4a, 4b, and 5 for at least 0.5 s

Grade	Definition
0	No observable bubbles
1	Occasional bubbles
2	At least 1 bubble every 4 heart cycles
3	At least 1 bubble every heart cycle
4a	At least 1 bubble per cm^2 in every image
4b	At least 3 bubbles per cm^2 in every image
5	'White-out', single bubbles cannot be discriminated

115-minute examination times. These five individuals were given scores of 0 for the last two exam times to calculate the medians and interquartile ranges in Figure 1.

Figure 1
The maximum VGE grade (modified Eftedal Brubakk scale grades, y-axis) of any exam for the rest condition and the movement condition. The box and whisker plots indicate the median, interquartile range, and the range



Discussion

The results support the specific hypothesis (H_0) that the VVal-79 schedule for 132 fsw / 20-minute bottom time with a 20 fsw last stop would result in a P_{DCS} not higher than 5%. The results indicate with high confidence that the P_{DCS} of the tested schedule is less than 3%, well below the 5% approximate upper limit of normal exposure dives in US Navy air decompression procedures.[3]

The elevated VGE grades in this study (hereafter referred to as the NEDU study) were consistent with the results of the DNC study. The median VGE at rest in the DNC study was KM (Kisman-Masurel) grade III. Three of the divers in the DNC study were treated with normobaric oxygen because of KM grade IV (maximum grade) that was still present one-hour post-dive.[4,5]

Excluding the three man-dives from the DNC study that were censored by oxygen breathing, the cumulative incidence of DCS observed in that study was 2/29 = 6.8% (95% exact binomial confidence interval: 0.8%, 22.8%). The observed cumulative incidence of treated DCS in the NEDU study (0/96) did not differ significantly from that of the DNC study (Fisher's exact test $P = 0.052$). However, the DNC study reported suspicious symptoms of heaviness and unease in one diver that occurred and resolved overnight between medical examinations.[4] If combined with the treated cases, this additional possible case of DCS results in an observed cumulative incidence (3/29) significantly higher than that of the NEDU study (Fisher's exact test $P = 0.012$). This latter difference motivates an examination of differences in the two study designs. The major differences were the total stop time, the number of dives in the preceding 48 hours, the water temperature and dress of the divers, and the diver activity levels on bottom and during ascent.

While the NEDU study was conducted with a total stop time of 9 minutes at 20 fsw (per the VVal-79 Thalmann algorithm), the DNC study conducted 20 dives with a total stop time of 7 minutes at 6 msw (in accord with USN-Rev6) and an additional 12 dives with a total stop time of 10 minutes (7 minutes at 6 msw and 3 minutes at a 3 msw safety stop). The NMRI-98 probabilistic-model-estimated P_{DCS} of the three schedules are very similar (see Table 1), indicating that the differences in total stop time between the schedules are trivial.

To participate in the NEDU study, all subjects had to refrain from hypo- or hyperbaric exposure for 48 hours preceding their experimental dive. The only exceptions to this rule were three divers who participated in a study dive approximately 24–27 hours after surfacing from a preceding study dive that was aborted during descent. In the DNC study, on the day preceding the 132 fsw / 20-minute bottom time air decompression dives, 20 of the 32 divers performed a decompression air dive (51 msw for 10-minute bottom time with a 2-minute stop at 6 msw) followed approximately 4 hours later by a no-decompression air dive (24 msw for 25-minute bottom time). No cases of DCS were diagnosed following the first diving day. Of the two DCS cases treated after the second diving day, following the 40 msw / 20-minute bottom time air decompression dives, one occurred in the dive series group and one occurred in the group of divers who only performed the single dive. The DNC study reported no significant difference in VGE grades between the dive series group and the single dive group.[4,5]

While it has long been held that multi-day diving is a risk factor for DCS, there is also evidence that dives conducted during the preceding days actually lead to acclimatization and decrease DCS risk.[12]

In the DNC study, divers wore dry suits and undergarments in 9–10°C water, while in the NEDU study, divers wore t-shirts and shorts in 29°C water. A large series of experimental air decompression dives established that colder temperature during decompression significantly increases the risk of DCS.[13] Notably, while cold during bottom time decreases the risk of DCS, this effect is not as pronounced as the effect during decompression.[13] However, neither the DNC nor NEDU studies assessed the thermal status of the subjects during the dive, limiting our ability to determine the impact of any thermal differences on the risk of DCS.

In the DNC study, divers performed 'light swimming' for 10 minutes of their bottom time and during decompression. For the other 10 minutes of their bottom time, the DNC divers solved a jigsaw puzzle. The NEDU divers exercised on bottom and rested during decompression. Exercise during bottom time has been shown to increase the risk of DCS, possibly due to increased blood flow to and increased gas uptake by exercising muscles.[12] The evidence regarding exercise during decompression indicates that light exercise during decompression decreases the risk of DCS by increasing gas washout.[12,14] This evidence suggests that the exercise profile of the NEDU study conveyed a higher risk of DCS compared to the DNC study.

In a departure from previous air decompression procedures, USN-Rev6 and USN-Rev7 introduced a 20 fsw last decompression stop instead of a 10 fsw last decompression stop due to the operational advantages of a deeper last decompression stop. The 20 fsw last stop was promulgated without man-testing but on the basis of evaluation with probabilistic models of DCS, which showed no difference in the P_{DCS} of the 20 fsw and 10 fsw last decompression stops.[15] The present results, along with those of the DNC study, are the first test of the 20 fsw last decompression stop instead of a 10 fsw last air decompression stop in US Navy air decompression procedures.

Conclusions

Testing of a short, deep air decompression schedule computed with the VVal-79 Thalmann algorithm, tested under diving conditions similar to earlier US Navy dive trials, resulted in low incidence of DCS.

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Acknowledgements

This work was sponsored by the US Navy Undersea Warfare Division and supported by the Naval Sea Systems Command Deep Submergence Biomedical Research Program. The views presented are those of the authors and do not necessarily represent the views of the US Department of the Navy. This work was presented at the Undersea Hyperbaric Medical Society Annual Scientific Meeting in June 2019. It was also reported in Navy Experimental Diving Unit (NEDU) technical report 19-06.

Conflicts of interest: nil

Submitted: 11 September 2019
Accepted after revision: 05 December 2019

Review articles

Diving with hypertension and antihypertensive drugs

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Key words
Diving medicine; Hypertension; Drugs; Fitness to Dive; Medicals – diving

Abstract

(Westerweel PE, Rienks R, Sakr A, Taher A. Diving with hypertension and antihypertensive drugs. Diving and Hyperbaric Medicine. 2020 March 31;50(1):49–53. doi: 10.28920/dhm50.1.49-53. PMID: 32187618.)
Hypertension is a common condition, which is highly prevalent amongst scuba divers. As a consequence, a substantial proportion of divers are hypertensive and/or on antihypertensive drugs when diving. In this article, we review available literature on the possible risks of diving in the presence of hypertension and antihypertensive drugs. Guidelines are presented for the diving physician for the selection of divers with hypertension suitable for diving, along with advice on antihypertensive treatment best compatible with scuba diving.

Introduction

Hypertension is a common condition affecting approximately 30–45% of the general population, with a steep increase in relation to age.[1] Several cohort studies have shown that hypertension is highly prevalent in recreational scuba divers and many use antihypertensive drugs. In a survey of Dutch divers, 12% reported to be hypertensive. Of the total divers, 4.3% used an ACE-inhibitor or angiotensin-receptor antagonist, 1.4% used a diuretic, 1.8% used a calcium-antagonist, and 1.0% used a beta-blocker.[2] In a Divers Alert Network (DAN) survey of US divers 24.6% reported being hypertensive, although this was lower than in the general US population.[3] In another US-focused survey, the Behavioural Risk Factor Surveillance System, an even higher prevalence was noted; 32.7% of divers were hypertensive.[4] In an analysis of divers treated at a hyperbaric facility, 8.9% were on antihypertensive drug treatment.[5]

In this perspective paper, we review available literature on the medical relevance of hypertension and antihypertensive drugs for scuba diving and provide practical advice for counselling divers with hypertension. This is based on best available evidence and expert opinions. The 2018 ESH/ESC guidelines for the management of arterial hypertension are used as a reference for the standard of general care.[6]

Methods

A systematic literature review was performed using the search string '(*diving* OR *scuba*) AND (*hypertension* OR *antihypertensive*)' in PubMed and the Rubicon repository in January 2017. From this, a literature summary was composed, and recommendations were drafted. This was limited to recreational scuba diving, thus excluding occupational and breath-hold diving. The findings were presented at an international educational meeting on diving medicine with various attending experts in May 2017 (mini-congress on diving medicine by Capita Selecta Duikgeneeskunde in Marsa Alam, Egypt). A revised draft including practical recommendations was then submitted for review by members from the Dutch Society for Diving Medicine and a final set of recommendations was adopted as a national recommendation for diving with hypertension and antihypertensive drugs at the Society meeting of 09 December 2017. For the current paper, the search was repeated on 30 May 2019. In PubMed, 161 hits were assessed for an applicability based on the abstract. In the Rubicon Research Repository, 43 hits were reviewed for applicability. Various observations have been published only in abstract form after presentation at scientific conferences, without having been published as a full article. These were included in this overview and designated as 'abstract' in the reference list.

Hypertension: definition and treatment

DEFINITION OF HYPERTENSION

The optimal blood pressure (BP) is < 120 mmHg systolic and < 80 mmHg diastolic. However, in the current society, most people have a blood pressure of 120–139 mmHg systolic and 80–89 diastolic, which could therefore be referred to as 'normal'. Hypertension is defined as an office blood pressure reading of systolic BP ≥ 140 mmHg and/or diastolic BP ≥ 90 mmHg. In cases of suspected situational hypertension, also known as 'white coat hypertension', the use of home blood pressure measurement or and 24-hour ambulatory blood pressure measurement may be more reliable. For home blood pressure measurement performed using a validated automatic device operated by the patient, hypertension is defined as a blood pressure ≥ 135/85 mmHg. For a 24-hour blood pressure reading, hypertension is defined as an average blood pressure exceeding ≥ 130/80 mmHg on average with ≥ 135/85 mmHg for daytime ambulatory blood pressure and/or ≥ 120/70 mmHg for night-time blood pressure. Of note, subjects with situational hypertension are at increased vascular risk compared to true normotensives.[6]

ANTIHYPERTENSIVE DRUG TREATMENT IN THE GENERAL POPULATION

Hypertension is a highly relevant risk factor for cardiovascular (CV) disease. The central aim of antihypertensive treatment is to prevent CV events. In low-risk individuals, the absolute risk reduction may be too small to justify treatment. Therefore, the indication for antihypertensive treatment depends not only on the grade of hypertension, but also on the overall absolute risk for a CV event. According to current ESC guidelines, all patients with hypertension grade 2 or higher should receive antihypertensive drug intervention irrespective of cardiovascular risk. Hypertension grade 2 is defined as a systolic blood pressure of ≥ 160 mmHg or a diastolic blood pressure of ≥ 100 mmHg. Patients with grade 1 hypertension (≥ 140/80 mmHg but not meeting the thresholds for grade 2) should be assessed for total CV risk based on concomitant presence of diabetes, symptomatic CV disease, chronic kidney disease, smoking, age, sex and plasma cholesterol. If their CV risk is high, drug treatment should be initiated. If their risk is low to moderate, the effect of life style interventions may first be observed.[6] Some other guidelines are more conservative in initiating drug treatment in low-risk individuals, such as the Dutch national guideline on cardiovascular risk management for general practitioners that advises limiting treatment in low-risk individuals with a blood pressure < 180/90 mmHg to lifestyle interventions only.[7] As a resultant, not all hypertensive subjects with grade 1 and even grade 2 receive drug treatment if their absolute CV risk is relatively low.

ANTIHYPERTENSIVE DRUGS

For antihypertensive drug treatment, the most common classes of antihypertensive drugs are:

- Angiotensin converting enzyme inhibitors (ACE-I);
- Angiotensin II receptor blockers (ARBs);
- Calcium antagonists (Ca-A);
- Diuretics;
- Beta-blockers.

More rarely used antihypertensive drugs are alpha-blockers, renin inhibitors, endothelin-inhibitors, alpha-2 adrenergic receptor agonists and direct-acting vasodilators. These will be considered beyond the scope of this article.

LIFESTYLE CHANGES

Appropriate lifestyle changes may prevent or help treat hypertension. The following lifestyle measures are recommended:

- Salt restriction to 5 $g \cdot day^{-1}$;
- Moderation of alcohol consumption (< 14 units per week for men and < 8 units for women);
- Increased consumption of vegetables, fresh fruits, fish, nuts, unsaturated fatty acids (olive oil), low consumption of red meat, and consumption of low-fat dairy products;
- Body weight control to avoid obesity (body mass index [BMI] > 30 $kg \cdot m^2$ or waist circumference > 102 cm in men and > 88 cm in women), aiming at a healthy BMI (20–25 $kg \cdot m^2$) and waist circumference (< 94 cm in men and < 80 cm in women);
- Regular aerobic exercise (≥ 30 min of moderate dynamic exercise on 5–7 days per week);
- Smoking cessation.

TREATMENT STRATEGY AND TARGET BLOOD PRESSURE

Lifestyle interventions are recommended for all subjects with hypertension. Prompt initiation of antihypertensive drugs is recommended in patients with grade 2 or more hypertension and/or at high CV risk. When treatment is indicated, this may be done using ACE-I, ARB, Ca-A, beta-blocker or diuretic; or a combination thereof. An initial BP goal of ≤ 140/90 mmHg is recommended in all hypertensive patients with a preferable target of ≤ 130/80 if the treatment is well tolerated.[6]

Diving-related risks in relation to hypertension

AGGRAVATION OF CENTRAL BLOOD PRESSURE BY IMMERSION AND EXERCISE

The presence of hypertension is likely to be aggravated during recreational diving through several mechanisms:

- Immersion, as this leads to a fluid shift from the extremities to the central core. This fluid shift has been estimated to comprise approximately 600–700 ml;[8]
- Peripheral vasoconstriction, particularly when diving in cold water conditions, which will exacerbate the central pooling of blood and thereby the increase in central

blood pressure;[9]
- Exercise, which may temporarily increase arterial blood pressure substantially.[10]

As a consequence, a significantly elevated blood pressure prior to a dive may accumulate to a cardiovascular strain that could elicit a cardiovascular event. After a dive, systemic blood pressure is unchanged compared to the pre-dive values.[11]

In addition to the above, there is also the effect of activity related stress (psychological), which is significant among novice divers and directly proportionate to the level of general physical fitness. Environmental conditions will also affect the conditions of exercise and stress levels thus potentially affecting blood pressure levels.

For physical activities and competitive sports in general, ACC/AHA/ESC guidelines recommend a blood pressure < 160/100 mmHg.[12] Together with the notion that immersion could increase blood pressure in patients with grade 1 hypertension, diving should be discouraged for subjects with a blood pressure > 160/100 mmHg. Of note, this implies that there may be subjects with a low CV risk and a systolic blood pressure between 160 and 180 mmHg that are not receiving drug treatment, but therefore should not dive. Alternatively, these subjects could consider taking antihypertensive drugs to be allowed to dive.

IMMERSION PULMONARY OEDEMA

There is substantial evidence suggesting that hypertensive subjects may be more prone to develop immersion pulmonary oedema (IPO). Hypertension was found to be relatively prevalent in a study of underlying predisposing factors in patients with IPO.[13] In a small observational study of divers suffering IPO, a disproportionally high number (eight out of 10) were on antihypertensive treatment at the time of their dive.[14] In subjects who have suffered an episode of IPO, the presence of hypertension is associated with a higher chance of later recurrence.[15] Finally, normotensive subjects who experienced IPO during scuba diving or swimming were more likely to develop arterial hypertension later in life.[16]

DECOMPRESSION ILLNESS

In an animal experiment, decompression sickness was found to occur more than twice as often in spontaneous hypertensive rats than in control rats.[17] This observation (only published as an abstract) indicates that hypertension may be a risk factor for decompression illness, but requires further research for confirmation.

SCUBA DIVING INDUCED CARDIOVASCULAR EVENTS

A substantial proportion of scuba-diving related incidents and fatalities are related to cardiovascular events.[18] As hypertension is a prominent risk factor for cardiovascular events, the risk of scuba-diving related cardiovascular events may be expected to be increased in hypertensive divers. In some cases of diving fatalities, hypertensive cardiomyopathy or hypertensive atherosclerotic vascular disease were indeed specifically identified as the suspected cause of death.[18]

Diving-related risks in relation to antihypertensive drugs

ANGIOTENSIN CONVERTING ENZYME INHIBITORS

Pulmonary symptoms, particularly a dry cough, may occur as a side effect for this drug class, which should be carefully evaluated. Otherwise, few specific diving-related risks are expected from this drug class, if well tolerated by the diver.

ANGIOTENSIN II RECEPTOR BLOCKERS

Few specific diving-related risks are expected from this drug class, if well tolerated by the diver.

CALCIUM ANTAGONISTS

Ca-A are vasodilators that act on smooth muscle cells in the arterial wall. A common side effect is orthostatic hypotension. A specific diving-related risk may involve a sudden drop in blood pressure when exiting the water as the central blood pooling effect of immersion is reversed at a time when the circulating blood volume has been reduced during the dive. Divers using Ca-A may be needed to take specific care to gradually exit the water to allow for blood pressure adaption during emersion. Otherwise, there are no specific diving-related risks.

DIURETICS

In the treatment of hypertension, the most commonly used diuretics are thiazide diuretics. These have a modest effect on water clearance and plasma volume contraction. Dehydration is commonly thought to be a risk factor for decompression sickness. Of note, although there is a strong theoretical basis for this notion, the scientific evidence is very limited with conflicting results in animal models[19–21] and only small supportive human studies.[22,23] Nonetheless, this does raise concern that plasma volume contraction may theoretically result in some degree of increased risk of decompression sickness when using thiazide diuretics. Although modest under otherwise normal circumstances, this may be greater during a tropical scuba diving trip: high fluid losses due to excessive sweating, repetitive diving and possible travellers' diarrhoea may be severely aggravated by use of thiazide diuretic. In the hypovolemic state, thiazide-induced electrolyte disturbances may also become more likely to occur.

BETA-BLOCKERS

Beta-blockers may adversely affect diving safety through

multiple mechanisms. First, beta blockers may cause chronotropic incompetence of the heart by limiting heart rate modulation during exercise. This may impair exercise capacity.[24] Secondly, beta blockers may induce a reduction in FEV1 (forced expiratory volume in 1 second) by off-target inhibition of bronchial beta-2 receptors in susceptible individuals,[25] although this effect seems to diminish after prolonged use.[26] Finally and of note, there have been multiple cases of immersion pulmonary oedema in divers using beta blockers (personal communication by Dr Adel Taher, Sharm el Sheik Hyperbaric Treatment Facility); an observation previously reported by others.[27,28] However there are no systematic studies investigating these clinical observations in properly controlled cohorts.

Summarized advice for divers with hypertension

It is recommended that individuals with a blood pressure exceeding 160/100 mmHg do not participate in scuba diving until the blood pressure has been treated appropriately. Subjects with a blood pressure < 160/100 mmHg may participate in scuba diving, irrespective of receiving treatment.

It is recommended that in subjects with hypertension receiving treatment, the hypertension should be well controlled to a minimal level of < 160/100 mmHg, but preferably to the general target range of < 140/90 mmHg.

It is recommended that certain antihypertensive drugs may be preferred to others in the context of scuba diving, and participation in scuba diving may be of consequence for antihypertensive treatment choices.

It is recommended that subjects with hypertension be assessed for signs of cardiac ischaemia and/or dysfunction and be referred to a vascular specialist or cardiologist for cardiovascular screening when deemed appropriate.

It is recommended that divers with hypertension should dive with an increased margin of safety to lower the risk of decompression sickness.

It is recommended that divers with hypertension be informed about the symptoms of IPO and receive specific instructions to immediately abort a dive in case of these symptoms. In case of suspected occurrence of IPO, the diver should undergo careful evaluation by a diving physician, pulmonologist and/or cardiologist before resuming diving.

Summarized advice on diving with antihypertensive drugs

ACE-I or ARBs: No specific concerns in relation to diving safety. Treatment of first choice for divers, if well-tolerated with specific attention to pulmonary symptoms.

CALCIUM ANTAGONISTS: Caution divers about orthostatic phenomena, particularly when exiting the water.

DIURETICS: Not preferred. Discontinue diuretics when suffering from diarrhoea and/or excessing sweating. Emphasize the importance of hydrating properly before and after diving.

BETA-BLOCKERS: Not preferred, but may be allowed when negative effects on exercise tolerance and pulmonary function are excluded.

Conclusions

Hypertension is prevalent amongst scuba divers and many divers use antihypertensive drugs. Hypertension may be aggravated by immersion and is associated with endothelial dysfunction and increased cardiovascular risk. This may increase the susceptibility to diving related illnesses and this is indeed observed in accident statistics. A specific concern is an increased risk for immersion pulmonary oedema. Antihypertensive drugs could influence diving safety. Preferred anti-hypertensive drugs in scuba divers requiring anti-hypertensive treatment are ACE-I or ARBs, followed by Ca-A. Less preferred are beta-blockers and diuretics.

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Conflicts of interest and funding: nil

Submitted: 22 June 2019
Accepted after revision: 24 October 2019

The current use of wearable sensors to enhance safety and performance in breath-hold diving: A systematic review

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Key words
Physiology; Patient monitoring; Telemetry; Computers; Equipment; Training

Abstract
(Vinetti G, Lopomo NF, Taboni A, Fagoni N, Ferretti G. The current use of wearable sensors to enhance safety and performance in breath-hold diving: A systematic review. Diving and Hyperbaric Medicine. 2020 March 31;50(1):54–65. doi: 10.28920/dhm50.1.54-65. PMID: 32187619.)
Introduction: Measuring physiological parameters at depth is an emergent challenge for athletic training, diver's safety and biomedical research. Recent advances in wearable sensor technology made this challenge affordable; however, its impact on breath-hold diving has never been comprehensively discussed.
Methods: We performed a systematic review of the literature in order to assess what types of sensors are available or suitable for human breath-hold diving, within the two-fold perspective of safety and athletic performance.
Results: In the 52 studies identified, sensed physiological variables were: electrocardiogram, body temperature, blood pressure, peripheral oxygen saturation, interstitial glucose concentration, impedance cardiography, heart rate, body segment inertia and orientation.
Conclusions: Limits and potential of each technology are separately reviewed. Inertial sensor technology and transmission pulse oximetry could produce the greatest impact on breath-hold diving performances in the future.

Introduction

Underwater activities are commonly performed for recreational, occupational or competitive purposes.[1,2] The most common approaches include either a self-contained underwater breathing apparatus (SCUBA) or breath-holding. These activities carry an intrinsic health risk due the physiological stresses related to hypoxaemia, hyper- or hypocapnia, hydrostatic pressure and cold water,[2] potentially resulting in loss of consciousness and drowning. Given that the majority of reported adverse events are related to a delay in recognizing a life-threatening problem,[1] the risk can be minimized through primary and secondary prevention strategies. In these contexts, field measurement of relevant physiological parameters is an emergent challenge, as the improvement of divers' safety requires a better understanding of diving physiology. This challenge is being met thanks to technological advances in wearable sensors (i.e., water and pressure proofing, miniaturization and underwater communication).[3,4] In breath-hold (BH) diving, remarkable increases in the number of active competitors and dramatic improvement in diving performance have occurred in the last 20 years.[5] As BH divers rely only on their own physiological capabilities, sensor technology provides potential for training feedback and enhancement of human performance and safety.

This work aimed to systematically review wearable sensor technologies usable during BH diving, with the twofold perspective of inferring its potential applications to safety and performance. Specifically, this review aimed at addressing the following questions:

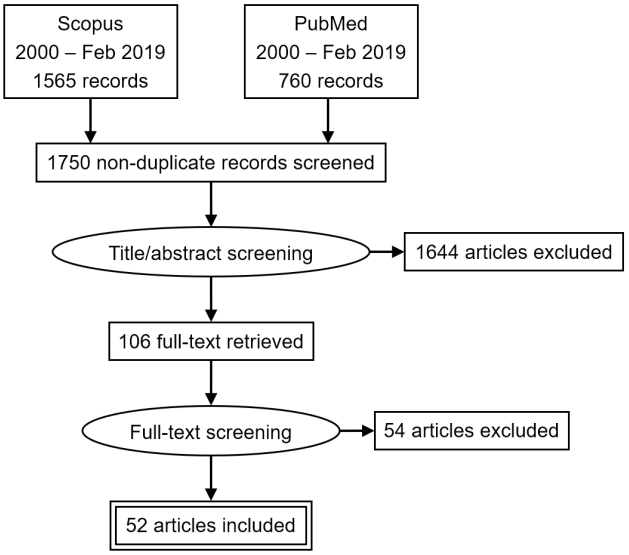
- What type of wearable sensors can be used in human BH diving?
- What wearable sensors used for SCUBA diving are potentially applicable also to BH diving?
- What water- and pressure-proofing strategies have been adopted to adapt monitoring technology to the underwater environment?
- At which depth have the various approaches been reported to work?

Although some of the physiological changes discussed in this review may apply to all types of diving (see e.g., the blood pressure increase[6]), the conclusions arrived at are specific to BH diving. Analogous reviews on SCUBA diving were previously published[3,4] and the interested reader may refer to them.

Methods

Article selection was based on a systematic search of the scientific databases PubMed and Scopus following the

Figure 1
PRISMA flow diagram for the systematic review



PRISMA guidelines.[7] To avoid outdated technology, only items published after January 2000 were included in the search. The keyword string was: (*sensor* OR *ECG* OR *electrocardiogram* OR "*heart rate*" OR "*blood pressure*" OR *hemodynamics* OR "*oxygen saturation*" OR *EEG* OR *IMU* OR "*inertial measurement unit*" OR *accelerometer* OR *gyroscope* OR "*body temperature*" OR "*blood glucose*") AND (*diver* OR *diving*).

The title and abstract of each result were reviewed and evaluated based on the relevance to the aims of this study. When appropriate, full-text was obtained for a more detailed analysis. Article references were examined for further pertinent publications.

Inclusion criteria were that the publication: appeared in a peer-reviewed academic source; was related to the utilization or the development of wearable sensors explicitly or potentially applicable to human BH diving; included experiments carried out completely below the water level, at a depth (either real or simulated with a hyperbaric chamber) of more than 2 m. Exclusion criteria were: studies performed in shallow water (less than 2 m deep); sensors applicable only to SCUBA diving; invasive or non-portable sensors.

The following information was extracted from articles meeting the inclusion criteria: sensed physiological variable, sensor technology, sensor sealing precautions, studied diving mode, test environment, maximal tested depth.

Results and discussion

The initial search yielded 1,565 titles on Scopus and 760 on PubMed updated to 28 February 2019. Duplicates were removed, 248 abstracts were further analysed and subsequently 106 full-text papers were downloaded. After full-text assessment, we finally selected 52 publications for inclusion in this review (Figure 1). The parameters extracted from each publication are specifically reported in Tables 1–7, which will be discussed in detail below.

Thirteen studies involved BH diving, 38 SCUBA diving and one saturation diving. Tested depths ranged from 2 to 160 metres' sea or fresh water. Sensed physiological variables were: electrocardiogram (ECG, 19 studies), body temperature (six studies), arterial blood pressure (ABP, five studies), peripheral oxygen saturation (SpO_2, five studies), interstitial glucose concentration (five studies), impedance cardiography (four studies), heart rate (13 studies), body segments inertia and orientation (three studies), electroencephalogram (one study). Six studies involved simultaneous measurements of multiple parameters, such as ECG and impedance cardiography (one study), ECG and SpO_2 (one study), ECG, ABP and SpO_2 (two studies), heart rate and core and skin temperature (one study), ECG and body temperature (one study). In all studies, an appropriate casing was used for the water- and pressure-proofing of electronic components.

ELECTROCARDIOGRAM AND HEART RATE

The ECG has previously been applied to BH diving and unsurprisingly was the most common physiological variable recorded.[8] As reported in Table 1, depth ranged between 2–70 m. In ECG monitoring there are two different elements that must be waterproofed: the electrodes and the electronics. Performing differential measurements between devices, such as ECG the front-end electronics typically require amplifiers which present high input impedance, high level of gain and a large common-mode rejection ratio (CMRR). These must provide a large amount of gain for very low-level signals, often in the presence of high noise levels. Immersion in salt water introduces a parallel resistance between electrodes, increasing the load and decreasing the signal by an amount that depends on water conductivity (i.e., salinity) and electrodes properties. Therefore, the optimal and most widespread solution was to place electrodes under a dry suit.[9–13] Alternatively, electrode insulation was achieved via direct coverage with biocompatible adhesive patches[14–19] or with hydrophobic dental impression material.[20–23] All the reported solutions avoided modifying the original manufactured skin-electrode interface while maintaining the correct inter-electrode insulation. Finally, a novel solution based on intrinsically waterproof electrodes has been recently developed.[24]

The ECG signal analysis can be restricted to heart rate only, as in commercial cardiotachometers and diving computers, which were studied at 3–65 m depth[25–37] or in shallow water during static apnoea competitions.[38,39] Cardiac arrhythmias are common during BH diving[40,41] and real-time ECG analysis can be used to trigger alert signals based on pre-

Table 1

Studies reporting measurement of the electrocardiogram and heart rate. BH = breath hold. HVP = hypdrophilic vinyl polysiloxane. NS = not specified. PC = personal computer. S = SCUBA. trans = transmission. WHC = wet hyperbaric chamber. * = probably not monitored in real-time due to Bluetooth constraints underwater

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data storage or display	Data trans	Water-and pressure-proofing of the wearable sensor	Max. depth (m)
Electrodes	40	BH	WHC	55	NS	Yes	ECG recorder	Not specified	Not specified	–
Electrodes + ECG transmitter	13	S	WHC	27	Fukuda-Denshi	Yes	ECG recorder (Dynascope DS-1040)	Wireless	All inside diver's dry suit	–
	12	S	Pool	2	Prototype	Yes	Data logger	Wireless (acoustic)	Electrodes: under diver's dry suit; ECG transmitter: inside cylindrical housing attached to an aqualung	–
	46	S	Sea	20	Nihon-Kohden	No	ECG transmitter	Cable	Electrodes: not specified; ECG transmitter: water- and pressure-proof case.	–
Electrodes + ECG recorder	17	BH	Sea	70	Sorin Group	Yes	ECG recorder (storage); PC (display)	Cable	Electrodes: covered with transparent adhesive (Tegaderm, 3M, St. Paul, Minn., USA); ECG Holter: plastic tube (Comex SA, Marseille, France)	190
	14	S	Pool	4	Reynolds Medical	No	ECG recorder	Cable	Electrodes: waterproof tape; ECG recorder: professional diving pouch (TMT, ewa-marine)	–
	47	S	Lake	8	PicoMed	No	ECG recorder	Cable	Electrodes: special clips; ECG recorder: not specified	–
	15	S	Sea	25	Mortara	No	ECG recorder	Cable	Electrodes: first layer (Visulin, Hartmann) + second layer (Steri-Drapes, 3M); ECG Holter recorder: pressure-proof anticorodal aluminium housing, with a plexiglass cover (Metralab s.r.l.)	50
	9,10	S	Sea	30[9] 61[9]	Rozinn-Electronics[9], NS[10]	No	ECG recorder	Cable	All inside diver's dry suit	–

Table 1 continued.

Electrode patches embedded in an ECG recorder	16	BH	WHC	20	NS	No	ECG recorder	Embedded	Electrodes: special adhesive patch; ECG recorder: water- and pressure-proof case	–
Electrodes + data logger	20–23	BH	Pool	2[20,21] 10.5[22,23]	Prototype	Yes	Data logger	Cable	Electrodes: HVP dental impression material (Elite H-D+, Zhermack); Data logger: lexan tube	200
	19	S	Pool	4.6	UFI	Yes	Data logger	Cable	Electrodes: benzoin + waterproof tape + moleskin; Data logger: not shown	–
Electrodes + ECG sensor + smartphone	11	S	Pool	2.7	Shimmer-Research Ltd	Only vibratory alerts	Smartphone	Wireless (Bluetooth)	All inside diver's dry suit; Smartphone: professional diving pouch	–
Electrodes + Monitoring Board	18	S	Sea	30	Prototype	Yes	PC	Cable to a Bluetooth buoy	Electrodes: hot glue + self-adhesive waterproof film (Tegaderm, 3M); ECG Monitor: Case (DryCase 2000, OtterBox)	–
Electrodes chest strap + ECG transmitter	24	S	Pool	4.5	Prototype	Yes	PC	Wireless (Bluetooth)*	Electrodes: intrinsically waterproof (hydrophobic, Carbon Black/ Polydimethylsiloxane electrodes, meshed with embedded copper mesh); ECG transmitter: not specified	–
Electrodes chest strap + wrist monitor	26 30 36 37	BH[37] S[26,30,36]	Sea	3[36] 5[30] 20[26,37]	Polar	Yes	Wrist monitor	Wireless	Electrodes: built-in water insulation (textile electrodes); Monitor: built-int waterproof case	50
	25	S	Pool	4.5	Timex	Yes	Wrist monitor	Wireless	Not specified	–
	27–29 31–35	S	Sea	18[27,28,33–35] 20[29], 54[32] 65[31]	Scubapro-Uwatec	Yes	Wrist monitor	Wireless	Electrodes: built-in water insulation; Monitor: built-int waterproof case	120

determined criteria.[11] Moreover, heart rate response to exercise is only partially suppressed by the diving reflex and still remains influenced by the metabolic rate:[17,42–45] it could be therefore monitored by an experienced diver as a real-time surrogate of the energy cost of underwater swimming.

ARTERIAL BLOOD PRESSURE

Underwater ABP measurement was successfully carried out at depths between 2–10.5 m (Table 2). In designing the pressure transducer, electrical component waterproofing without preventing (or excessively delaying) barometric equalization in the reference chamber is critical to allow correct measurement in the aquatic environment, especially in dynamic conditions (ascent and descent).[48] We found only two different approaches to achieving this. The first solution was putting a commercial ABP device inside a downwardly-open plexiglass housing,[6] whose resulting water-air interface was set at the level of the middle of the blood pressure cuff. Subsequent studies improved the portability of the sensor, with the ABP device encapsulated into a Lexan tube directly located over the cuff, inflated with the gas coming from a SCUBA tank.[20,21,48,49] BH was reported to increase ABP either modestly[48] or dramatically.[50] Therefore, it would be useful to monitor individual ABP responses to BH diving both for research and screening purposes.

IMPEDANCE CARDIOGRAPHY

Impedance cardiography allows for non-invasive monitoring of the electrical impedance changes in the thorax thus providing estimation of the cardiac stroke volume and, together with the ECG measurement, of several derived cardiovascular parameters. These systems usually rely on the use of a set of electrodes (at least four) placed on the thorax. An alternating high frequency small amplitude current is applied through two electrodes, whereas the electrical potential difference is measured using the other pair. Secured in a pressure chamber[40] or into an underwater torch case in open sea,[51–53] the device allows measurements up to 55 m depth (Table 3). While it represents an index of myocardial performance, it adds limited benefits for BH diving safety and performance compared to ECG alone.

PERIPHERAL OXYGEN SATURATION

Arterial haemoglobin saturation is a key performance parameter for BH and reflects the partial pressure of O_2 in the arterial blood. It can be measured non-invasively in the peripheral circulation (SpO_2), although motion artefacts and reflex peripheral vasoconstriction prevents the utilization of classical transmission pulse oximeters at fingertip or earlobe. Accordingly, only reflectance pulse oximeters at the forehead were used underwater,[20–22,54] at a depth of 2–10 m (Table 4). In the design of the device, waterproofing was specifically obtained by soaking it in a highly sealing and electrically insulating polymeric material. Battery change was facilitated by introducing a separate waterproof compartment.

The descent phase of a BH dive cannot be guided by pulse oximetry, because the depletion of oxygen stores is counterbalanced by transmission of the surrounding hydrostatic pressure to the alveolar gas, thus increasing arterial partial pressure of oxygen and resulting in a fairly stable SpO_2 at 100%. Only during a prolonged period at depth and/or during the ascent (when there is reversal of the above process) would O_2 depletion manifest as a decrease in SpO_2. As a consequence of circulation time between lungs and forehead, the nadir of SpO_2 at forehead occurs 4–8 s after surfacing,[55] or even later if cardiac output is reduced by a marked diving response.[53]

BODY SEGMENT INERTIA AND ORIENTATION

Classical movement analysis systems (optical motion capture, force and pressure measurement sensors, global positioning systems) are not suitable for the deep underwater environment. Inertia measurement units (IMU) incorporate accelerometers, gyroscopes and magnetometers in a small space and can be easily waterproofed. For these reasons, IMU arose as a powerful tool for the investigation of competitive swimmers' biomechanics[56] and the energetics of air-breathing diving animals.[57,58] IMUs have been used in experimental studies on human divers in only three studies (Table 5), two conducted at a depth of 2 m[59,60] and one at 10 m.[61] Electrical insulation was achieved by means of either external cases[59,60] which can be easily acquired and applied, or by embedding the electronics in a polymeric potting compound.[61]

The main outcomes of Kuch et al.[60] and Goodfellow et al.[61] were, respectively, the reconstruction of diver's posture (to detect anomalous behaviours) and path (to build an inertial based underwater navigation system). However, potential applications of IMU to BH diving extend to investigating the energy cost of underwater swimming, a major determinant of BH distance or depth.[62] Feedback on swimming economy would be crucial for improving performances of both dynamic and deep apnoeas, especially if provided in real-time. Groh et al.[59] moved in that direction, trying to establish a biomechanical model to describe leg and upper body orientation during fin kicking. Their proposed algorithm has the potential to be implemented into a wider training system for competitive or recreational divers. However, additional parameters still need to be measured in order to obtain a complete biomechanical model.

BODY TEMPERATURE

Superficial, rectal and ingestible temperature sensors were easily adapted to hyperbaric environments to investigate heat exchange in SCUBA[18,36,63–65] and saturation diving[66] at 3–160 m depth (Table 6). Built-in cases are the most common solutions to properly insulate superficial sensors, while rectal and ingestible sensors are designed to be resistant to gastrointestinal fluids thus are already waterproof. However no specifications were found concerning maximum ambient

Table 2
Studies reporting measurement of arterial blood pressure. BH = breath hold. S = SCUBA, trans = transmission

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data storage or display	Data trans	Water- and pressure-proofing of the wearable sensor	Max. depth (m)
Cuff + differential pressure sensor + microcontroller (based on Korotkoff sounds)	6	S	Pool	3	Bosch & Sohn (BoSo)	Yes	On screen via a video-camera	Cable	Plexiglass housing for inflator/ display (downwardly open for hydrostatic pressure equalisation); silicone sheath for cuff microphones	–
Cuff + differential pressure sensor + microcontroller (based on the oscillometric method)	20 21 48 49	BH[20,21,48] S[49]	Pool	10.5	Prototype	Yes	Microcontroller	Cable	Lexan tube, inflation air coming from a SCUBA tank	200

Table 3
Studies reporting measurement of impedance cardiography. BH = breath hold. NS = not specified. trans = transmission. WHC = wet hyperbaric chamber

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data storage or display	Data trans	Water- and pressure-proofing of the wearable sensor	Max. depth (m)
Electrodes	40	BH	WHC	55	Bomed	Yes	Recorder	NS	Not specified	–
Electrodes + recorder	51 52 53	BH	Pool[52,53] Sea[51]	3[52,53] 30[51]	2C Technologies Inc	No	Recorder	Cable	Recorder: underwater torch case; Electrodes: surgical 15x10 cm patches (Plastod, Bologna, Italy)	90

Table 4
Studies reporting measurement of peripheral oxygen saturation. BH = breath hold. trans = transmission

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data storage or display	Data trans	Water- and pressure-proofing of the wearable sensor	Max. depth (m)
Reflectance sensor (8000R) + module (OEM III) + data logger	20–22 54	BH	Pool	2[20,21] 10.5[22,54]	Nonin	Yes	Data logger	Cable	Data logger: either (i) inside a lexan tube or (ii) filled with silicone gel (SilGel 612, Wacker Chemie AG) with a water- and pressure-proof compartment for battery.	200

Table 5

Studies reporting measurement of body segment inertia and orientation. IMU = Inertia measurement unit. PC = personal computer. S = SCUBA. trans = transmission. * = personal communication

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data storage or display	Data trans	Water- and pressure-proofing of the wearable sensor
Accelerometer + magnetometer + gyroscope (IMU)	60	S	Pool	2	ST Microelectronics + InvenSense	Yes	PC at surface	Cable	Lexan tube
	61	S	Pool	10	Pololu	Yes	PC at surface	Cable	Spokes: 3D printed housing, filled with polyurethane potting compound; Hub: 5083 grade aluminium alloy housing
	59	S	Pool	2*	Prototype	No	IMU	Cable	Professional diving case or pouch for cameras or mobile phones

pressure in which those sensors may be operated. Electrical insulation of the data loggers was achieved by means of cases or housings designed to allow easy access.

Monitoring body temperature would be useful in repetitive diving, such as spearfishing competitions and professional dives, because it allows timely diagnosis and prevention of hypothermia.[67] This was reported to be a frequent event in Ama divers,[68] which could eventually elicit chronic adaptation to cold.[69] The usefulness of such monitoring is underscored also by the reduction in maximal BH duration in cold water due to an increased resting metabolic rate.[70] Some commercially available diving computers offer skin temperature measurement from the heart rate chest strap,[27–29,31–35] but have not been the subject of published scientific studies. In fact, it is noteworthy that the gold standard for a comprehensive characterization of human thermal balance is to measure both skin and core temperature.[71]

INTERSTITIAL GLUCOSE CONCENTRATION

Subcutaneous sensors for interstitial glucose concentration have been waterproofed with adhesive films and dental impression material[72,73] or simply kept under the dry suit[74,75] or even the wet suit.[76] In this case, there is no issue related to the direct contact with water, since the sensor (i.e. a thin needle) is placed within the interstitial fluid. Electrical insulation had to be ensured only to avoid issues related to power supply and data transmission. Devices were studied at depths 22–40 m (Table 7). In insulin-dependent diabetic SCUBA divers these devices may diagnose hypoglycaemia during the dive, although the very short immersion times hamper their usefulness for BH diving.

ELECTROENCEPHALOGRAM

One pilot study obtained electroencephalographic (EEG) recordings 4 m underwater[77] by protecting the electrodes under a full-face latex mask, further covered by a bathing cab. In this case, waterproofing is essential to ensure inter-electrode insulation and prevent surface biopotentials becoming equipotential, as discussed earlier in relation to ECG and impedance cardiography. Signals were transmitted via cable to an amplifier at the surface. Although acute cognitive impairment is an important safety issue in extreme BH diving, real-time applicability of EEG in this field remains unfeasible at this time. Nevertheless, it could be important to develop portable underwater EEG devices, especially to study development of adaptive changes in EEG reported in trained breath-hold divers.[78]

Conclusions

Since the first tests on BH diving populations,[79,80] the potential for carrying out physiological measurements during actual BH diving has increased dramatically. The wearable sensors implemented so far have contributed significantly

Table 6

Studies reporting measurement of body temperature. NS = not specified. PC = personal computer. S = SCUBA. Sat = Saturation. trans = transmission

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data Storage or display	Data trans	Water- and pressure-proofing of the wearable sensor
Ingestible temperature sensor + data logger	65	S	Pool	3	HQ Inc.	No	Data logger	Wireless	Temperature sensor: capsule; data logger: inside diver's dry suit
	36	S	Pool	3	Philips- Respironics	Yes	Data logger	Wireless	Temperature sensor: capsule; data logger: not specified
	18	S	Sea	30	Philips- Respironics	Yes	Data logger + PC on surface	Wireless (to data logger); Cable to bluetooth buoy (to PC)	Temperature sensor: capsule; data logger: case (DryCase 2000, OtterBox)
	66	Sat diving	Sea	160	Biomed d.o.o.	No	Data logger	Wireless	Temperature sensor: capsule; data logger: professional diving pouch
Rectal temperature sensor + data logger	63	S	Sea	10	Grant- Instruments	Yes	Data logger	Cable	Temperature sensor: inside divers' dry suit; data logger: above water surface
Skin temperature sensor + data logger	63	S	Sea	10	Grant- Instruments	Yes	Data logger	Cable	Temperature sensor: inside divers' dry suit; data logger: above water surface
	64	S	Sea	8	Grant- Instruments	Yes	Data logger	Cable	Temperature sensor: surgical tape (Blenderm, 3M); data logger: above water surface
	36	S	Sea	3	Philips- Respironics	Yes	Data logger	Wireless	Temperature sensor: built-in waterproof case; Data logger: not specified
	18	S	Sea	30	Philips- Respironics	Yes	Data logger + PC on surface	Wireless (to data logger); Cable to bluetooth buoy (to PC)	Temperature sensor: built-in waterproof case; data logger: Case (DryCase 2000, OtterBox)
	66	Sat diving	Sea	160	Biomed d.o.o.	No	Data logger	Embedded	Temperature sensor: embedded in the data logger; data logger: professional diving pouch

Table 7
Studies reporting measurement of interstitial glucose concentration. S = SCUBA. trans = transmission

Sensor	Ref.	Diving mode	Setting	Tested depth (m)	Manufacturer	Real-time display	Data storage or display	Data trans	Water- and pressure-proofing of the wearable sensor
Subcutaneous glucometer + monitor	72	S	Sea	21.5	Medtronic	No	Monitor	Cable	Glucose sensor: hydrophilic vinylpolysiloxane material (Elite H-D, Zhermack) + doubled plastic adhesive dressing + an elastic collodion film between the two dressings; monitor: pressurized aluminium container
	73	S	Sea	20	Medtronic	No	Monitor	Cable	Glucose sensor: taped with an Opsite film; monitor: water- and pressure-proof case
	74 75	S	Sea	22^{75} 24^{74}	Medtronic	No	Monitor	Cable	All inside diver's dry suit
	76	S	Sea	40	Dexcom	Yes	Monitor	Wireless	Glucose sensor: under diver's wet suit; monitor: waterproof case with glass screen

to our understanding of BH diving physiology and to the safety of dives. Adequate waterproof characteristics seem to be achievable for systems originally designed for terrestrial use, provided that the issues of both sensor-body interface and electrical insulation are taken into account. However, the intrinsic depth limits of the adopted technology was not reported in several studies.

Another recent improvement involves the transmission and real-time processing of physiological measurements. On-line medical and physiological information transmission during diving could allow a prompt recognition of an increased risk or a clinical adverse event, leading to timely termination of the dive (for example, significant cardiac arrhythmias or an excessive rise in ABP). Further advances could be obtained by integrating different sensors into a unique "*smart*" suit. In addition to safety, the analysis of multiple data collected in the field would positively impact training and competition strategies, as happens in several other sporting disciplines. Among the sensors that we discussed, transmission pulse oximetry and inertial sensor technology seem to have the greatest potential for further technical improvement and innovative uses. The former could give feedback on available oxygen stores (with the limitations outlined above), and the latter on factors influencing oxygen consumption rate, possibly identifying the most economical swimming technique. Therefore, we expect them to produce the greatest impact in the future.

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Conflicts of interest and funding: nil

Submitted: 25 March 2019
Accepted after revision: 19 October 2019

Case reports

Pulmonary barotrauma: a case report with illustrative radiology

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Key words
Pulmonary barotrauma; Diving; Pneumothorax; CT scan

Abstract

(Bigeni S, Saliba M. Pulmonary barotrauma: a case report with illustrative radiology. Diving and Hyperbaric Medicine. 2020 March 31;50(1):66–69. doi: 10.28920/dhm50.1.66-69. PMID: 32187620.)
A case of a 24-year-old gentleman who had pulmonary barotrauma (PBT) after diving is reported. He presented with chest pain after the second of two uneventful shallow SCUBA dives. Computerized tomography (CT) scan confirmed the diagnosis and he was treated conservatively. Relevant radiology and a discussion of PBT are presented.

Introduction

Barotrauma refers to the injuries that may occur in gas-containing compartments of the body when there is a pressure change. To understand how barotrauma occurs, certain laws of physics have to be applied. According to Boyle's Law, as the pressure decreases, the volume of a gas space increases and vice versa ($P_1V_1=P_2V_2$). When a diver starts ascending from a dive, the ambient pressure decreases and the volume in gas-filled spaces such as the lungs would increase.[1] Consequently, a golden rule of SCUBA diving is to never breath-hold. As the ambient pressure decreases during ascent, the compressed gas in the lungs expands and this gas needs to be exhaled. The lungs are insensate when over-expanded.[2] Thus, the scuba diver has no warning to prevent lung injury if breath-holding on ascent. Unlike SCUBA diving, pulmonary barotrauma in breath-hold-diving is extremely unlikely since a 'lungful' of gas inhaled at the surface is compressed during descent, and simply re-expands safely to its original volume on ascent.[3]

Case report

The patient provided written consent for his case and radiology to be reported. A 24-year-old male presented to the accident and emergency department in Gozo General Hospital complaining of chest pain. During the day, he had done SCUBA dives and had no symptoms during the first dive which was at 6 metres' sea water (msw) for 20 minutes. His second dive was at 12 msw for twenty minutes. He was a novice diver who smoked 20 cigarettes a day.

About two and a half hours after surfacing from the second dive, he started complaining of chest tightness. He then noticed 'bubbles under the skin' at the left base of his neck associated with discomfort. He came to the emergency department with persisting chest tightness and increasing severity of the neck pain. He denied any other symptoms such as shortness of breath, cough, and haemoptysis. Examination of his cardiovascular, respiratory and neurological systems was normal. Blood pressure was stable at 130/70 mmHg with a regular pulse of 83 beats/min. Hamman's sign (a cracking sound heard over the precordium during systole) was negative. He was afebrile and oxygen saturation on air was 99%.

A chest X-ray showed no pneumothorax, however, there was left subcutaneous emphysema in the left axillary area and pneumomediastinum (Figure 1). Although there were no obvious precipitating events during the dives (such as a rapid panic ascent) the gas was presumed to have arisen from pulmonary barotrauma (PBT) during diving. He was admitted to the male general ward for observation. He was started on intravenous crystalloid fluids and high flow oxygen. After 24 hours, his chest discomfort persisted. All other investigations came back within the normal range (blood results including troponins and D-dimer, and ECG). Thus, further imaging was requested because of the persisting symptoms and to exclude pneumothorax, in which case, he would be unfit to fly home immediately.

A CT scan revealed the presence of a pneumomediastinum, minimal pneumothorax on the right side and subcutaneous emphysema in the neck and chest wall on the left side more than on the right side (Figures 2–7).

He was reviewed by the surgeons and treated conservatively. His subcutaneous emphysema disappeared after two days

Figure 1
Chest X-ray performed in the emergency department showing left axillary subcutaneous emphysema and pneumomediastinum (arrows)

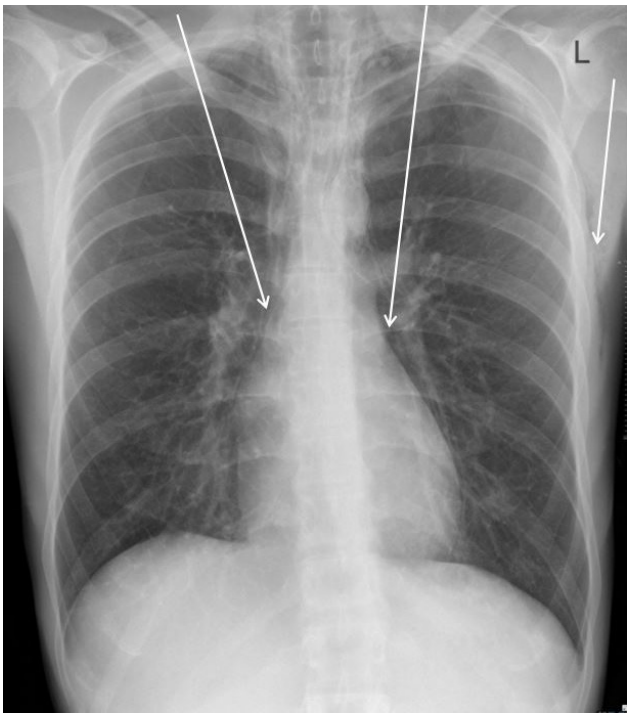
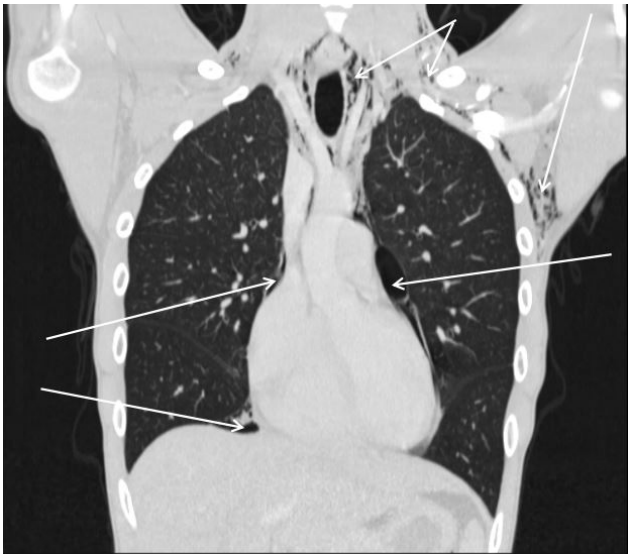


Figure 2
Sagittal section of CT scan showing the effects of pulmonary barotrauma: air leaks shown as a radio-lucent outline in the mediastinum and subcutaneous emphysema (arrows) present in the left axilla and neck



and he was fit for discharge. He was advised not to dive again since PBT is often considered a contraindication for diving. This was not an issue with this novice diver since he still had not acquired a passion for diving. He was supposed to fly back home three days after the event but was strongly advised against it. He flew back home after two weeks with no complications.

Figure 3
Pneumomediastinum and surgical emphysema (arrows) at the level of the great vessels

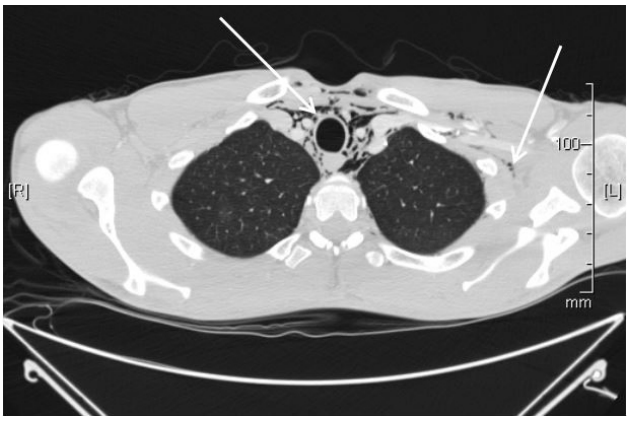
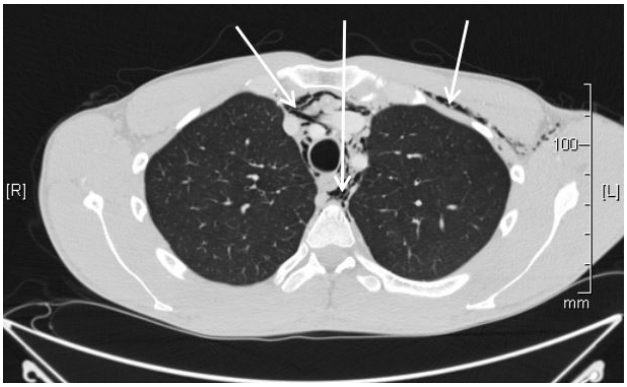


Figure 4
Pneumomediastinum and subcutaneous emphysema (arrows) at the level of the 2nd thoracic vertebral body



Discussion

PBT is damage to the lung parenchyma caused by an increase in pulmonary gas volume during a decrease in ambient pressure. PBT may occur in the following scenarios: involuntary laryngospasm on ascent which can be caused in loss of consciousness or panic; intentional or involuntary breath-holding while ascending (even if it's for a short period e.g., coughing), a sudden increase in the volume of gas supplied by SCUBA equipment, and during a fast ascent.[4] As in this case, PBT is often seen in novice divers; probably because they hold their breath.

Multiple symptoms can occur in patients suffering from PBT. These include discomfort due to minor degrees of pneumomediastinum or pneumothorax, through to life-threatening arterial gas embolism (AGE).[5] It was also noted in a study that recurrent PBT tends to be worse than the first incident and more likely to include AGE.[6]

Figure 5
Pneumomediastinum with subcutaneous emphysema (arrows) at the level of the bifurcation of the right bronchus

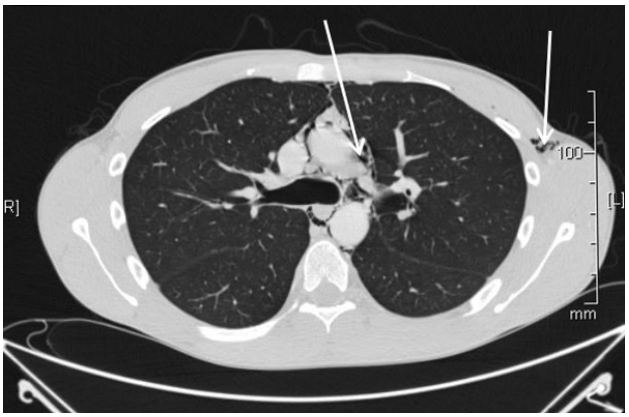


Figure 6
Pneumomediastinum (arrow) at the 5th thoracic vertebral body

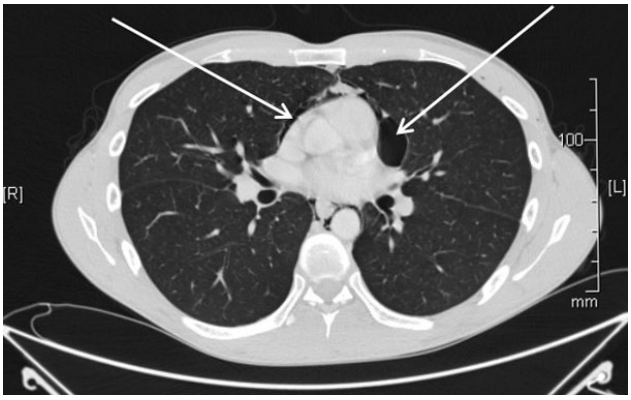
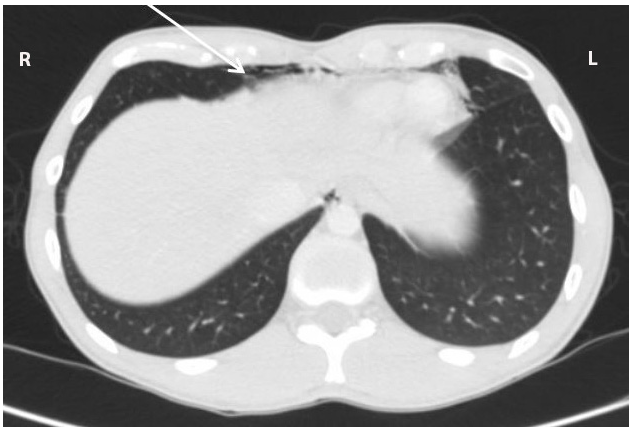


Figure 7
Small right sided pneumothorax (arrow) at the level of the diaphragm



There may be predisposing factors for PBT. Conditions that increase air trapping in the lungs resulting in a degree of obstruction and parenchymal disease with regional differences in the level of compliance have been implicated in promoting pulmonary barotrauma.[7] Obstruction of the bronchi is frequent in asthma, acute and chronic bronchitis, respiratory tract infections, tuberculosis, tumours of the lung, calcified glands, cysts in the lung, and emphysema. Heavy smoking may obstruct the airways by increasing the formation of mucous plugs. Obstructions may act like a ball valve, allowing air to enter the lungs but restricting its exit.[8] Although certain respiratory conditions are thought to increase risk of PBT, in most cases, no respiratory predisposing factor is found.

Previously, it was recommended that prior to air travel there should be a six week wait after complete resolution of a pneumothorax but this has been abandoned.[9] Current guidelines are based on sparse data but recommend postponing air travel for one to three weeks after full resolution of the pneumothorax.[10]

Conclusions

In this patient, the cause of PBT was probably breath-holding. PBT can occur in someone without predisposing factors, however, smoking affects the lungs and the airways in such a way that it may increase the risk of PBT.

Chest X-ray was useful in diagnosing subcutaneous emphysema but a CT scan provides higher sensitivity in detecting the extent of the PBT.

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Conflicts of interest and funding: nil

Submitted: 19 July 2019
Accepted after revision: 06 November 2019

Symptoms of central nervous system oxygen toxicity during 100% oxygen breathing at normobaric pressure with increasing inspired levels of carbon dioxide: a case report

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Key words
Case reports; Carbon dioxide; Diving; Diving medicine; Hypercapnia; Oxygen; Pressure

Abstract

(Eynan M, Arieli Y, Taran B, Yanir Y. Symptoms of CNS-oxygen toxicity during 100% oxygen breathing at normobaric pressure with increasing inspired levels of carbon dioxide: a case report. Diving and Hyperbaric Medicine. 2020 March 31;50(1):70–74. doi: 10.28920/dhm50.1.70-74. PMID: 32187621.)

The greatest danger faced by divers who use oxygen-enriched gas mixtures is central nervous system oxygen toxicity (CNS-OT). CNS-OT is characterised by convulsions resembling grand-mal epileptic seizures, which may terminate in drowning and death. Elevated arterial levels of carbon dioxide (CO_2) (hypercapnia) represent a major risk factor for CNS-OT when breathing hyperoxic gas mixtures. To reduce the risk of a diver being involved in a CNS-OT incident due to hypercapnia, candidates for combat diving are examined at our institute using a routine physiological training procedure, in which they are tested for CO_2 detection and retention. We present the case of a candidate for combat diving, who unexpectedly exhibited signs typical of CNS-OT while breathing pure oxygen under normobaric conditions with > 3 kPa inspired CO_2. Severe headache and nausea, as well as facial muscle twitching, appeared during one of these routine tests. Subsequent medical examination including neurological tests, magnetic resonance imaging and an electroencephalogram were unremarkable. To the best of our knowledge, an event such as this has never previously been published in the medical literature. We present a discussion of the case, and a review of the relevant literature regarding CO_2 as a risk factor for the development of CNS-OT.

Introduction

Central nervous system oxygen toxicity (CNS-OT) represents a major risk for combat and recreational divers who use oxygen-enriched mixtures as their breathing gas. CNS-OT is characterised by tunnel vision, tinnitus, headache, nausea, and twitching of the muscles of the face. Convulsions similar to epileptic seizures may also appear, as well as sudden loss of consciousness, sometimes without any warning symptoms.[1] CNS-OT may be observed at oxygen pressures above 200 kPa with the dry chamber.[2,3] However, the limit of concern for CNS-OT when using an oxygen rebreather underwater may well be less, as low as 146 kPa.[4] The cellular mechanisms underlying the development of CNS-OT include reactive oxygen species (ROS), which can oxidise specific cellular components, producing neurochemical alterations that conclude in neurotoxicity.[5,6] Reactive nitrogen species (RNS) also play a role,[7–11] as does nitric oxide (NO), which modifies GABA metabolism and may contribute to neuroexcitation and seizures.[12,13]

Elevated arterial levels of CO_2 (hypercapnia) due to CO_2 production/elimination mismatch during submerged exercise (termed CO_2 retention), an inherent tendency to retain CO_2, or failure of the CO_2 absorbent in the breathing apparatus, all carry an added risk of CNS-OT when breathing hyperoxic gas mixtures.[14] The correlation between elevated inspired PCO_2 (P_ICO_2) and an increased risk of CNS-OT has been well established in animal models.[15–19] This correlation has also been reported in divers with a low ventilatory response to inhaled CO_2 ('CO_2 retainers'), who may convulse while apparently within the safety limits for hyperoxic exposure.[20]

There are a number of possible mechanisms which might explain the higher risk of CNS-OT in the presence of elevated levels of CO_2. First, CO_2 induces cerebral vasodilatation, which increases the blood flow through neural tissues, and in turn increases the transfer of O_2 to these tissues. Second, hyperoxia, unlike normoxia, suppresses the sensitivity of peripheral CO_2 chemoreceptors to [H^+], which might lower the potential ventilation rate and result in higher

arterial levels of CO_2.[21] Third, at hyperbaric pressure, CO_2 retention may be presumed to increase the production of NO, which also results in cerebral vasodilatation.[22,23] Fourth, at hyperbaric pressure, there is increased production of RNS, such as peroxynitrite, due to the reaction of nitric oxide with superoxide. It may be presumed that in the presence of CO_2 retention, molecular CO_2 will react with peroxynitrite to generate the RNS nitrosoperoxocarboxylate ($ONO_2CO_2^-$), which may cause oxidation as well as nitration and nitrosylation reactions.[24] Finally, ROS production in the presence of CO_2/H^+, such as the Fenton reaction, might generate hydroxyl molecules.[24]

To reduce the risk of a diver being involved in a CNS-OT incident due to hypercapnia, candidates for diver training are examined at our institute using a routine physiological training procedure. In this test, subjects are checked for CO_2 retention and detection while breathing a hyperoxic gas mixture. We expect a candidate to be able to detect P_ICO_2 before it reaches 4 kPa (27 mmHg). Those unable to detect a rise in P_ICO_2 by the time it reaches this level, which is the detection threshold for conscious recognition of elevated CO_2, is defined as a poor CO_2 detectors. The assessment is performed using an electric scale board with a matrix of push-buttons related to five subjective symptoms typical of hypercapnia. CO_2 retention is defined as an end tidal PCO_2 ($P_{ET}CO_2$) in excess of 9.5 kPa (71 mmHg) when inhaling 6 kPa (45 mmHg) CO_2. We have previously shown that a diver who is defined as both a poor CO_2 detector and a CO_2 retainer is prone to suffer from CNS-OT.[25] The purpose of the present case report is to bring to light the uncommon event of an individual who displayed twitching of the facial muscles, a symptom of CNS-OT, while breathing 100% normobaric oxygen to which 3 kPa (22 mmHg) CO_2 had been added.

Methods

EXPERIMENTAL SYSTEM AND PROTOCOL

The CO_2 retention test is performed with the subject seated on a bicycle ergometer (Ergonomics 800, Sensormedics Corp., Yorba Linda, CA, USA). The experimental system and protocol have been described in detail in our previous studies.[25,26]

Before the test, subjects receive an oral lecture on the role of CO_2 in closed-circuit diving, the signs and symptoms of hypercapnia, and the nature of the test.

In the training and test protocols, the subject under examination inhales 100% oxygen while pedalling at a work rate of approximately 50 W. After 5 min, the CO_2 level in the inspired gas is arbitrarily cycled within a range of 0–5.6 kPa (0–42 mmHg). In the training session, the subject is provided with a digital display of the inspired CO_2 concentration, as well as being informed verbally, until he/she is able to sense the presence of CO_2 in the inspired gas without hints and signal accordingly.

The test session usually starts 15–30 min after training, when the subject's $P_{ET}CO_2$ has returned to baseline (pre-training) levels and any of the symptoms (such as headache or dizziness) which may have occurred during the training session have disappeared. It comprises the same procedure as the training session, but the gradual elevation of P_ICO_2 begins immediately after the start of oxygen breathing. The CO_2 level in the inspired gas is arbitrarily cycled two or three times within a range of 0–5.6 kPa. Subjects are not informed of the F_ICO_2, other than that it will at some point start to rise and that they should indicate on the electric board (with a matrix of push-buttons related to five subjective symptoms: hyperpnea, air hunger, headache, dizziness, and a warm sensation, each of which can be scored according to 5 degrees of intensity) the moment they detect it. This first detection is unsolicited. The minimum level of inspired CO_2 for which we consider a response to be a true detection is found for every subject individually, according to his/her detection repeatability during the test session.

Case report

A 19 year-old male diver on active duty in the Israel Navy, weighing 67 kg, height 1.73 m, came to our laboratory at the Naval Medical Institute to perform the routine physiological test designed to examine his CO_2 retention and detection traits. During his interview before the test, he complained of dizziness, headaches and nausea he had experienced during the series of dives using closed-circuit apparatus commenced two weeks earlier. The diver began the test as described above. During the training session, when the CO_2 in his inspired gas reached a level of 2 kPa ($P_{ET}CO_2$ 4.9 kPa), he complained of severe dizziness and headache. At the same time, with the inspired CO_2 somewhere in excess of 3 kPa ($P_{ET}CO_2$ 5.7 kPa) he also reported twitching of his facial muscles, especially around the mouth, which was indeed observed clearly by the medical staff. When the level of CO_2 in his inspired gas was reduced the twitching stopped, although the sensations of dizziness and headache remained. The level of CO_2 was raised and lowered between 0–4 kPa twice more, which resulted in reappearance of the facial muscle twitch. During the actual test, his sensitivity to inspired CO_2 was found to be very high. He had severe headache and dizziness at an inspired level of 2 kPa CO_2. This is considered quite low, the average value for CO_2 detection being 3 (SD 0.2) kPa. Most of the divers who undergo the test hardly have any sensation at all at an inspired level of CO_2 at 2 kPa. In most cases, when a candidate indicates any subjective change as a result of inspiring CO_2 at a level as low as 2–2.5 kPa, his/her $P_{ET}CO_2$ is usually lower than the average level for all divers who have participated in the test.[25] Therefore, the diver in the present case indeed seems to be particularly, if not uniquely sensitive to CO_2.

We asked the diver to repeat the test two weeks later in exactly the same format. The symptoms of dizziness, headache and twitching of the facial muscles appeared as they had on the first test, and the candidate was sent for medical investigation.

The diver's medical history was unremarkable. All aspects of the medical check-up he underwent to qualify for combat diving, performed prior to the CO_2 tolerance test, were normal. This included examination by a cardiologist, electrocardiogram, spirometry and blood analysis.

A detailed medical interview, conducted after the CO_2 test, revealed that the diver had experienced headaches, dizziness and nausea after many of his closed-circuit oxygen dives, and apparently had to terminate some of the dives as a result. The diver had never experienced these symptoms in any other situation apart from diving with an oxygen rebreather, even during very strenuous exercise.

The diver was examined by a senior neurologist, who noted no pathological findings. Magnetic resonance imaging did not show any abnormalities, and electroencephalography was interpreted as normal. A 24-hour EEG recording was performed, during which he underwent another CO_2 detection and retention test as described above. Despite normal findings on the continuous EEG recording, the same symptoms appeared once again.

Despite the fact that all the examinations he performed were found to be normal, providing no definite explanation for the events, it was decided that due to the diver's symptoms during oxygen breathing (appearing both in his prior oxygen dives and in the CO_2 detection and retention test), he would not continue to dive with oxygen-enriched mixtures. The decision was based on the likelihood of excessive risk for CNS-OT.

Discussion

The present case represents a very rare phenomenon, of a subject in whom breathing ~100% normobaric oxygen to which 3% CO_2 had been added (P_ICO_2 = 3 kPa, 22 mmHg) triggered signs often associated with CNS-OT. To the best of our knowledge, no signs or symptoms of CNS-OT have ever previously been reported during breathing of normobaric oxygen, even with the addition of CO_2 to the inspired gas.

In contrast to pulmonary oxygen toxicity, which may be observed with prolonged oxygen-enriched breathing in normobaric conditions, CNS-OT has always been related to breathing oxygen at hyperbaric pressure, both during a dry dive or clinical treatment in the hyperbaric chamber, and in the wet conditions of underwater diving. The breakthrough of CO_2 to the inspiratory limb of the breathing loop in the diving apparatus, or CO_2 retention, represent a major risk factor for CNS-OT with which divers may have to contend. For that reason, rebreather divers attend our laboratory for a training session to give them experience of hypercapnia. They thus have an opportunity to familiarise themselves with the sensations induced by CO_2, so that they will know when to abort the dive should the need arise. Seizures occurring underwater may have a fatal outcome.

This raises questions concerning other mechanisms which may result in physical hypersensitivity to oxygen. Chronic obstructive pulmonary disease can cause basic hyperpnoea, and increased susceptibility to oxygen toxicity.[27] Certain brain processes (against an epileptic or other epicenter), such as brain damage after carbon monoxide poisoning, may cause hypersensitivity to oxygen.[28] Therefore extra care should be taken with such patients when they undergo hyperbaric oxygen treatment. There may be a decrease in the CO_2 carrying capacity of venous haemoglobin, due to its being saturated with O_2 on hyperbaric exposure, which will bring about an increase in tissue and venous PCO_2.[22] The resultant hypercapnia-induced intracellular acidosis will make cells more susceptible to ROS. Molecular CO_2 reacts with peroxynitrite (ONOO-), a RNS that may also cause cellular damage.[24] Exercise may contribute to CNS-OT, most likely due to the increase in cerebral blood flow and metabolic rate.[13] In the present case, the diver was breathing 100% oxygen together with an elevated percentage of CO_2 when cycling on an exercise ergometer at 50 W, which is considered a low work rate.

The results of EEG and MRI studies in our diver did not indicate any abnormal brain pathology, including an epileptogenic focus expressed on exposure to oxygen in normobaric conditions. It is possible that more specific EEG or MRI testing could have shed light on delicate changes which standard tests were not sensitive enough to detect.

Arieli et al.[4] summarised CNS-OT symptoms reported from 2,527 dives. They found that the most prevalent symptoms after four-hours diving were headache and nausea. Moreover, the authors concluded that if facial twitching appears, the probability of losing consciousness is 700 times greater than in a diver who does not have that symptom. Our diver reported severe headache, dizziness and nausea, both on his O_2 dives and during his CO_2 test on 100% normobaric oxygen. These symptoms are by no means exclusive to hyperbaric hyperoxia but may also be observed in hypercapnia. It is thus plausible that our diver may have been highly sensitive not only to hyperoxia, but also to hypercapnia. Using a rebreather naturally places the diver in a situation where he is breathing hyperbaric oxygen, while also at a high risk of hypercapnia. The decision in the present case was therefore to disqualify this diver from diving with oxygen-enriched gas mixtures, due to a serious possibility that he might lose consciousness during an O_2 dive.

Conclusions

We have described a diver who is possibly at high risk for CNS-OT, manifesting in symptoms which developed

consistently in all hyperoxic conditions: wet hyperbaric and dry normobaric. These included severe headache, dizziness and nausea when using closed-circuit oxygen apparatus, and twitching of the facial muscles while breathing 100% normobaric oxygen to which 3% CO_2 had been added (P_ICO_2 = 3 kPa, 22 mmHg). We have experience going back many years testing CO_2 retention and detection.[25] Never before have we seen a symptom so typical of CNS-OT appear at normobaric pressure. We feel this exceptional event should be brought to the knowledge of the diving community to heighten awareness of the danger concealed in the use of oxygen rebreathers.

CNS-OT represents a grave danger for both combat and recreational divers. A major risk factor for the development of CNS-OT is an increase in the level of inhaled CO_2. This is why we conduct the test to determine our divers' ability to detect CO_2, and check the possibility that they may be CO_2 retainers, in all candidates for oxygen diving. In recent years, more and more civilians have begun using electronic rebreathers. It is therefore of great importance that divers be made aware of the potential danger of hypercapnia in accelerating the development of CNS-OT. A poor detector who also has a tendency to retain CO_2 may suffer from CNS-OT when using a rebreather, even at a depth considered safe.

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Acknowledgements

We should like to thank the patient for giving his written informed consent for publication of this case report. The authors thank Mr R Lincoln of the Israel Naval Medical Institute for skillful editing.

Conflicts of interest and funding: nil

Submitted: 04 July 2019
Accepted after revision: 20 September 2019

Letter to the Editor

Effect of an air break on the occurrence of seizures in hyperbaric oxygen therapy may be predicted by the power equation for hyperoxia at rest

In their recent report in the September 2019 issue of *Diving and Hyperbaric Medicine*,[1] Costa, et al. summarized seizure frequency in hyperbaric oxygen treatment (HBOT). The frequency of central nervous system oxygen toxicity (CNS-OT) manifesting as seizures was reported to be 3.4 per 10,000 sessions before the introduction of a 5-min air break, and 1.2 per 10,000 sessions after air break introduction to the treatment protocol. Because exposures in the two groups were similar apart from the air break, its effect on seizure frequency should have been observed in the second part of the exposure (that which followed the air break). This in effect amounted to a reduction of 3.4–1.2 = 2.2 seizure events per 10,000 sessions.

We have proposed the power equation as a measure of pulmonary and CNS oxygen toxicity, and I believe it has the best predictive power of any approach suggested to date. The CNS-OT index K for exercise at 4 metabolic equivalents of task (METs) is given by the equation:

$$K = t^2 PO_2^{6.8} \quad [1]$$

where t is the time in min and PO_2 is the inspired oxygen pressure in bar.

Recovery of the index K (Krec) was calculated by the equation:

$$Krec = K \times e^{-0.079trec} \quad [2]$$

where trec is the recovery time in min. If we introduce a 5-min air break into the recovery equation, it will reduce the toxicity index to 67% of its value without the break. This explains the advantages of such a procedure, and using the power equation will also allow us to choose the appropriate time for the air break.

The value of the CNS-OT index enables us to calculate the risk of toxicity in active diving.[2–4] However, the power equation at rest (1 MET) has not yet been calibrated. A preliminary attempt has been presented,[4] however, still employing exercise parameters to derive values for resting CNS-OT. The wealth of data amassed by Costa, et al.[1] together with those from other hyperoxic exposures at rest, such as the German mandatory oxygen tolerance test described by Koch, et al.[5] may be used to calculate the resting power equation. In rats, we showed that the power of PO_2 increases as metabolic rate is reduced.[3]

I would encourage the authors of the cited paper[1] to compile the individual data (PO_2 and time for each session), and in accordance with the procedure we used,[2] to derive the power equation for resting conditions. They will thus obtain the power of PO_2 (time should remain as the square of the time) and the appropriate risk (Z) for resting conditions. This should be similar in form to the algorithm we derived for hyperoxic exercise from the normal distribution using the CNS-OT index, namely:

$$Z = [\ln(K^{0.5}) - 9.63] / 2.02 \quad [3]$$

Once this is done, the power expression obtained, together with the recovery function, should influence HBOT protocols, and any other hyperoxic exposures at rest (1 MET).

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Submitted: 23 November 2019
Accepted after revision: 29 November 2019

doi: 10.28920/dhm50.1.75-76. PMID: 32187622.

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Key words
CNS Oxygen toxicity; Recovery; Resting conditions; Prediction; Letter (to the Editor)

Obituary

Francis Alfred (Frank) Blackwood

Frank was born in 1926 and passed away in January 2020. After leaving school at 14 and a variety of jobs, he moved to Sydney and got a job building radios after the war and passing a Radio Trades Certificate course before moving to Defence as an electronics tradesman. In the early seventies, he took a job as Technical Officer at the Royal Australian Navy School of Underwater Medicine (RAN SUM) and and rapidly became a major force in the team that Carl Edmonds and his successors directed. He later told his family that the twenty years he spent there were by far the best time of his working life.

If he could not do a task, Frank would ask around and find someone who would teach him the needed skill, or enrol in a course on the subject. As a result, he soon became SUM's expert in hearing and vestibular function testing. In that role, he earned his position as an author of *Otological Aspects of Diving* by Edmonds C, Freeman P, Thomas R, Tonkin J and Blackwood FA.

Frank completed courses in machining and then produced prototypes of a diving set to meet a specified RAN need. This could function as a closed circuit oxygen set or a semi-closed mixed gas set. This project got to the stage of having prototypes produced by industry.

Another interesting job was to produce an emergency scrubber for use in submarines. This was to remove CO_2 if the powered scrubbers failed. The Royal Navy had produced a man powered bellows system that did not work well and the SUM version worked rather better. It was ridden like a stationary bicycle where the pedals turned a set of gears, which connected to an air pump to push air through the scrubbers. The air pump was made from a discarded vacuum cleaner. With both these tasks, SUM obtained promising results, unfortunately the RAN people involved moved on and their replacements were not as keen for SUM to persevere. Frank's response was to shrug his shoulders and say, "*well we had fun with that problem, what is next*".

When Des Gorman took on his Ph.D, he had a requirement to keep a rabbit anaesthetised in a small animal recompression chamber (RCC). After discussions on how it might work, Frank assembled an electronics package that timed the operation of some solenoids that controlled the flow of gases to the rabbit. He also built the frame that held the animal in the needed position in the RCC. If my memory is correct, he also operated the video system that recorded the behaviour of the bubbles in the surface vessels of the exposed rabbit's brain. Frank would also collect the unfortunate rabbit on his way to work, so he really earned his acknowledgement in the resulting thesis.

Carl Edmonds encouraged his staff to dive and at 40+, Frank did a RAN diving course, joined SPUMS and enjoyed the first conference at Heron Island in 1972.

He continued working at SUM retiring at 65 and in his spare time, Frank was an instructor and radio room supervisor for a Civil Defence organisation.

Frank was treasured by the staff who cared for him later in life because he retained his cheerful and enquiring nature. He is survived by two daughters, numerous grandchildren and great-grandchildren.

John Pennefather
Life member SPUMS

Diving and Hyperbaric Medicine reviewers in 2019

The editorial team wish to take this opportunity to thank all those who reviewed submissions for us in 2019. The numbers refer to reviews rather than manuscripts, since each manuscript is typically reviewed more than once and manuscript numbers alone don't capture the effort that is put in to reviewing them. Diligent peer review is an essential component of scientific publishing and without it the journal could not function. We are deeply grateful for the input of all those listed in the table. Our sincere thanks to all of you.

Reviewer	Country	Number of reviews
Gavin Anthony	UK	2
Charles Azzopardi	Malta	2
Costantino Balestra	Belgium	2
Neil Banham	Australia	4
Pedro Barata	Portugal	2
Michael Bennett	Australia	6
Nick Bird	USA	2
Jean-Eric Blatteau	France	1
Phil Bryson	UK	1
Jay Buckey	USA	1
Francois Burman	USA	5
Peter Buzzacott	Australia	5
James Caruso	USA	1
Dick Clarke	USA	3
Susan Coleshaw	UK	5
Paul David Cooper	Australia	1
Dominic D'Agostino	USA	1
Mike Davis	NZ	8
Petar Denoble	USA	2
David Doolette	USA	4
Douglas Ebersole	USA	2
Chris Edge	UK	9
Ingrid Eftedal	Norway	1
Nic Flemming	UK	2
Andrew Fock	Australia	3
Folke Lind	Sweden	2
Oskar Frånberg	Sweden	4
Mikael Gennser	Sweden	2
Peter Germonpré	Belgium	7
François Guerrero	France	2
Neil Hampson	USA	4
Karin Hasmiller	Germany	1
Ole Hyldegaard	Denmark	1
Thomas Kertez	Australia	2
Cristoph Klingmann	Germany	2
Andreas Koch	Germany	2
Jacek Kot	Poland	5
Pierre Lafère	France	5
Karen Lam	NZ	1
Jan Lehm	Australia	2

Diving and Hyperbaric Medicine reviewers in 2019 continued.

Peter Lindholm	Sweden	7
John Lippmann	Australia	3
Heather Massey	UK	5
Ian Miller	Australia	1
Andreas Møllerløkken	Norway	2
Richard Moon	USA	3
Peter Mueller	Germany	2
Heather Murphy-Lavoie	USA	1
George Perdrizet	USA	2
Michael Perez	Philippines	1
Neal Pollock	Canada	4
Andrew Proctor	UK	2
Monica Rocco	Italy	2
Andérs Rosen	Sweden	2
Charlotte Sadler	USA	2
Chris Sames	NZ	5
Martin Sayer	Scotland	3
Erica Schagatay	Sweden	1
Fiona Seddon	UK	1
Susannah Sherlock	Australia	2
Barbara Shykoff	USA	5
Arne Sieber	Austria	3
Jamie Sleigh	NZ	2
David Smart	Australia	1
Gary Smerdon	UK	2
Marguerite St Leger Dowse	UK	3
Adolfo Talpalar	Sweden	1
Kay Tetzlaff	Germany	2
Sigrid Theunissen	Belgium	2
Stephen Thom	USA	1
Frauke Tillmans	USA	4
Akin Toklu	Turkey	1
Mark Turner	UK	2
Greg van der Hulst	NZ	2
Hanna van Waart	NZ	2
Charles Van Wijk	South Africa	2
Xavier Vrijdag	NZ	2
Dan Warkander	USA	2
Lindell Weaver	USA	1
Jennifer Weller	NZ	1
Jurg Wendling	Switzerland	1
Graham White	UK	1
David Wilkinson	Australia	6
Peter Wilmshurst	UK	3
Colin Wilson	UK	1
Weigang Xu	China	2

EUBS Notices and news

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

Announcement of EUBS 2020

Please book your flight, hotel and register for our next EUBS Annual Scientific Meeting, in Prague, Czech Republic, from 16–19 September 2020.

The meeting will be organised by the local organising committee chaired by Michal Hajek MD, PhD, a longtime member of EUBS, and member of Executive Board of ECHM; in collaboration with the Czech Society of Hyperbaric and Aviation Medicine, the City Hospital of Ostrava, the Faculty of Medicine of Ostrava University, the Faculty of Medicine of Charles University in Hradec Kralove, the Cochrane Institute Czech Republic, The Czech Republic (Middle European) Centre for Evidence-Based Healthcare: The Joanna Briggs Institute Centre of Excellence, the Masaryk University GRADE Centre, DAN Europe, and others.

Hyperbaric medicine has a long tradition in Czech Republic and in 2020 it will be 55 years since this field of medicine in this country has been established.

Prague is the capital and largest city in the Czech Republic, the fourteenth largest city in the EU and the historical capital of Bohemia. The city is home to about 1.3 million people, while its metropolitan area is estimated to have a population of 2.6 million. Prague has been a political, cultural and economic centre of central Europe complete with a rich history. It was founded during the Romanesque and flourishing by the Gothic, Renaissance and Baroque eras. Prague was the capital of the kingdom of Bohemia and the main residence of several Holy Roman Emperors, most notably of Charles IV (1346–1378). It is located in the centre of the European continent, with direct air links from most European capitals and direct air connection from Frankfurt a. Main, Germany, for connecting to overseas flights to other continents.

Please register in time, to benefit from the early registration rate. Also, favorable airfares are dependent on early booking and hotel accommodation tends to be in high demand. Please submit your Abstracts too, as your input is an important part of the success of our annual meeting.

Every year, EUBS ExCom supports young scientists by awarding Student Travel Grants and other awards. You can find all information on the conditions and application process on the conference website and also on the EUBS website. Save the date! Prague, 16–19 September 2020

For more information visit the websites
https://eubs2020.com/ or https://www.eubs.org/

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). Candidates will be presented by the Executive Committee by June 2020, and the voting will be by internet ballot, starting on 30 June 2020. If you want to contribute and help our society, please come forward and send your short CV to our secretary secretary@eubs.org.

This year, we require a new Member-at-Large. If you do not feel that this is for you, why not nominate someone else? Suggestions are welcome at the same email address.

EUBS Affiliate Society agreements

For 2020, an 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 worldwide. Members of these societies benefit from a 10% reduction in the EUBS membership fees, when providing proof of their membership of the 'other' society. Simply indicate the affiliate society on the EUBS membership application or renewal form.

Belgian Society for Diving and Hyperbaric Medicine
http://www.sbmhs-bvoog.be
Scott Haldane Foundation, The Netherlands
http://www.scotthaldane.org
Italian Society for Diving and Hyperbaric Medicine
http://www.simsi.it/
German Society for Diving and Underwater Medicine
http://www.gtuem.org
French Society for Diving and Hyperbaric Medicine
http://www.medsubhyp.com
Swiss Society for Underwater and Hyperbaric Medicine
http://www.suhms.org
Undersea and Hyperbaric Medical Society
http://www.uhms.org

Spanish Society for Diving and Hyperbaric Medicine
www.asemhs.org

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 in discussions about new agreements and invite other national societies to contact us in order to expand these affiliate agreements.

Obviously, members of SPUMS already automatically benefit from most of our EUBS membership benefits, such as the DHM Journal, a reduced registration fee for the EUBS Annuals Scientific Meetings and access to the GTÜM Database of non-indexed scientific literature.

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 for 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. Available on this page are logos and links for organizations, societies and companies that support EUBS financially. EUBS is grateful for their continuing support and would suggest that if you contact any of them, please do so by clicking on the link on our Corporate members that page, so they'll know that you did so through the EUBS website.

OXYNET Database to be updated

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

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

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

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

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.

Hyperbaric Oxygen, Karolinska

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

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

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

The EUBS website is at
https://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.

Fifty years of the Dutch Foundation for Diving Research

The Stichting Duik Research, Foundation for diving research (SDR) was founded in Amsterdam, the Netherlands, in 1970. In October 2020 the SDR celebrates their 50th anniversary with a symposium (for the programme, see 'Courses and meetings'). Although SDR is a small non-profit organisation it is run by inspired volunteers and in 50 years many significant activities were undertaken. The SDR started out building a (trans)portable monoplace compression chamber with chest X-ray and hyperbaric oxygen treatment capabilities, designed by Harry van Grol, MEng.

Nico Schellart joined SDR in 1973 when construction had just been completed (see image). After training chamber-operating teams, some 1,000 divers underwent a simulated dive. In the 1970s it was also used for (visual-N2 narcosis) research. Later, a multiplace chamber was acquired from the Dutch salvage company Smith International. Numerous diving clubs experienced dive simulations. In the 1990s many dive computers were introduced where SDR tested dozens of types under a broad range of conditions. Although the majority usually performed to an acceptable standard, some specimens failed miserably. Fortunately quality has improved over the decades. In the 1980s the first open water study (contrast vision at 40 m) was concluded and lasted until the retirement of Nico as Associate Professor in Neurophysics before new open water studies followed.

Some challenged old dogma's in diving medicine, resulting in more nuanced insights and others aimed to shed light on controversial issues. By its statute SDR had to undertake activities to promote dive safety such as education. This was realised by organizing advanced courses via Capita Selecta Diving Medicine in the Academic Medical Centre of the University of Amsterdam and some dive locations abroad. For more information about SDR, its publications and programmes please see http://www.duikresearch.org/.

Image: Harry (left) and Nico (his successor as President).

ECHM Workshop 2020

The ECHM Workshop on 'New technologies in education and training systems' will be conducted on Wednesday 16 September 2020 as the pre-conference event of the EUBS Conference in Prague, Czech Republic.

More information can be found on both:
EUBS 2020 https://eubs2020.com/
ECHM website http://www.echm.org/

Baltic International Symposium on Diving and Hyperbaric Medicine

The 2nd Baltic International Symposium on Diving and Hyperbaric Medicine (BIS_on_DHM) will take place in Gdynia, Poland, from 04–06 June 2020. There will also be two satellite Masterclasses; one on Advanced Diving Medicine and the other one on Complications in HBOT with a possibility to participate in the Fire Drills inside the hyperbaric chamber, to get wet under pressure!

More information at: http://www.bisdhm.events/

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

Notices and news

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

SPUMS President's message

David Smart

SPUMS Presidents Report April 2020 for AGM

The annual general meeting this year completes my second three year term in my role as SPUMS president. It has been an honour to lead SPUMS, and I hope that my contribution has made a small positive difference to the field of diving and hyperbaric medicine. During my six years as president, I have been very fortunate to work with a very motivated, supportive and competent executive committee. I will not be standing for re-election as president; it is time for some new blood, and fresh ideas. Dr Neil Banham was elected as 'president-elect' at the AGM in the Solomon Islands. He is extremely well qualified to lead SPUMS, as a pioneer in diving and hyperbaric medicine in Western Australia for over 30 years. I wish Neil all the best as president, and will be available to support the transition to the best of my ability.

2020 will be our second general election since adopting our new purposes and rules in 2014, with committee positions up for election for three year terms: Secretary and five general committee members. In 2019, Soon Teoh kindly took over the role of SPUMS treasurer. This has meant that the treasurer position is out of phase with president and secretary, and does not need re-election, having two more years to run. I would regard this as an (accidental) advantage for the corporate knowledge of ExCom.

In addition there are five non-elected members of the executive team: immediate past president (myself), editor in chief of *Diving and Hyperbaric Medicine Journal* (Professor Simon Mitchell), education officer, ANZHMG subcommittee chair and webmaster. The immediate past president changes once a new president assumes the position. The education officer, ANZHMG chair and webmaster will be appointed by the ExCom, following expressions of interest, in the four months after this general election (ANZHMG chair is appointed in August at the ANZHMG AGM). The journal editor is appointed as a separate joint process by DHM publishers, SPUMS and EUBS.

Summary of six years activity as president

A recap of the last six years while I have been president demonstrates that the ExCom has been very active on behalf of members with the following deliverables:

- New *Purposes and Rules* 2014.
- Appointment of a *Journal Governance Committee* to facilitate our joint governance of *Diving and Hyperbaric Medicine Journal* with EUBS.
- Five successful annual scientific meetings ably achieved by excellent conveners and speakers, and a successful TRICON meeting in 2018.
- Movement of SPUMS banking from St George to ANZ.
- Clearly identifying the cost structure of *Diving and Hyperbaric Medicine Journal*, permitting more accurate forward budgeting.
- Complete rebuild of the SPUMS website with concomitant restructuring of processes:
  - Subscriptions and banking linkages to website
  - Revision of membership processes
  - Rationalisation of SPUMS membership database
  - Diving Doctors list
  - Linkages to the SPUMS ASM
  - Commencement of a SPUMS history and archives section
  - Development of processes around SPUMS position statements
  - SPUMS Terms and Conditions of membership
  - SPUMS Governance and essential policies
- The complete rebuilding of the Australian and New Zealand College of Anaesthetists advanced training in diving and hyperbaric medicine led by SPUMS ExCom members (Bennett, Mitchell, Smart and Wilkinson), which was launched in July 2017, as the *Diploma of Advanced Diving and Hyperbaric Medicine*.
- Appointment of a new editor, Professor Simon Mitchell, a world academic leader in diving and hyperbaric medicine.
- Migration of our scientific journal *Diving and Hyperbaric Medicine* to a fully electronic format. This task required incredible amounts of editorial input from Mike Davis and Simon Mitchell, with superhuman efforts from editorial assistant Nicky Telles. The editors were also supported by deputy editor, Lesley Blogg from Europe, and some executive oversight by SPUMS and EUBS ExCom's. After some early challenges, we are now starting to see the potential of the e-journal. This is the beginning, rather than the end of a process, we still have a lot to learn – the cyber world evolves very quickly.
- Establishment of SPUMS finances in a professional accounting package (Xero). This was achieved by Dr Sarah Lockley and her husband Cal Johnson while she was treasurer.
- Appointment of a new treasurer – Dr Soon Teoh. I am extremely grateful to Soon for his willingness to step up and volunteer for the role of treasurer.

- Deeper understanding of SPUMS finances, and what it costs to run SPUMS Inc. SPUMS is in a healthy position financially, but we should not be complacent.
- With my EUBS counterpart Prof Ole Hyldegaard and his EUBS president predecessor, Jacek Kot – editor contracts, journal budgets and deputy editor contracts, and an ongoing memorandum of understanding between the societies.
- I believe we have strengthened our relationship with our EUBS co-publishers.
- Governance of SPUMS – Production of terms and conditions of membership, corporate membership processes, privacy policies, ExCom travel policies and multiple other standard procedures and policies. We have also updated our registration with Copyright Agency Australia.
- As president I have been actively involved in the above issues. Sometimes I have been out of my depth, particularly with IT in recent years. There have been some very steep learning curves.

Future challenges for SPUMS

SPUMS has some future challenges to consider, as I step down and I have listed some of these below:

- Risk management – we need strategies if the editor became incapacitated, and a strategic plan should Nicky Telles become incapacitated.
- Membership numbers and recruitment: SPUMS membership numbers have plateaued at around 440. We need to be around 500 members for long term viability and to cover SPUMS running costs.
- Again, I ask all members to 'recruit a friend'. Don't just leave it to someone else.
- Increasing member attendances at the Annual Scientific meeting – we currently have around 25% of all members attending the ASM – it would be great if it was 50%. Hopefully our 50th Anniversary ASM can attract more members to attend.
- Costs of e-journal, especially cyber security – requires continual monitoring.
- Workload of the SPUMS treasurer – there is a very significant amount of work done to support journal financial transactions and budgeting. This requires greater appreciation by members of the Journal Governance Committee. I consider the dual workload of the SPUMS treasurer to be challenging (for SPUMS and for DHMJ). It is a key position and a key risk for the publishing societies. Without the treasurer's continual input, we stop trading.
- SPUMS membership fees – will need to increase slightly each year. It is my opinion that our current membership fees are a bargain compared to college fees.
- SPUMS diving medical needs a broader overhaul – most recently had update of CVS health risk assessment guidelines, which are about to be published.

In working with ANZCA for the DipAdvDHM, SPUMS members have been afforded status and cooperation, for which we are very grateful. There is now a defined career path for diving and hyperbaric medicine in Australia and New Zealand, which is equal to any in the world. I offer our sincere thanks to ANZCA for the way they have embraced us in the common goal. ANZCA has also recognised the status of the SPUMS DipDHM, incorporating it into their programme. The SPUMS Diploma is now in its 47th year, and a credit to Carl Edmonds and other foundation SPUMS members.

Thank you to all who have supported me during my time as President

I offer my sincere thanks for the long-term support provided by Steve and Sue Goble who have run the SPUMS Administrative Office for decades. To Nicky Telles, I also offer sincere thanks. Nicky has provided amazing expertise in the development and administration of SPUMS website, support for various ExCom members, and for DHMJ. The move to electronic format would not have occurred without Nicky's dedicated work. I express my thanks to the editors of DHM, who I have worked with, Mike Davis and Simon Mitchell. They have produced a world class publication, and it keeps getting better. I offer my thanks to all the member volunteers who have convened and supported our annual scientific meetings over the years.

I will now move into the role of immediate past president. I am stepping into the shoes of Professor Mike Bennett. He completes his time on SPUMS ExCom this year having spent the last 12 years as a committee member – in the role of president and immediate past president. Mike is a giant in the field of diving and hyperbaric medicine. His wisdom, work ethic, wit and perspectives will be missed, and I wish him good health, happiness and great stamina as he pursues other challenges.

I wish to thank my SPUMS ExCom and the broader SPUMS membership for your continued support of SPUMS, and of me personally during my time as president. Without our members, we would not exist. Please encourage your medical colleagues who care about the ocean, to join up! It is great to mix with medical colleagues who share similar interests.

Thank you to my EUBS colleagues as partners in publishing our journal. Our relationship is cooperative, supportive and growing positively. I am optimistic for our future as publishers.

I also express my sadness, during the last 12 months we have lost members Carl Edmonds and Fiona Sharp. They were good friends of mine and I share everyone's sense of loss in their parting.

SPUMS advocacy for the marine environment

The ocean is a key to the future of the planet, covering 71% of earth. At present it is acting as a heat sink, ameliorating potential rises in global temperature. In 49 years of SPUMS – human population has increased from 3.7 billion to 7.8 billion. Atmospheric CO_2 levels have risen from 325 PPM to 413. Humanity has wiped out up to 60% of all mammals, birds, fish and reptiles and vast tracts of land have been cleared. There are simply too many humans on the planet, and too much plastic. Targets of 2°C rise in average global temperature are frightening. How *do you feel* if you have a fever of 39 °C? Biological organisms just don't cope when rapidly pushed to limits outside their evolved temperature range.

I strongly believe that SPUMS must take on a future role with vigorous advocacy for the underwater environment. In the song, 'A horse with no name', by the group 'America', the lyrics describe; "*the ocean is a desert with its life underground and the perfect disguise up above*." That perfect disguise has led to its neglect and far less groups advocating for the undersea environment. Political 'green' lobbying is frequently land based and stops at the water's edge. We need to add SPUMS to the voices speaking up for the oceans and synergise with other groups who also lobby on behalf of the marine environment.

Diving doctors have a unique and expert perspective – we have experienced the undersea environment and we are health experts as physicians. We also understand the human health impacts of a sick marine environment.

***Corona virus* COVID-19 pandemic and SPUMS Annual Scientific Meetings 2020 and 2021**

My first draft of this president's report flagged the impact of corona virus as a potential issue. This issue is now real and beyond anything any of us have experienced. With great regret, on March 12th, SPUMS ExCom took the unprecedented step of cancelling the 2020 Annual Scientific Meeting in Tutukaka New Zealand. We express our sincere gratitude to Greg, Kate, Xavier and Hanna for their enormous commitment in putting together the programme, accommodation, venue, logistics and practical workshops. Thanks also to our registered delegates and conference speakers. There will be communications in due course from the 2020 convener regarding refunds. I do ask that all delegates are respectful of Greg, because not all funds can be recovered at this late stage, due to non-refundable costs already paid to run the conference.

SPUMS still needs to hold its 2020 Annual General Meeting. It is likely that we will need to do this using electronic media. Once the process is decided by ExCom, SPUMS Secretary Douglas Falconer will be in touch with all members.

As an added blow, the 2021 50th anniversary conference (for which I am convener), is not viable in the current climate of uncertainty. I thank Simon Mallender for his professional assistance with the 2021 ASM initial planning. At this point everything is on hold for both conferences and members need to wait as this global emergency unfolds. SPUMS ExCom has voted to postpone both conferences by a minimum of one year, until the risk posed by the virus returns to acceptable levels. We can only hope that the impact of the virus will be over in the near future.

Thank you to everyone for your continued support of SPUMS. We are part of a very special society. Stay safe, resilient and most of all, take care of your loved ones, colleagues and friends.

Clinical Professor David Smart
Hon President SPUMS

Key words
Medical Society, Membership, Diving, Environment, Ecology, Ocean Health; *Corona virus* COVID-19

Royal Australian Navy Medical Officers' Underwater Medicine Course 2020

Venue: HMAS Penguin, Sydney

Date: 19–30 October 2020 (these dates are yet to be confirmed)

The MOUM course seeks to provide the medical practitioner with an understanding of the range of potential medical problems faced by divers. Emphasis is placed on the contraindications to diving and the diving medical assessment, together with the pathophysiology, diagnosis and management of common diving-related illnesses. The course includes scenario-based simulation focusing on the management of diving emergencies and workshops covering the key components of the diving medical.

Cost: AUD$1,355.00 without accommodation (TBC with accommodation and meals at HMAS Penguin).

For information and application forms contact:
Rajeev Karekar, for Officer in Charge
rajeev.karekar@defence.gov.au

Celebrate 50 Years
South Pacific Underwater Medicine Society
Preliminary Notice
Annual Scientific Meeting
Save the dates 16–21 May 2021

Labuan Bajo (Komodo) Indonesia

SPUMS for the future:
Integration of diver health and ocean health.
Medical collaboration with marine science.

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 http://www.anzca.edu.au/training/diving-and-hyperbaric-medicine.

Training
Documents to be found at this site are:

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

Examination dates for 2020
Viva examination: 09 September 2020

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.

Carl Edmonds Memorial Scholarship

The Australasian Diving Safety Foundation is delighted to announce the release of a new Diving Medical Officers Training scholarship to honour the memory of Carl Edmonds, a Founder of SPUMS and a mentor to diving physicians throughout the world. The AUD$5,000 scholarship is to encourage doctors to attend a Royal Australian Navy Underwater Medicine Course at the School of Underwater Medicine in Sydney. One scholarship is available for each course, two of which are planned for 2020.

Application details are available at:
http://adsf.org.au/grants/scholarships/diving-medical-training

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: www.nhmrc.gov.au/_files_nhmrc/publications/attachments/r39.pdf, or the equivalent requirement of the country in which the research is conducted. All research involving humans, including case series, or animals must be accompanied by documentary evidence of approval by an appropriate research ethics committee. Human studies must comply with the Declaration of Helsinki (1975, revised 2013). Clinical trials commenced after 2011 must have been registered at a recognised trial registry site such as the Australia and New Zealand Clinical Trials Registry http://www.anzctr.org.au/ and details of the registration provided in the accompanying letter. Studies using animals must comply with National Health and Medical Research Council Guidelines or their equivalent in the country in which the work was conducted.

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

Projects will be deemed to have lapsed if:

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

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

The Academic Board reserves the right to modify any of these requirements from time to time. As of January 2016, the SPUMS Academic Board consists of:

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

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

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

Courses and meetings

Capita Selecta Diving Medicine

The Capita Selecta Diving Medicine of the University of Amsterdam annually offers symposia presented by internationally renowned speakers to a multinational audience of diving physicians, paramedics and highly educated instructors. The level is advanced (1 and 2d) and often beyond that. All lectures are in English.

2020 is a year of transition. Dr Nico Schellart will step down as director in 2021 and the regular Capita Selecta in Amsterdam will by continued under the directorship of Dr Bernadette de Bakker, MD.

Date: 09–16 May 2020
Venue: Marsa Shagra, Marsa Alam, Egypt
The Ageing Diver
Topics: Ageing of the cardiac, pulmonary, neuro-muscular and sensory systems and the brain; their effects on diving safety and the consequences for the medical exam of older divers. 6 cp.

Date: Saturday 31 October 2020
Venue: AMC, Amsterdam
Symposium to celebrate the 50 years anniversary of the Dutch Stichting Duik Research (SDR, Foundation of Diving Research)
Topics: 50 years research by SDR, diving cardiology, safety of professional diving; diving to perform coral biotope research and open sea under water archaeology, physiological adaptations of diving mammals. 4 cp.

Visit: http://www.duikresearch.org/
For more information: n.a.schellart@amsterdamumc.nl

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

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

Scott Haldane Foundation

As an institute dedicated to education in diving medicine, the Scott Haldane Foundation (SHF) has organized more than 290 courses all over the world, over the past 25 years. SHF is targeting more and more of an international audience with courses worldwide. Below are the upcoming SHF courses in 2020.

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).

2020

27–28 March	Medical Examiner of Divers part 1, Zeist, NL
02–04 April	Medical Examiner of Divers part 2. Amsterdam Univ. Med. Centre, NL
17–18 April	In-depth course Decompression, Recompression and HBOT (Level 2d) Mil. Hospital, Brussels, Belgium
22–23 April	Internship different types of diving (2d) Royal Dutch Navy, Den Helder, NL
09–16 May	Medical Examiner of Divers part 2 Bonaire
12–13 June	In-depth course Diving with your heart (2d) Driebergen, NL
On request	Internship HBOT (level 2d certification) NL/Belgium

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

Hyperbaric oxygen lectures

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

German Society for Diving and Hyperbaric Medicine (GTÜM)

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

Diving and Hyperbaric Medicine: Instructions for Authors (summary)

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

Address: The Editor, Department of Anaesthesiology, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand
Email: editor@dhmjournal.com
Mobile: +64 (0)27 414 1212
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 word count); structure of the article and abstract is at the author(s)' discretion.

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

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

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

Formatting of manuscripts

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

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

- Instructions for authors 2020 (full version)
- DHM Key words 2019
- DHM Mandatory Submission Form 2020
- Trial design analysis and presentation
- EASE participation and conflict of interest statement
- English as a second language
- Guideline to authorship in DHM 2015
- Helsinki Declaration revised 2013
- Is ethics approval needed?

DIVER EMERGENCY SERVICES PHONE NUMBERS

AUSTRALIA – DAN
1800-088200 (in Australia toll free)
+61-3-7018 3076 (International)

NEW ZEALAND – NZUA
0800-4DES-111 (in New Zealand toll free)
+64-9-445-8454 (International)

JAPAN – DAN
+81-3-3812-4999 (Japan)

EUROPE – DAN
+39-6-4211-8685 (24-hour hotline)

UNITED KINGDOM
+44-7740-251-635

AFRICA – DAN
0800-020111 (in South Africa toll free)
+27-828-106010 (International call collect)

USA – DAN
+1-919-684-9111

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 enroll in the chosen course, then complete the relevant ADSF Scholarship application form available at: http://adsf.org.au/grants/scholarships/diving-medical-training 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.