Diving and Hyperbaric Medicine

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

SPUMS

Volume 46 No. 3 September 2016

EUBS

Diving with insulin-dependent diabetes

Your wetsuit alters pulmonary mechanics

Deaths in American caves and in Scandinavian waters

Intensive care HBOT – safe transfers to a stand-alone unit

General anaesthesia improves Eustachian tube compliance

Sudden deafness – does HBOT help?

Bubble counts in ischaemia-conditioned rats

Print Post Approved PP 100007612

ISSN 1833-3516, ABN 29 299 823 713

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

---

DIVING AND HYPERBARIC MEDICINE

<www.dhmjournal.com>

Editor:
Michael Davis <editor@dhmjournal.com>
PO Box 35
Tai Tapu 7645
New Zealand
Phone: +64-(0)3-329-6857

European (Deputy) Editor:
Lesley Blogg <euroeditor@dhmjournal.com>
Editorial Assistant:
Nicky Telles <editorialassist@dhmjournal.com>
Journal distribution:
Steve Goble <admin@spums.org.au>

Journal submissions:
Submissions should be made at http://www.manuscriptmanager.com/dhm

Diving and Hyperbaric Medicine **is published jointly by the South Pacific Underwater Medicine Society and the European Underwater and Baromedical Society (ISSN 1833-3516, ABN 29 299 823 713)**

Editorial

Poorly designed research does not help clarify the role of hyperbaric oxygen in the treatment of chronic diabetic foot ulcers

Diabetic foot ulcers (DFUs) are one of the most common indications for hyperbaric oxygen treatment (HBOT). The role of HBOT in DFUs is often debated. Recent evidence-based guidelines, while recommending its use, urge further studies to identify the patient subgroups most likely to benefit from HBOT.[1] A recent study in *Diabetes Care* aimed to assess the efficacy of HBOT in reducing the need for major amputation and improving wound healing in patients with chronic DFUs.[2] In this study, patients with Wagner grade 2–4 diabetic foot lesions[3] were randomly assigned to have HBOT (30 sessions/90 min/244 kPa) or sham treatment (30 sessions/90 min/air/125 kPa). Six weeks after the completion of treatment (12 weeks after randomization) neither the fulfillment of major amputation criteria (11/49 vs. 13/54, odds ratio 0.91 [95% CI 0.37, 2.28], $P = 0.846$) nor wound-healing rates (20% vs. 22%, 0.90 [0.35, 2.31], $P = 0.823$) significantly differed between groups. The authors concluded that HBOT does not offer any additional advantage over comprehensive wound care.

Since this paper was published in *Diabetes Care*, one of the most prestigious diabetes journals, it is likely it will have a major impact on the clinical practice of many physicians dealing with diabetic foot problems. Although from a methodological standpoint the conduct of the study (prospective, double-blind, randomized, controlled) seems to be close to ideal, several significant flaws render the conclusions weak.

Firstly, there were some problems with the assessment of the primary outcome of "*meeting the criteria for amputation*". In their published protocol paper,[4] the triallists indicated that "*At the end of the 6-week follow-up phase……, the patient is sent to the participating vascular surgeon for an amputation evaluation*". However, in the published report in *Diabetes Care*, it is evident that patients were not assessed in a face-to-face consultation, but rather by the remote examination of wound photographs and clinical data "*Participant clinical data together with digital photographs of the study wound progress were presented to the vascular surgeon*". This departure from the original intent undermines the primary outcome of the study significantly. Fedorko et al claim this method of assessment has been validated, but neither of their supporting citations appear to substantiate this claim.[5,6]

Wirthlin et al assessed the level of agreement about a collection of wounds between surgeons who were present at the bedside and a remote group who assessed the wounds using a short clinical account and digital photography.[5] There was reasonable agreement between onsite and remote, although the specificity for particular signs ranged from just 27% (erythema) to 100% (ischaemia). Importantly, only a subset of eight of the 24 included patients had non-healing wounds and the proportion of those that were associated with diabetes mellitus is unknown. Further, the need for amputation was not among the management decisions examined. Wirthlin et al concluded "*a prospective trial of remote wound management …. is needed to further validate this technology.*"

The authors of the second supposedly supporting citation were mainly interested in the assessment of pressure ulcers by digital photography using the Photographic Wound Assessment Tool (PWAT) compared to the Pressure Sore Status Tool (PSST).[6] Of the 81 included lower leg ulcers, it is not clear how many were associated with diabetes mellitus. Indications for amputation were not considered. The authors concluded "*The PWAT may be valuable when a bedside assessment cannot be made. However, the size of circular wounds, wound depth, undermining/tunneling, and odor cannot be assessed using photographs.*"

In the Fedorko paper, the decision that there was an indication for amputation was made by the remote vascular surgeon by meeting any of the following criteria: "*persistent deep infection involving bone and tendons (antibiotics required, hospitalization required, pathogen involved); ongoing risk of severe systemic infection related to the wound; inability to bear weight on the affected limb; or pain causing significant disability*".[2] We are particularly concerned that the criteria, "*persistent deep infection involving bone and tendons*", is subjective. Recent studies have demonstrated that diabetic foot osteomyelitis may not necessarily require amputation and some cases may be cured with antibiotic therapy alone.[1] It is interesting to note that despite the high numbers of participants assessed as fitting the requirements for amputation (23% overall), no patient actually had a major amputation. The amputation outcome is inappropriately assessed, done at the wrong time, and the study is grossly underpowered to find any difference in the rate of true major amputation. Finally, whether the surgeon performed a baseline assessment of amputation prior to the randomised intervention is unknown. A comparison between the pre- and post-study estimates of amputation rates could have contributed to the interpretation of the results.

Secondly, the authors fail to provide a clear comparison of peripheral arterial disease (PAD) between the groups. Although patients were randomized and those who were possible candidates for major vessel revascularization were excluded from the study, microvascular status was not assessed. No transcutaneous oxygen measurements were made on any of the patients. Given that, firstly, the risk of microvascular vessel compromise increases with

diabetes duration, and secondly, transcutaneous oxygen measurements correlate with the possibility of good response to HBOT,[7] it is possible that clinically significant differences between groups were undetected. As an example, patients in the HBOT group had a markedly longer mean duration of diabetes (19.1 vs. 12.4 years) and would be likely to have more severe microvascular disease.

Thirdly, the follow-up period of six weeks after completion of treatment is very short. The study to which the authors refer to justify this follow-up period enrolled only patients with ulcers of Wagner grade 1 or 2 and specifically excluded patients with infection or ischaemia.[8] These are not representative of the patient population treated with HBOT.[7] The outcomes in patients with DFUs treated with HBOT should be assessed over a longer period. One such randomized controlled study demonstrated that patients receiving HBOT had significantly higher healing rates than placebo at one-year follow-up (25/48 (52%) versus 12/42 (29%); $P < 0.03$), but not at 12 weeks.[9]

Fourthly, the authors also failed to describe the experience of the vascular surgeon who adjudicated the wounds for amputation; how many years he was involved in the management of diabetic foot wounds or how specialized his practice was with these patients. Objective and universally recognized indications for amputation are yet to be established. Therefore, a multidisciplinary decision-making approach, rather than a single physician's decision, would have increased the credibility of the conclusion the authors reached. Notably, all previous studies of HBOT in this area have used actual amputation rates in order to have a clear clinical endpoint.

Careful patient selection is paramount for the cost-effective use of HBOT as an adjunct to normal wound care in diabetic wounds. As it is possible to identify wounds that have no potential to heal despite HBOT, all studies should incorporate transcutaneous oxygen measurements in their baseline evaluation. As the wounds in this study tended to be small (6.1cm² and 5.8cm² on average) and had persisted for (on average) one year despite state-of-the-art previous wound care, it is likely that at least some of these would not meet the predictive minimal criteria for healing potential with HBOT.[7]

The findings of this study do indeed show that the indiscriminate treatment of all diabetic wounds with HBOT is probably not (cost-) effective; however, the study conclusion that "*HBO has no benefit in the treatment of chronic diabetic foot wounds*" is erroneous.

References

1 Lipsky BA, Aragón-Sánchez J, Diggle M, Embil J, Kono S, Lavery L, et al. International Working Group on the Diabetic Foot. IWGDF guidance on the diagnosis and management of foot infections in persons with diabetes. *Diabetes Metab Res Rev*. 32 Suppl 1:45-74. doi: 10.1002/dmrr.2699.

2 Fedorko L, Bowen JM, Jones W, Oreopoulos G, Goeree R, Hopkins RB, O'Reilly DJ. Hyperbaric oxygen therapy does not reduce indications for amputation in patients with diabetes with non-healing ulcers of the lower limb: a prospective double-blind, randomized controlled clinical trial. *Diabetes Care*. 2016;39:392-9. doi: 10.2337/dc15-2001. Epub 2016 Jan 6.

3 Wagner FW. The dysvascular foot: a system for diagnosis and treatment. *Foot Ankle*. 1981;2:64-122.

4 O'Reilly D, Linden R, Fedorko L, Tarride JE, Jones WG, Bowen JM, Goeree R. A prospective, double-blind, randomized, controlled clinical trial comparing standard wound care with adjunctive hyperbaric oxygen therapy (HBOT) to standard wound care only for the treatment of chronic, non-healing ulcers of the lower limb in patients with diabetes mellitus: a study protocol. *Trials*. 2011;12:69. doi: 10.1186/1745-6215-12-69.

5 Wirthlin DJ, Buradagunta S, Edwards RA, Brewster DC, Cambria RP, Gertler JP, et al. Telemedicine in vascular surgery: feasibility of digital imaging for remote management of wounds. *J Vasc Surg*. 1998;27:1089-99; discussion 1099-100.

6 Houghton PE, Kincaid CB, Campbell KE, Woodbury MG, Keast DH. Photographic assessment of the appearance of chronic pressure and leg ulcers. *Ostomy Wound Manage*. 2000;46:20-6, 28-30.

7 Fife CE, Cakir CB, Otto GH, Sheffield PJ, Warriner RA, Love TL, Mader J. The predictive value of transcutaneous oxygen tension measurement in diabetic lower extremity wounds treated with hyperbaric oxygen therapy: a retrospective analysis of 1144 patients. *Wound Rep Reg*. 2002;10:198-207.

8 Sheehan P, Jones P, Caselli A, Giurini JM, Veves A. Percent change in wound area of diabetic foot ulcers over a 4-week period is a robust predictor of complete healing in a 12-week prospective trial. *Diabetes Care*. 2003;26:1879-82.

9 Löndahl M, Katzman P, Nilsson A, Hammarlund C. Hyperbaric oxygen therapy facilitates healing of chronic foot ulcers in patients with diabetes. *Diabetes Care*. 2010;33:998-1003.

Mesut Mutluoglu[1], Gunalp Uzun[2], Michael Bennett[3], Peter Germonpré[4], David Smart[5] and Daniel Mathieu[6]

[1] Associate Professor, Department of Underwater and Hyperbaric Medicine, GATA Haydarpasa Teaching Hospital, Istanbul, Turkey
[2] Professor, Department of Underwater and Hyperbaric Medicine, GATA Ankara, Turkey
[3] Professor, Anaesthesia, Diving and Hyperbaric Medicine, University of New South Wales, Australia
[4] Centre for Hyperbaric Oxygen Therapy, Military Hospital Brussels, Belgium
[5] Clinical Professor, Medical Co-director and Senior Visiting Specialist, Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, Tasmania, Australia
[6] Professor, Centre d'oxygenotherapie hyperbare, Hopital Roger Salengro, CHU Lille, Lille, France

drmutluoglu@gmail.com

Key words
Hyperbaric research; chronic wounds; diabetes; evidence; outcome; editorial

The Editor's offering

Diabetic foot ulcers

A report on the management of diabetic foot ulcers (DFUs) has been released recently by the Agency for Healthcare Research and Quality through the National Guideline Clearinghouse based on a paper by the Society for Vascular Surgery in collaboration with the American Podiatric Medical Association and the Society for Vascular Medicine.[1] Using the Grades of Recommendation Assessment, Development and Evaluation (GRADE) system, five systematic reviews focused on (1) prevention of diabetic foot ulceration, (2) off-loading, (3) diagnosis of osteomyelitis, (4) wound care, and (5) peripheral arterial disease. In the wound-care section, amongst additional therapies recommended for poorly healing DFUs (< 50% wound area reduction after a minimum of four weeks of standard wound therapy) hyperbaric oxygen treatment (HBOT) is listed with an evidence level 2B (2B in the GRADE system states "*RCTs with important limitations (inconsistent results, methodologic flaws, indirect, or imprecise) or exceptionally strong evidence from observational studies)*".

Professor Michael Bennett commented on the Australian and New Zealand Hyperbaric Medicine Group (ANZHMG) chatline "*this looks a good summary of where we are with* [DFUs]." Much work is needed yet to demonstrate the role of HBOT in DFU, despite the ethical challenges for most hyperbaric physicians who would have to care for patients in a clinical study where one arm does not include HBOT.

Scuba diving fatalities

In this issue Vinkel et al[2] comment that "*Of the 25 divers who were known to use weights, only two ditched their weights during the course of the diving incident. Through careful review of these cases, it is thought that in 21 cases the odds of survival would have been enhanced if the diver had dropped their weights, improving the probability of reaching the surface alive"* and *"establishing positive buoyancy by the release of weight underwater is a mandatory element in dive training because it can be a critical response to threatening circumstances*".

Establishing positive buoyancy is the one action that more than any other can save a diver's life, if only divers (or their buddies, if they have one) who get into trouble would do this. In reviewing the Danish deaths, Australian fatalities papers from 2006 to 2010[3] and NZ deaths between 1980 and 2000,[4] of 67 divers in whom the individual report documents whether or not the weight belt was dropped by the diver, 51 (76%) were still wearing it when their bodies were recovered. Further, in a paper on 40 NZ fatalities from 2000 to 2006,[5] it is stated that "*there was no definite history of weight-belt release by any diver, although one scuba diver had possibly dropped his weight belt.*"

This is a feature of every published series of scuba diving fatalities that I have read and has been remarked on by many investigators. This is the message that I wish to emphasise – divers do NOT ditch their weight belt in an emergency.

This reflects a failure of current teaching methods by the dive training agencies and it is time that they reconsidered how this aspect of emergency training is taught and emphasised during their courses. I believe that it could/should be a component repeated in every single skills course and at every level subsequent to basic Open Water, including instructor courses. It needs to be repeated time and time again if such a potentially life-saving action is to become a properly learned response to a major incident underwater or on the surface. The data have been there for all to see for many years. How the agencies resolve this problem needs their close attention. I challenge them that it is time to rethink this component of diver training.

Having mentioned the ANZHMG chatline, physicians working in hyperbaric units may apply to join the group by e-mailing <M.Bennett@unsw.edu.au> or applying online at Yahoo groups – search for 'anzhmg'. The group discusses a wide range of issues and anonymous problem cases (the principal discussant having obtained patient permission) and insights from our colleagues are welcome.

References

1 Hingorani A, LaMuraglia GM, Henke P, Meissner MH, Loretz L, Zinszer KM, et al. The management of diabetic foot: a clinical practice guideline by the Society for Vascular Surgery in collaboration with the American Podiatric Medical Association and the Society for Vascular Medicine. *J Vasc Surg*. 2016;63(Suppl):3S-21S.

2 Vinkel J, Bak P, Hyldegaard O. Danish diving-related fatalities 1999–2012. *Diving Hyperb Med*. 2016;46:142-9.

3 Lippmann J, Lawrence CL, Wodak T, Fock A, Jamieson S, Walker D, Harris R. Provisional report on diving-related fatalities in Australian waters 2010. *Diving Hyperb Med*. 2015;45:154-75.

4 Davis M, Warner M, Ward B. Snorkelling and scuba diving deaths in New Zealand, 1980-2000. *SPUMS Journal*. 2002;32(2):70-80.

5 McClelland A. Diving-related deaths in New Zealand 2000-2006. *Diving Hyperb Med*. 2007;37:174-8.

Michael Davis

Key words
Chronic wounds; diabetes; diving deaths; buoyancy; evidence; editorials

---

Frontpage photo of Rebecca Johnson, showing her blood glucose monitor before a dive in Western Australia, was taken by Rebecca Tunks.

Read Ms. Johnson's articles in this issue.

The Presidents' pages

David Smart, President SPUMS

SPUMS taking the lead via Position Statements

SPUMS has prided itself as a leader in the diving and hyperbaric medicine field for over 40 years. As a scientific society, we also regard ourselves as progressive, moving with evolving information and applying available knowledge to maintain safety in the diving industry, and to facilitate innovation. One method of succinctly summarising a body of knowledge and expert opinion is through publication of position statements. A recent example was the joint position statement with the United Kingdom Sports Diving Medical Committee on persistent (patent) foramen ovale and diving, published last year.[1]

SPUMS position statements summarise where SPUMS stands on issues that relate to diving and hyperbaric medicine. The position statements are published in *Diving and Hyperbaric Medicine* (DHM) from time to time and are produced as a result of targeted workshops, or commissioned reviews by SPUMS members. Where a position statement relates to hyperbaric oxygen treatment, the document may be prepared by members of the Australian and New Zealand Hyperbaric Medicine Group, a subcommittee of SPUMS. The position statements are produced after assessment of the latest available literature and reflect what is considered to be best practice at the time of publication. It is expected that the documents are publicly accessible, and when well written, greatly assist practitioners to apply the knowledge in practice. It can be a challenge keeping these statements up to date and relevant, particularly for a volunteer organisation such as SPUMS. The challenge can be even greater if the position statements of another organisation are in conflict with those developed by SPUMS.

The article by Johnson in this issue highlights the recreational diver with diabetes, and inconsistency between the positions of the Australian Diabetes Society and SPUMS.[2] In the modern era, SPUMS has brought its medical assessment of prospective divers with diabetes in line with the DAN/UHMS guidelines, recognising that with appropriate risk mitigation strategies it is possible for suitable individuals with stable diabetes to dive safely. At the 2015 SPUMS ASM in Palau, a workshop was held with multiple presentations about diving and diabetes, and to which Johnson contributed. It was anticipated that following the workshop, the SPUMS position statement on diabetes and diving would be updated and made consistent with the dive medical. At this point our organisation is yet to publish such a document.

During the last 12 months, a complete rebuild of the SPUMS website has taken place and should have gone live by the time you read this, with improved functionality, searchability and security. The new structure will allow improved passage of corporate memory in secure members-only and executive sections. As an organisation, we will be better placed for the future to use the website as a platform for public education, through an improved front end.

The website will have a structure for position statements to be available in a public area of the website, so they can be accessed by interested individuals, organisations and doctors. In my opinion, all SPUMS position statements and other public documents should first be published in DHM, so they are searchable, even if the interested party knows nothing about SPUMS. As published documents, they will be clearly stamped with the date of publication, drawing awareness to the currency (or otherwise) of the document. Some SPUMS members have been working with the Australian Diabetes Association to update their position statement; however, progress has been slow. This process will require further initiatives to be taken by SPUMS. Hopefully, one of the first additions to the new SPUMS website will be a position statement on diabetes and diving.

References

1 Smart D, Mitchell S, Wilmshurst P, Turner M, Banham N. Joint position statement on persistent foramen ovale (PFO) and diving. South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Sports Diving Medical Committee (UKSDMC). *Diving Hyperb Med*. 2015;45:129-31.

2 Johnson R. Insulin-dependent diabetes mellitus and recreational scuba diving. *Diving Hyperb Med*. 2016;46:54-6.

president@spums.org.au

Key words
Medical society; diabetes; fitness to dive; general interest

The SPUMS website is at **<www.spums.org.au>**

A completely new, much improved website is about to be launched

(This has been delayed owing to the time needed to organise the membership payment aspects of the site)

Jacek Kot, President EUBS

This year our Society will have its 45th anniversary. This is not sufficiently notable to celebrate too much, but being in the middle of a decade it is worthwhile to look back and see how it projects into the near future. Since the foundation of the EUBS in 1971, every member involved in its activities has seen hyperbaric oxygen treatment (HBOT) used in various ways and for a variety of indications in medicine and faced different attitudes of other physicians and health care decision makers to this modality of treatment. In the past, hyperbaric medicine has been used either as a "*remedy for every illness*", or as a "*therapy in search of a disease*" or some kind of alternative or fringe medicine.

In April 2016, a revised set of clinical indications for HBOT was discussed and presented during the European Committee for Hyperbaric Medicine (ECHM) Consensus Conference in Lille, France. The preliminary report has been published in DHM.[1] Whilst still awaiting the final report, it must be noted that the methodology used at this consensus meeting was based on a thorough review of the best available research and evidence-based medicine (EBM) with extensive use of the scientifically approved methods of the modified GRADE system for evidence analysis, together with the DELPHI system for consensus evaluation. The conclusions reached are in striking agreement with those presented several years ago by the US-based Undersea and Hyperbaric Medical Society (UHMS), also based on EBM.[2] This is so, despite the detailed scientific methods used to achieve the final UHMS recommendations differing slightly from those used by the ECHM; in particular, not using the DELPHI system for reaching consensus in those diseases and conditions where EBM was not able to provide the basis for strong recommendations.

Sadly in some countries around the world, these recommendations, published by the scientists and clinical experts involved, are not perceived as reliable enough to accept HBOT as an approved therapy in various diseases and conditions. For example in the United Kingdom, HBOT has been re-approved recently by the National Health Service only for the treatment of decompression sickness and arterial gas embolism and not for any other indications, including selected cases of hypoxic diabetic foot lesions or severe anaerobic infections.[3]

Ironically, as reported, this decision was made based on the same reports and publications which were used by the ECHM and UHMS. How is it possible that the same evidence allows for such far-reaching differences in conclusions? Is it still medicine based on facts, or are we turning the clock back to opinion-based medicine, like in the past? Is it simply a convenient, but poorly-judged economic decision? I do not dare to discuss this problem in any more detail in this short message but, rather, I wished to draw your attention to this situation, as this could happen in any country; as indeed it has, such as in Germany and to some degree in Australia. It shows how fragile science is and how much its perception depends on the biases of the recipient and how much effort we need to put into convincing others of the proper use of HBOT.

Any such local or temporary policy is a threat to hyperbaric medicine in general. Therefore, we must always keep in mind our main goal which is to practice medicine on the basis of scientific research on the mechanisms of HBOT and EBM. The next opportunity to achieve these goals is the forthcoming Annual Scientific Meeting of the EUBS to be held in Geneva, Switzerland in September. It is our professional obligation to share our data and to discuss results of our studies. I hope to meet all of you there.

References

1 Mathieu D, Marroni A, Kot J. Tenth European Consensus Conference on Hyperbaric Medicine: preliminary report. *Diving Hyperb Med*. 2016;46:122-3.

2 Weaver L, editor. *Hyperbaric oxygen therapy indications*, 13th ed. Durham, NC: Undersea and Hyperbaric Medical Society; 2014. ISBN: 978-1930536-73-9.

3 Specialised Services Clinical Commissioning Policies and Service Specification – 11th Wave. *Hyperbaric oxygen therapy*. Redditch: National Health Service, UK; June 2016. [cited 2016 August 01]. Available at: https://www.engage.england.nhs.uk/consultation/clinical-commissioning-wave11.

jacek.kot@eubs.org

Key words
Medical society; hyperbaric medicine; policy; general interest

---

Journal articles

Influence of the diving wetsuit on standard spirometry

Nico AM Schellart and Wouter Sterk

Abstract

(Schellart NAM, Sterk W. Influence of the diving wetsuit on standard spirometry. *Diving and Hyperbaric Medicine*. 2016 September;46(3):138-141.)

Introduction: A well-fitting wetsuit exerts a pressure on the body that may influence spirometry. This pressure is expected to reduce the forced vital capacity (FVC) due to hampered inspiration. Since the shape of the spirometric flow curve should not be changed by the pressure effects of the wetsuits, FVC, the forced expiratory volume during the first second of expiration (FEV_1), the peak expiratory flow (PEF) and the flow between 25 and 75% of FVC ($FEF_{25–75}$) should change to the same degree. This study investigates the influence of a wetsuit on spirometric variables using age, suit thickness and suit type as the parameters.

Methods: Spirometry (dry) was performed in 28 volunteers (12 women), aged 27–69 years.

Results: The wetsuit (3.8 mm, range 2–7 mm) resulted in a change in FVC of -4.0% ($P = 2{\cdot}E{-}08 < 0.001$), in FEV_1 of -3.6% ($P = 3{\cdot}E{-}05 < 0.001$) and in PEF of -2.4% ($P = 0.03$); the $FEF_{25–75}$ may also diminish. The FEV_1/FVC ratio did not change. The decreases can be regarded as a quasi-ageing effect of about 3.5 years. No influence of age, suit thickness and suit type was found.

Conclusion: The wetsuit appears to impair ventilatory mechanics. Both the medical examiner and the diver should be aware that a too-thick or too-tight suit might be a potential pulmonary risk factor in diving.

Key words

Lung function; pulmonary function; age; risk factors

Introduction

A variety of factors may affect respiratory mechanics when diving. In addition to factors related to the underwater environment (gas density, hydrostatic forces on the body, etc.), the artificial breathing source and other equipment,[1] an effect of a diving wetsuit may be expected. The wetsuit, particularly when tight, increases central vascular volume,[2] and is thought to be a factor in swimming-induced pulmonary oedema in triathletes due to the assumed increased cardiac pre-load of immersion.[3,4] In addition to blood redistribution, hydrostatic pressure differences over the body result in considerable shifts in fluid and electrolyte balance.[5] Similarly, the compression effect of a wetsuit may also change fluid and electrolyte homeostasis. A wetsuit of 5 mm produces an interface pressure between the suit and skin of about 0.034 bar (= 34 cm water).[5] This value is independent of immersion and diving depth, since the elastic recoil tension of the suit is not depth-dependant.[5] All these factors are likely to affect pulmonary mechanics.

The force exerted by the suit will diminish the forced inspired volume (FIV) and, consequently, the forced vital capacity (FVC). This restrictive effect is the assumed underlying mechanism of the suit effect. It is reported that chest wall strapping can decrease spirometric volumes and capacities by 15–50%.[6]

The standard spirogram (here, only expiration is considered) is defined as the (dV/dt)/V diagram. When the (dV/dt)/V curve is changed by a constant (along the vertical axis) due to some condition, such as fatigue, the flow changes with the same factor and the curve retains its shape. As a result, FVC, the forced expiratory volume during the first second of expiration (FEV_1), the flow between 25 and 75% of FVC ($FEF_{25–75}$) and the peak expiratory flow (PEF) will change by the same factor and, consequently, the FEV_1/FVC ratio will remain the same. We assume that this shape invariance also applies to the wetsuit.

The pressure effect of a tight and/or very thick wetsuit (e.g., 16 mm thick) will seriously affect spirometric volume and flow characteristics and, during diving, also the (sub) maximal RMVs (respiratory minute volumes), whereas a 2 mm neoprene T-shirt will result in a much smaller effect. In general, with increasing age, the ability to cope with physical stress (e.g., thermal stress, dehydration) diminishes. This implies that when a constant load is increased by a small amount, this increase is harder for older persons to cope with than younger persons. An indication of this in older subjects has been described in a pulmonary exercise study.[7] Therefore, increasing age may increase the wetsuit effect.

In view of these data and assumptions, the present study investigates the effect of the wetsuit on spirometric values in recreational divers by testing the following hypotheses:

1. FVC decreases when wearing a wetsuit ('in-suit').
2. FVC, FEV_1, FEF_{25-75} and PEF decrease with the same factor when in-suit.
3. FEV_1/FVC does not change.

4. All effects increase with suit thickness.
5. With increasing age, the spirometric differences between in-suit and not wearing a wetsuit ('out-of-suit') become larger.

Methods

This study included 28 (12 women) fit-to-dive recreational divers who volunteered to participate. For this non-invasive study, ethical approval was not required by the Medical Ethical Committee of the University of Amsterdam (Project W15_278, Decision #15.0329). The study was part of a course in diving medicine on the island of Bonaire (Dutch Caribbean) that focused on pulmonary examination of divers. All participants provided informed consent.

The spirometric measurements (NDD Easy on-PC spirometer, NDD Medical Technologies, Andover, MA, USA) were performed at a temperature of ca. 26°C and humidity of ca. 85%. Half of the participants performed the sequence 'in-suit' followed by 'out-of-suit' (i.e., in thin and loose clothing) and half in the reverse order to avoid a possible learning effect. In each condition the participants had to perform three accepted (according to the spirometer evaluation algorithm) attempts. The values of these attempts were averaged and the difference between the two conditions was calculated. The period between in-suit and out-of-suit measurements was about 7 min. The neoprene wetsuits were intended for tropical waters; either complete or a 'shorty', but without hood, gloves or boots.

Reproducibility of the spirograms obtained with the two conditions was compared by calculating the (largest - smallest)/largest of the values of the three attempts in both conditions and statistically analysing their difference (the higher the outcome, the poorer is the reproducibility). This was done for FVC and FEV_1 but not for $FEF_{25–75}$ and PEF, since the two latter parameters behave much more erratically owing to 'ripples' in the spirogram; this is seen particularly in older people.

The Kolmogorov-Smirnov (KS) test was used to test normality. Analyses were performed with paired Student's *t*-test, and with Pearson's and Spearman's correlation coefficient (r). Testing was double-sided and a *P*-value ≤ 0.05 was considered statistically significant.

Results

Table 1 summarizes the demographic characteristics and data on the FVC, FEV_1, FEV_1/FVC, $FEF_{25–75}$ and PEF of the participants. Age, height, BMI and the spirometric variables were normally distributed (KS test); suit thickness was not (mean 3.8 mm, median 3 mm, 25, 50 and 75 percentiles 3.0, 3.0 and 4.9 mm respectively). The FVC reproducibility according to (largest − smallest)/largest in-suit (5.1%) was less than with out-of-suit (3.6%); $P = 0.05$; for FEV_1 values of 4.9% and 3.0%, respectively, were found ($P = 0.02$).

Table 1
Demographic and reference spirometric quantities of the 28 participants (mean ± SD); suit thickness (median (range)); * see Results for details

	Mean	SD
Age (years)	49.0	± 13.5
Height (cm)	178.6	± 7.8
BMI ($kg \cdot m^{-2}$)	25.5	± 4.2
FVC (L)	4.8	± 0.9
FEV_1 ($L \cdot s^{-1}$)	3.6	± 0.7
FEV_1/FVC (%)	80	± 10
$FEF_{25–75}$ ($L \cdot s^{-1}$)	2.9	± 1.1
PEF ($L \cdot s^{-1}$)	9.3	± 1.6
	Median	Range
Suit thickness (mm)*	3	(2–7)

Table 2
Change in spirometric values when wearing a wetsuit: expressed as 100 (in-suit minus out-of-suit)/out-of-suit (%)

	Mean	SD	95% CI	*P*-value
ΔFVC	-4.0	± 2.7	-5.0, -3.0	2.E–08
ΔFEV_1	-3.6	± 3.8	-4.9, -2.0	3.E–05
ΔFEV_1/FVC	0.2	± 2.5	-0.73, -1.22	0.69
ΔFEF_{25-75}	-2.6	± 9.5	-6.2, -1.1	0.15
ΔPEF	-2.4	± 5.6	-4.5, -0.24	0.03

Table 2 shows the differences between in-suit minus out-of-suit of the spirometric variables. All are normally distributed (KS test). FVC and FEV_1 showed a significant decrease ($P < 0.001$ in both cases) and ΔPEF was also significantly smaller (less reduction, but not significantly different from the former two). The decrease in $\Delta FEF_{25–75}$ was not significant. However, after removing one extreme outlier (+33%), $\Delta FEF_{25–75}$ was -3.9% ($P = 0.005$). FEV_1/FVC did not change.

ΔFEV_1 is correlated with ΔFVC, with $FEF_{25–75}$ and (of course) with FEV_1/FVC (all r's > 0.67; $P < 0.0005$). No other significant correlations were found between the spirometric Δ-quantities, between age and the spirometric Δ-quantities (Pearson's correlations), between suit thickness and any other quantity (Spearman's correlations) or between the type of wetsuit used (complete or shorty) and any other quantity (Spearman's correlations). No effects of gender were found.

Discussion

This study shows that wearing a wetsuit (median thickness 3 mm) reduces FVC by 4.0%, implying that hypothesis 1 is correct. Reductions were found in FEV_1, $FEF_{25–75}$ and PEF. However, none of these reductions were significantly different from each other, or from the reduction in FVC (Table 2). Thus, hypothesis 2 is probably correct and,

as FEV_1/FVC did not change, hypothesis 3 correct. Hypothesis 4, the increasing effect with increasing suit thickness, could not be confirmed, as also holds for the expected increase of the suit effect with increasing age (hypothesis 5).

Generally, a stressor (mental or physical) results in a lower reproducibility of the correct performance of a task as compared to performing the task in the reference condition (no stressor). In the present study, in which wearing a wetsuit represents a stressor, the triple sets of FVC and FEV_1 are less reproducible in-suit than out-of-suit. This was confirmed by evaluations of the spirograms using the spirometric software.

In addition to the expected and experimentally confirmed decrease in FVC due to the reduced FIV caused by the wetsuit, FEV_1 and PEF also diminished, but seemingly to a lesser extent than FVC. This may be due to the elasticity of the wetsuit facilitating flow. This counteracts the decrease of the flow characteristics in accordance with the shape invariance of the spirogram when FVC decreases. Finally, this would result in a larger PEF/FVC ratio in-suit than out-of-suit. However, Δ(PEF/FVC) was only 1.6% larger in-suit, being non-significant ($P = 0.15$). With chest wall strapping, which is much more restrictive than wearing a wetsuit, the PEF also decreases.[6] However, in contrast to our study, the use of rigid straps blocks inspiration half way through the inspiratory phase. This implies that lung mechanics data acquired with such strapping cannot be realistically compared with data acquired when wearing a wetsuit.[6]

The double sets of spirograms show a tendency for the in-suit spirograms to be more concave, suggesting constriction of the small airways as also occurs with ageing.

Data from the literature shows that FVC and FEV_1 decrease by about 1.25% per year (linearly from 40 years onwards).[8,9] Therefore, the 4.0% decrease in FVC (median suit thickness 3 mm) can be regarded as a quasi-ageing effect of about 3.5 years. Similarly, 2.5-year quasi-ageing is found for FEV_1. Whilst diving, the suit effect is superimposed on the limitations of lung function due to the higher density of the breathing gas and physiological submersion effects such as pulmonary blood pooling, an effect of about 200 ml when submerged (in addition about 4% reduction of FVC or a quasi-ageing of ca. 3.5 years).[10]

It is unknown whether the effect of the wetsuit is in linear relation with suit thickness. However, a 16-mm thick suit (as may be used in very cold waters) is assumed to give a much higher reduction and, consequently, a quasi-ageing effect of possibly > 10 years. Also a too-tight suit will impair pulmonary function even more and, moreover, will strongly reduce blood flow in the respiratory and other musculature. This is a potential risk factor in diving situations demanding high levels of exercise. This item should be addressed during diving education and medical examination, since it has a direct impact on diving safety.

DISPUTABLE AND STRONG POINTS

With the use of a complete wetsuit we expected some pulmonary pooling since the pressure at the extremities would be larger (Pascal's law), similar to compression pants of a combat flyer. With the use of a 'shorty' the reverse will happen. However, in both cases the main effect is the pressure effect of the suit on the thorax and abdomen. The present study was underpowered to find a significant difference between a complete wetsuit and a 'shorty', and the same applies to an effect of wetsuit thickness. With both types of wetsuit, the many different brands of suits, as well as differences in the age of the suits and the tightness of the fitting, the effect of suit thickness is corrupted. The lack of a significant effect of age might also be attributed to the small number of participants.

A learning effect can be excluded since half of the group started with spirometry in-suit and the other half with out-of-suit (e.g., ΔFVC; $P = 0.27$). Moreover, most volunteers were aware of the pitfalls of spirometry and many (as a medical examiner) had practiced spirometry themselves.

The present sample had a relatively high age. However, the recreational diving community is ageing and older divers are especially at risk. The suit effect contributes to this risk. In fact, it was surprising that, despite the small sample, wetsuits of varying thickness, participants with a large age range, and no data on the fitting precision of the wetsuits, such a clear effect on FVC and FEV_1 was shown. Methodologically, the use of new wetsuits made of the same fabric would have been more optimal. However, to measure the effect of suit thickness precisely, the suits would need to be covered by many strain gauges with subsequent modelling of the pressure effects. This was beyond the scope and aims of this small study.

Conclusions

The wetsuit appears to impair ventilatory mechanics, particularly FVC and FEV_1. The effects of the wetsuit can be considered as a quasi-ageing effect of about 3.5 years for divers wearing a thin wetsuit. It is speculated that too thick and too tight suits are a pulmonary risk factor. Even with a thin wetsuit, it could contribute to problems during diving for persons with less than optimal lung function. More research is needed to establish the effects of wetsuit type and thickness on spirometric variables, the possible effect of age on in-suit spirometry, and to elucidate in more detail the effects on respiratory mechanics.

References

1 Sterk W. *Respiratory mechanics of diver and diving apparatus*. Doctoral thesis, University of Utrecht, The Netherlands; 1973.
2 Prado A. *The wetsuit effect: physiological response to wearing a wetsuit*. Doctoral thesis, University of Nevada, USA; 2014.

3 Miller CC, Calder-Becker K, Modave F. Swimming-induced pulmonary edema in triathletes. *Am J Emerg Med*. 2010;28:941-6.
4 Carter EA, Koehle MS. Immersion pulmonary edema in female triathletes. *Pulmonary Med*. 2011;2011:261404,4 p. doi.org/10.1155/2011/261404.
5 Castagna O, Blatteau J-E, Vallee N. Schmid B, Regnard J. The underestimated compression effect of neoprene wetsuit on divers hydromineral homeostasis. *Int J Sports Med*. 2013;34:1043-50.
6 Eberlein M, Schmidt GA, Brower RG. Chest wall strapping. An old physiology experiment with new relevance to small airways diseases. *Ann Am Thorac Soc*. 2014;11:1258-66.
7 Johnson BD, Reddan WG, Seow KC, Dempsey JA. Mechanical constraints on exercise hyperpnea in a fit aging population. *Am Rev Respir Dis*. 1991;143:968-77.
8 Lubinski W, Gólczewski T. Physiologically interpretable prediction equations for spirometric indexes. *J Appl Physiol*. 2010:108:1440-6.
9 Gólczewski T, Lubinski, W and Chciałowski A. A mathematical reason for FEV1/FVC dependence on age. *Respir Res*. 2012;13:57-63.
10 Lundgren CEG. Immersion effects. In: Lundgren CEG, Miller JN, editors. *Lung biology in health and disease: the lung at depth*. Vol. 132. New York: Marcel Dekker Inc; 1999. p. 91-128.

Acknowledgements

The authors thank the Dutch Society of Diving Medicine (NVD) for sponsoring the purchase of the spirometer, Tjeerd van Rees Vellinga for loaning a second spirometer, and all the participants for their invaluable cooperation.

Conflicts of interest: nil

Submitted: 17 November 2015; revised 05 March, 24 April and 05 June 2016
Accepted: 20 June 2016

Nico AM Schellart[1,2], Wouter Sterk[3]

[1] Biomedical Engineering and Physics, Academic Medical Centre, University of Amsterdam, Amsterdam, The Netherlands
[2] Foundation for Dive Research (SDR), Amsterdam, The Netherlands
[3] Dadcodat, Zuidwolde, The Netherlands

Address for correspondence:
Nico AM Schellart
Biomedical Engineering and Physics
Academic Medical Centre
University of Amsterdam
Amsterdam, The Netherlands
n.a.schellart@amc.uva.nl

Danish diving-related fatalities 1999–2012

Julie Vinkel, Peter Bak and Ole Hyldegaard

Abstract

(Vinkel J, Bak P, Hyldegaard O. Danish diving-related fatalities 1999–2012. *Diving and Hyperbaric Medicine*. 2016 September;46(3):142-149.)

Aim: The purpose was to explore causative tendencies among diving fatalities to prevent similar injuries in the future.

Methods: We report 33 fatal diving injuries that occurred among Danish divers during the period 1999–2012 in Scandinavian waters. The study was performed as a retrospective overview. The empiric data consists of police reports, forensic autopsy reports and examination of the diving equipment. Data were assembled and analyzed using Pivot and Excel. Frequencies and means (+/- SD) were used to describe categorical and continuous variables respectively.

Results: The mean age was 38.9 years and drowning was considered the cause of death in 24 of 28 divers for whom a diagnosis was possible. Elevated body mass index (18 of 22 divers had a BMI > 25) was overrepresented in our group compared to the background population. A drysuit was worn by 17 divers. Diving independently of a dive centre and mishandling of buoyancy aids were common risk factors. Only two divers released their weights. Three-quarters of those who did not would have increased their chance of survival by doing so; nevertheless, in a quarter of cases the weights were not readily releasable or not releasable at all.

Conclusion: Unfamiliarity with drysuit diving, lack of a diving buddy and mismanagement of weights were important contributors to diving injuries.

Key words

Diving injuries; diving deaths; buoyancy; drowning; scuba diving; root cause analysis

Introduction

Diving for recreational purposes has gained increasing interest among Danes during recent years. There are currently 8,500 members of the Danish Sports Diving Association spread over 160 local diving organizations. Furthermore, a significant number of professional diving schools are operating to train recreational divers in numbers that equal the number trained by the National Federation. These represent different professional diving organizations, for example, the Professional Association of Diving Instructors, National Association of Underwater Instructors and Scuba Schools International.

A dive certificate, which includes instruction in various safety procedures and a medical review, is not required to dive in Denmark. The law regulates diving equipment sales and these must be CE-certified, but there are no regulations for the general maintenance of this equipment, except for pressure cylinders which are required to be pressure-tested regularly.[1] Hence, it is the responsibility of the diver to ensure that he or she is ready for the dive to be undertaken. The maintenance of medical, physical and psychological fitness, knowledge and competence lies within the hands of the individual diver. As reviewed in this article, this responsibility is not always complied with, resulting in sometimes fatal consequences.

In an analysis of diving-related injuries and fatalities in Denmark between 1966 and 1980, 30 divers died over a 15-year period, with an increasing incidence over time.[2] Similar analyses have been conducted in our neighboring countries; Sweden (1960–1976) and Norway (1983–2007).[3,4] However, a quantitative report on fatal diving injuries in Denmark has not been published since 1982. The present study aimed to investigate fatal diving injuries in Denmark, with the intention of exploring potential causes, in order to disseminate recommendations that might prevent similar diving injuries in the future.

Methods

DATA COLLECTION

The study was performed as a retrospective analysis of diving fatalities in Danish and other Nordic waters during the period of 1999 through 2012. Data collection was approved by the Danish Data Protection Agency (reference no: 03861) and upon individual request in each case from relevant government-regulated authorities and local police departments. The study abides by the principles of the Declaration of Helsinki. The empiric data consisted of police reports describing the circumstances surrounding each fatality, post-mortem forensic autopsy along with toxicological testing and examination of the dive equipment used. Data were primarily collected from the Danish Maritime Authority archives or from the local police responsible for the diving injury investigations. Additional information was gathered from the webpage <www.hyperbar.dk>, the Danish Navy Diving School and Technical Department and Norwegian Underwater Institute (Jensen R, personal communication, 12 November 2013).

DATA ANALYSIS

Two reviewers reviewed the files and data were analyzed using Pivot tables and diagrams in Excel. Frequencies and means (+/- SD) are used to describe categorical and continuous variables respectively. Not all parameters were described in every case. When calculating frequencies (e.g., of alcohol intoxication), we used the number of cases where this parameter was described as the total (i.e., the total number of cases where toxicological screening was performed). When a parameter was inaccessible, either because the file was incomplete or because it was not described in the file, we noted the parameter as 'not specified' (NS). Data included gender, age, year of diving injury, body mass index (BMI), the autopsy result including the type of death, cause of death, pre-existing illnesses, toxicological testing and other related conditions, technical defects of the dive equipment, type and ownership of the dive suit, type of breathing apparatus and gas used for diving. In addition, safety factors included the type of diving certificate, whether or not the diver was using a diving computer, dive time and depth, bottom time and the degree to which the dive was organized and planned.

'Organized' was defined as through a company or dive centre and 'planned' was the type of principle applied to deliberately prevent decompression sickness. Circumstances leading to the diving injury included visibility, the phase of the dive, the presence of a psychological panic reaction described by witnesses and nitrogen narcosis. Additionally, we applied an assessment practice to the process and summarized the proceedings and triggers leading to the diving injury in a root cause analysis.[5] Furthermore, positive buoyancy was evaluated by whether the weights were released during the event of the diving injury, and if the outcome could have been improved by ditching the weights.

Results

A total of 33 diving fatalities among foreign divers in Danish waters and Danes diving in Scandinavian waters during 1999 through 2012 were recorded, with a mean of 2.4 per year. Fourteen cases contained complete information, whereas nine cases lacked forensic examination reports, Thirteen cases lacked examination of the diving equipment and four cases lacked both. In eight cases, the circumstances around the diving injury were reproduced from sources other than original police records, such as newspaper reports from interested organizations and official reports.

DEMOGRAPHY

The age span was 21–59 years (mean 38.9 +/- 11 years); half were over 40 y.o. Among the deceased, there were 26 males and seven females. The incidence of death by season showed the majority occurred during summer, and only one fatality occurred during winter. The purpose of the dive was recreational except for one victim who was in training to obtain her certificate, two were professional divers and one victim was performing an errand when the incident occurred (trying to recover a pair of lost sunglasses). Table 1 shows a summary of the diving fatalities.

SAFETY PRECAUTIONS AND PRE-DIVE PREPARATION

The experience of the deceased diver was classified into six categories (Table 1). The sample shows a predominance of novice divers and only two professional divers. Twelve of the 33 cases were classed as organized dives. Nineteen dives were privately arranged, whilst the two professional divers were not included in this category. All of the divers who were uncertified were diving independently of an organized dive association, (except the diver in training). Twenty-three were diving with a buddy, five connected by a buddy line and ten were using a mooring line, fixed between the surface and the dive site. In 13 cases, the dive was planned using a dive computer. Only five reports suggested preparation for the dive using dive tables and in six cases it was deducible that no planning had occurred prior to the dive.

CIRCUMSTANCES LEADING TO THE FATALITY

The possible cause and trigger leading to each fatality are summarized using root cause analysis (Table 2). Fatalities were rarely caused by a single factor; rather, they followed a chain of events with a number of contributing factors. In 12 cases, failure, error or improper operation of the equipment was the main trigger and, in four additional cases, equipment factors may have disabled the diver from regaining control and thereby contributed to the outcome. For example, one diver lost drysuit control with air trapped in the legs, panicked and drowned. The subsequent testing of the equipment showed that the regulator took in water when turned upside down. Seven diving injuries were triggered by environmental factors; these were either a strong current or entrapment/entanglement. The psychological factors were nitrogen narcosis, occurring in two cases (range 41–53 metres' seawater (msw), breathing air) and 11 were reported by eyewitnesses to have shown signs of panic at the time of the incident. In two cases, the diver ran out of air and signalled this properly to the dive buddy; however, the subsequent rescue procedure was unsuccessful. In another two cases, the dive tanks were found to be empty when the diver was rescued but the events leading to the incidents were not witnessed. The pathophysiological factors comprised a wide range of conditions (Table 1), the most serious being cardiac factors, with two fatalities directly related to cardiac disease and another three fatalities being linked to poor cardiopulmonary fitness.

We classified the maximum depth of the dives into four categories based on certification depth ranges. A large proportion (10 of 30 divers) of diving injuries occurred

Table 1

Summary of diving related fatalities; BMI – body mass index; NA - not available; NS - not specified; SSBA - surface support breathing apparatus

Diver #	Year	Age (y)	Sex	Height (cm)	Weight (kg)	BMI (units)	Certification level	Dive Purpose	Organized dive	Depth (max. m)	Incident	Weights released	Breathing apparatus	Autopsy	Buddy status
1	2012	43	M	194	100	26.6	Advanced	Spearfishing	No	5	Bottom	No	Rebreather	Yes	Solo
2	2012	39	M	174	85	28.1	Novice	Recreation	No	8	Bottom	No	Scuba	Yes	Buddy
3	2012	21	M	NS	NS	NS	Novice	Recreation	No	15	Ascent	No	Scuba	NS	Solo
4	2012	44	F	175	78	25.5	Novice	Recreation	Yes	20	Bottom	No	Scuba	Yes	Buddy
5	2012	44	M	179	81	25.3	Advanced	Recreation	Yes	20	Ascent	No	Scuba	Yes	Buddy
6	2012	50	M	182	103	31.1	Novice	Recreation	No	11	Ascent	No	Scuba	Yes	Solo
7	2011	35	M	188	96	27.2	NS	NS	No	NS	NS	NS	NS	Yes	Solo
8	2011	21	F	168	67	23.7	Novice	Errand	No	8-9	Surface	No	NS	Yes	Solo
9	2011	44	M	183	108	32.2	Novice	Recreation	No	2−3	Surface	No	Scuba	Yes	Solo
10	2011	46	F	167	77	27.6	Novice	Recreation	No	3−4	Bottom	No	Scuba	Yes	Buddy
11	2010	38	M	NS	NS	NS	Novice	Recreation	No	30−70	Bottom	No	Scuba	No	Buddy
12	2010	45	F	NS	NS	NS	Novice	Recreation	No	30−70	Bottom	NS	Scuba	No	Buddy
13	2010	41	M	NS	NS	NS	Professional	Professional	NA	41	Bottom	No	SSBA	No	Solo
14	2008	NS	M	NS	NS	NS	Advanced	Recreation	Yes	42	Bottom	No	Scuba	No	Buddy
15	2007	38	F	176	115	37.1	Not certified	Recreation	No	3	Bottom	No	Scuba	Yes	Buddy
16	2007	45	M	NS	NS	NS	NS	Recreation	Yes	40	Ascent	NS	NS	Yes	Buddy
17	2007	59	M	190	109	30.2	Novice	Recreation	Yes	34	Ascent	No	Scuba	Yes	Buddy
18	2007	44	M	176	88	28.4	Novice	Recreation	No	3	Surface	No	Scuba	Yes	Buddy
19	2006	46	M	169	80	28	NA	Recreation	Yes	0	Surface	NS	NS	Yes	Buddy
20	2005	59	M	NS	114	NS	NA	Recreation	No	0	Surface	NA	NA	NS	Buddy
21	2004	23	M	183	92	27.5	Not certified	Recreation	No	2	Surface	No	Scuba	Yes	Solo
22	2003	44	M	173	81	27.1	Novice	Recreation	No	3	Bottom	NS	NS	Yes	Solo
23	2002	42	M	NS	NS	NS	Advanced	Recreation	No	NS	NS	Yes	Scuba	NS	Buddy
24	2002	32	M	NS	NS	NS	Advanced	Recreation	No	150	Ascent	NS	NS	No	Buddy
25	2002	35	M	168	71	25.2	Professional	Professional	NA	NA	NA	NA	SSBA	Yes	Solo
26	2001	30	F	185	109	31.8	Advanced	Recreation	Yes	NS	NS	No	Scuba	Yes	Buddy
27	2001	34	M	184	NS	NS	Advanced	Recreation	Yes	53	Descent	No	Scuba	Yes	Buddy
28	2001	35	M	180	75	23.1	Advanced	Recreation	No	3	Bottom	No	Scuba	Yes	Buddy
29	2001	22	M	189	69	19.3	Not certified	Recreation	No	1−3	Bottom	No	Scuba	Yes	Buddy
30	2001	30	M	NS	NS	NS	Novice	Recreation	Yes	42	Bottom	No	NS	No	Buddy
31	2000	45	M	177	83	26.5	Novice	Recreation	Yes	43	Bottom	NS	Scuba	Yes	Buddy
32	1999	49	F	163	78	29.4	NA	Recreation	Yes	0	Surface	Yes	NA	Yes	Buddy
33	1999	23	M	170	66	22.8	Novice	Recreation	Yes	24	Bottom	NS	Scuba	Yes	Buddy

Table 2. Root cause analysis in 33 Danish diving fatalities

Diver	Trigger	Disabling agent	Disabling injury	Cause of death
1	Rebreather; low O_2	Poor cardiopulmonary fitness; hypoxia	Asphyxia	Drowning
2	Missing valve on BCD; no buoyancy control	Negative buoyancy; weights not releasable; panic	Unknown; asphyxia?	Drowning
3	Resistance at second stage	Respiratory difficulty? Panic; negative buoyancy; weights not releasable	Unknown; asphyxia?	Drowning
4	Tight drysuit neck; buoyancy-related; inversion	Respiratory difficulty; laryngeal haematoma; aspirated when inverted	Asphyxia	Drowning
5	Strong current; regulator free-flow	Panic; ascent-related	Air embolism	Barotrauma
6	Out of air	Negative buoyancy; weights not released; panic; solo-dive	Aspiration; asphyxia	Drowning
7	Unknown; solo-dive	Poor cardiopulmonary fitness	Unknown	Drowning
8	Loss of swim fin; negative buoyancy	Panic; weights not releasable	Unknown; asphyxia?	Drowning
9	Dropped BCD at surface; Submerged by connection to inlet valve on dry suit	Loss of air supply; aspiration	Asphyxia	Drowning
10	Drysuit; buoyancy-related; inverted position	Panic; weights not releasable	Sudden respiratory difficulty after surfacing	Cerebral hypoxia/ drowning
11	Entrapment in wreck	Unknown	Unknown	Unknown
12	Entrapment in wreck	Unknown	Unknown	Unknown; corpse not recovered
13	Stricture on air supply (surface supplied)	Nitrogen narcosis; problem with communication with surface	Asphyxia	Drowning
14	Fits or epilepsy? Nitrox-related?	Oxygen toxicity? Panic?	Unknown; asphyxia	Unknown
15	Ear barotrauma; panic	Negative buoyancy; lack of BCD and swim fins; weights not releasable	Asphyxia	Drowning
16	Unknown; out of air	Panic; ascent-related?	Unknown; asphyxia?	Drowning
17	Out-of-air; panic	Emergency ascent; poor cardiovascular fitness	Barotrauma? Asphyxia	Drowning
18	Negative buoyancy; panic; Sudden unconsciousness at surface	Weights not released; aspiration?	Unknown; asphyxia?	Drowning
19	Cardiac incident; immersion	Unknown	Cardiogenic shock	Natural death
20	Cardiac incident	Poor cardiovascular fitness	Acute myocardial infarct	Natural death
21	Inexperience; improper operation of equipment	Buoyancy-related – water in BCD; aspiration	Asphyxia	Drowning
22	Unknown; solo-dive	Unknown	Unknown	Drowning
23	Entanglement	Strong current; loss of air supply	Asphyxia	Drowning
24	Gas supply-related; 150 m dive on heliox and O_2	Ascent related? Panic?	Unknown	Unknown
25	Entrapment during overhead diving	Strong current; loss of air supply	Asphyxia	Drowning
26	Strong current; separated from buddies; panic	Night dive; darkness	Unknown	Drowning
27	Deep dive; narcosis	Separated from buddy	Asphyxia	Drowning
28	Unknown	Unknown; not fit for diving; traces of cocaine and alcohol	Unknown	Drowning
29	Unknown; out of air?	Unknown; not fit for diving; traces of alcohol; inexperience; uncertified	Unknown; asphyxia?	Drowning
30	Dry suit; improper operation of equipment	Negative buoyancy; weights not released; panic; loss of air supply	Asphyxia	Unknown
31	Improper fixation of air cylinder	Resistance to breathing; aspiration	Laryngospasm; asphyxia.	Drowning
32	Exhaustion; panic	Poor cardiopulmonary fitness; aspiration	Unknown; asphyxia	Drowning
33	Entrapment in wreck	Damaged buddy line; separated from buddy; poor visibility	Unknown; asphyxia	Unknown

during dives > 30 msw with a maximum recorded depth of 150 msw, performed by a scuba diver breathing a mixture of helium and oxygen. This number includes the two professional divers who were breathing from a surface supplied umbilical. An equally high proportion (n = 12) occurred at depths < 5 msw.

Most of the fatalities (n = 15) occurred at the maximum depth of the dive. Seven fatalities occurred at the surface and of these three scuba divers died prior to submersion, two of whom felt discomfort after immersion and later autopsy showed death due to cardiac disease. A third diver also felt discomfort and exhaustion after immersion and lost consciousness and respiration on the surface. It was reported that the body was submerged briefly during the subsequent rescue attempt. The autopsy showed atherosclerosis and adiposity, but revealed no specific cause of death apart from signs of drowning at autopsy. Four divers deceased at the surface following ascent.

CAUSE OF DEATH AND CONTRIBUTING FACTORS

The body of one diver was never recovered. The primary factors causing death were classified into groups based upon the conclusions of the autopsy and witness statements. The principal cause of death reported was drowning, accounting for 24 victims. The autopsy was definite about barotrauma in only one diver, whilst in two cases the causes of death were cardiogenic shock and acute myocardial infarction.

A forensic autopsy was available in 24 of the 33 divers. Beside the two cardiac disease cases mentioned above, there were 11 divers who had signs of pre-existing diseases reported at autopsy. The most common findings were cardiomegaly (n = 4) and atherosclerosis (n = 6). BMI was obtainable in 22 divers, 18 of whom had a BMI > 25 and five of these had a BMI > 30. Toxicological screening was performed in 17 cases; however, the results were only available to us in 11 cases. Two were positive for cocaine, a third for antidepressants, two divers tested positive for ethanol and one had traces of both cocaine and ethanol.

Information about medical history was obtained in 22 cases and, of those, six cases were known to have one or more risk factors for cardiovascular disease (primarily hypertension, diabetes and adiposity). This group had an average age (45 years) that was six years older than the rest of the cohort and four of these had atherosclerosis at autopsy. However, four of the victims with no previous medical history of cardiovascular disease had signs of it at autopsy.

DIVE EQUIPMENT

The majority of deceased divers (n = 21) were using open-circuit scuba. Two divers were on surface supply and one was using a rebreather. Seventeen divers were diving in a drysuit and nine in a wetsuit. In five cases, information regarding the type of suit was unavailable and in two cases they were diving in regular swimwear. Only in three cases was it explicitly stated that the diver was unfamiliar with drysuit diving and in one case the diver was wearing an unaccustomed, new drysuit and got into trouble with her buoyancy. In the remaining drysuit cases, the diver's level of experience was unknown.

The vast majority of cases were diving using compressed air. Only five of 26 divers were out of air at the time the victim was recovered, the remainder still having air left in their tanks on examination. Particular information on residual air was lacking in five cases. Of the 25 divers who were known to use weights, only two ditched their weights during the course of the diving incident. Through careful review of these cases, it is thought that in 21 cases the odds of survival would have been enhanced if the diver had dropped their weights, improving the probability of reaching the surface alive. Six divers had placed their weights in such a manner that they could not be released easily in an emergency.

EFFICIENCY OF FIRST AID AND LIFE SUPPORT

The last step in the chain of events when rescuing a diver is efficient first aid, resuscitation and oxygen administration. In 17 cases there was no specific first aid equipment available in proximity to the diver, even though four of these dives were organized dives. In nine cases, the diver received basic first aid and only in 11 cases was the diver treated with oxygen. In three of these cases, the oxygen was available and administered at the scene by other divers or instructors, and in the remaining cases the oxygen was delivered by an emergency health care provider upon arriving at the scene.

Discussion

GENERAL DEMOGRAPHY

The absolute number of known fatal diving injuries has increased over the past two decades with a mean of 2.4 per year in our study and a mean of two per year in the earlier study from 1966 to 1980).[1] However, in that study, the incidence increased steadily during the period reviewed with a mean of three deaths per year in the latest five years. In neither study period are the numbers of active divers or the number of divers known, so fatality rates cannot be estimated. Since the previous Danish study, diving with nitrox and mixed gas, including with rebreathers, has been introduced, typical diving profiles have changed from bounce-dives to multi-level dives and dive computer use is more widespread.

CAUSES OF DEATH AND GENERAL HEALTH

In the recent study on fatal diving injuries from Norway, which included 40 scuba divers, surface-supplied and saturation divers, 31 divers were reported to have

Table 3
Comparison with similar studies from Norway and Australia; *no data for six divers

	Total number	Number per year	Mean age (y)	Number drowned	Cardiac disease
Norway (1998–2007)	40	4.4	31.4	31	6
Western Australia (1992–2005)	24	1.8	39.2	16	8
Denmark (1999–2012)	33	2.4	38.9	24 of 27*	8 of 27*

drowned.[3] Five died from sudden decompression, two from barotraumas, one from mechanical trauma and only one diver died from cardiac disease. BMI measurements were obtained in 39 divers; however, only four divers were found to be obese and there was no correlation between BMI and cause of death. Six divers had medical histories that included lung surgery, hypertension, diabetes and coronary artery disease. These conditions might have contributed to the incident, but could not be directly linked as the cause of death.

A recent epidemiological analysis among insured members of DAN found that their mean age had increased over time.[5] The risk of mortality was greater for men and increased with age for both sexes. According to this study, cardiac disease was the most significant risk factor for death during diving, the risk being 12.9 times greater in divers > 50 years of age.[5] Other authors have brought the topic into focus with similar work.[6–9] Amongst these, in a Western Australian study of 24 recreational divers who died whilst diving over a 14-year period (1992–2005), the mean age of the divers was 39.2 years old.[7] In two-thirds of the cases drowning was considered the immediate cause of death. Cardiac issues were noted in eight cases with a mean age of 50.3 years. Our study showed a similarity to these data (Table 3); but in only two divers was death directly attributed to cardiac disease.

Most remarkable was that 18 of 32 divers in our study were found to have a BMI above 25, whereas this is only true for 47% of the general population (The National Health profile 2014, Danish National Board of Health). The BMI measurements were obtained from the autopsy report and, therefore, their availability was solely dependent on whether or not an autopsy report was accessible. Although our cohort is a selected population, this discrepancy in BMI measures suggests the possibility that adipose people practice diving more frequently than people of normal weight or that there might be an increased risk of death in divers with a higher BMI.

In the comparable study from Norway, toxicological screening was performed in 33 out of 40 cases, and one diver had a positive blood ethanol. Another two divers had positive urine ethanol concentrations indicating previous alcohol consumption.[3] In our study, four divers showed traces of either ethanol or drugs; however, the relationship between intoxication and cause of death was not apparent.

The most common psychological factor was panic. Panic occurred in nine cases either as the eliciting factor or as a significant contributor that arose during the sequence of events. Panic as a psychological factor was only noted in cases where affirmed in a witness statement. Equipment was also noted as a trigger in cases where it was poorly maintained, failed or used improperly.

SAFETY PRECAUTIONS

In the study from Western Australia, faulty equipment contributed to only two cases.[7] The safety rules most often broken were: maintaining the buddy system throughout the dive; planning the dive with a buddy; maintaining good physical and psychological health; use of surface support when feasible and establishing positive buoyancy in an emergency.

The waters around Denmark are relatively cold with a mean temperature of 17°C during summer where the majority of the fatalities occurred. However, it is not mandatory to wear a drysuit under these temperatures and wetsuit diving is practiced and taught at the majority of commercial diving courses in Denmark. Nevertheless, nearly two-thirds of the fatalities in our cohort were using a drysuit. Lack of buoyancy control in relation to drysuit diving might have been a contributing factor in some of these accidents, and attention should be placed on this topic to reduced future incidents.

Establishing positive buoyancy by the release of weight underwater is a mandatory element in dive training because it can be a critical response to threatening circumstances. In every published study of scuba diving fatalities that we have reviewed, many divers failed to drop their weights. In our study, some had even placed their weights in such a manner that they could not be released easily or at all in an emergency, so this training message is not getting through.

The initiation of first aid immediately after a diving injury and in particular administration of 100 % oxygen is the gold standard for diving injury management regardless of whether the diver suffers from respiratory or circulatory insufficiency or decompression illness.[10] Techniques for correct implementation of first aid and oxygen administration are well described elsewhere.[11] Despite all of the described beneficial physiological effects of administering high flow oxygen, this practice was rarely performed in our case series.

IMPROVEMENTS AND VALIDITY OF DATA

When a fatal diving injury is unwitnessed or the report of the diving injury is incomplete, it is difficult to determine the exact sequence of events and the actual cause of death. In such cases, we have avoided speculation and present only data that were found in the case reports. This means that some data might be underreported when notified as 'not specified'. Although this report includes only data made available through reasonable effort, we have obtained full reports, including technical investigations and autopsies in almost all cases where these were performed. However, the reliability of these data might be discussed, because many variables are based on subjective reports. Likewise, in many cases it was obvious from interviews with witnesses that the investigator had little knowledge about diving. This was apparent through the incorrect use of terms in connection to events and equipment, and the handling of cases. In some cases, the investigator would disassemble the equipment or empty the cylinders at the scene, thereby obliterating valuable information.

As has already been emphasized by our Nordic colleagues 40 years ago, a proper investigation of a diving injury is of tremendous importance for the prevention of future mishaps.[2] According to Danish regulations, any death classified as a diving injury should be followed by a forensic autopsy and CT scans have been an obligatory element in this since 2006. Unfortunately in our study this radiographic modality was not applied promptly as recommended in order to reveal information on barotrauma, but instead both the autposy and the CT scan were delayed by hours or even days.

Not all deceased divers in our study had a post-mortem examination performed. Likewise, some autopsies were not performed by forensic pathologists knowledgeable about diving, so important information was lost. Even when a careful, timely autopsy is performed, it cannot always reveal the primary event that has taken place. An example of such a primary event is immersion pulmonary oedema.[12,13] The autopsy findings are very similar to drowning, and diagnosis requires the presence of reliable witnesses that can report on the likelihood or not of primary aspiration of water during the fatal dive. A forensic pathologist with no specific knowledge about diving physiology and conditions would most likely overlook this diagnosis when observing airways obstructed with frothy sputum on autopsy.

In order to improve future scientific investigation of fatal dives and individual diving fatality investigation, the investigators should possess expert skills and knowledge of diving and a systematic investigation guideline would be desirable.[14]

Conclusion

This study shows that many Danish diving fatalities could have been avoided if adequate safety procedures and diving skills had been initiated. Lack of familiarity with drysuit diving, lack of a good buddy system and mismanagement of weights were important contributors to diving injuries. Our data indicate that there might be an increased risk of diving with a higher BMI; conversely, people with higher BMI may be more likely to participate in diving in Denmark. Interventions that might reduce fatalities in the future include a focus on health maintenance and physical fitness, better training of establishing positive buoyancy and effective first aid of a distressed diver. Lastly, proper investigation of diving fatalities, including informed witness questioning and expert autopsy is desirable for the understanding and prevention of future casualties.

References

1 [*Act on diving work and diving equipment, etc.*] See Consolidation Act No. 936 of 20. July 2010 with amendments following from Act No. 1231 of 18. December 2012 and § 2 in Act No. 618 of 12. June 2013, chapter 3. Available from: https://www.retsinformation.dk/forms/r0710.aspx?id=160632. Danish.

2 Madsen J. [Diving accidents in Denmark 1966-80]. *Ugeskr Laeger*. 1982;144:523-7. Danish.

3 Carlsson K, Lidholm SO, Maehly AC. Scuba diving accidents in Sweden 1960-1976. *Forensic Sci*. 1978;11:93-108.

4 Ramnefjell MP, Morild I, Mork SJ, Lilleng PK. Fatal diving accidents in western Norway 1983-2007. *Forensic Sci Int*. 2012;223:e22-6.

5 Lippmann J, Lawrence C, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2009. *Diving Hyperb Med*. 2013;43:194-217.

6 Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA, Vann RD. Scuba injury death rate among insured DAN members. *Diving Hyperb Med*. 2008;38:182-8.

7 Buzzacott P, Rosenberg M, Pikora T. Western Australian recreational scuba diving fatalities, 1992 to 2005. *Aust N Z J Public Health.* 2009;33:212-4.

8 Ihama Y, Miyazaki T, Fuke C, Mukai T, Ohno Y, Sato Y. Scuba-diving related deaths in Okinawa, Japan, from 1982 to 2007. *Leg Med* (Tokyo). 2008;10:119-24.

9 Lippmann J, Walker D, Lawrence CL, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2007. *Diving Hyperb Med*. 2012;42:151-70.

10 Longphre JM, Denoble PJ, Moon RE, Vann RD, Freiberger JJ. First aid normobaric oxygen for the treatment of recreational diving injuries. *Undersea Hyperb Med*. 2007;34:43-9.

11 Lippmann J, editor. *Advanced oxygen first aid*. Melbourne: DAN Asia Pacific; 2005.

12 Cochard G, Arvieux J, Lacour JM, Madouas G, Mongredien H, Arvieux CC. Pulmonary edema in scuba divers: recurrence and fatal outcome. *Undersea Hyperb Med*. 2005;32:39-44.

13 Coulange M, Rossi P, Gargne O, et al. Pulmonary oedema in

healthy SCUBA divers: new physiopathological pathways. *Clin Physiol Funct Imaging*. 2010;30:181-6.

14 Edmonds C, Caruso J. Diving fatality investigations: recent changes. *Diving Hyperb Med*. 2014;44:91-6.

Acknowledgements

We gratefully acknowledge the following individuals and institutions for providing information concerning diving fatalities: Per Ragnar Jensen, Redningsdykning, Bergen University College Diver Education, Bergen; Christina Jacobsen, Department of Forensic Medicine, University of Copenhagen; Michael Bering Sifakis and Johnny Frederiksen, "*Dive Safe*", Hyperbar.dk; Sten Emborg, The Danish Pleasure Craft Safety Board, Danish Maritime Authority; Kenneth Larsen, Royal Danish Navy Academy, Diving School and Technical Department; Danish National Police; local police departments in North Zealand, South-East Jutland, East Jutland, Central and West Jutland, Bornholm and Funen.

Conflicts of interest and funding: nil

Submitted: 16 November 2015; revised 28 April and 22 June 2016
Accepted: 30 June 2016

Julie Vinkel, Peter Bak, Ole Hyldegaard

Hyperbaric Medicine Centre, Department of Anesthesiology and Surgery, Head and Orthopedic Centre, University Hospital of Copenhagen, Rigshospitalet, Copenhagen, Denmark

Address for correspondence:
Julie Vinkel
Hyperbaric Medicine Centre
Department of Anesthesiology and Surgery, Head and Orthopedic Centre
Rigshospitalet
2100 Copenhagen, Denmark
julievinkel@gmail.com

Thirty years of American cave diving fatalities

Leah Potts, Peter Buzzacott and Petar Denoble

Abstract

(Potts L, Buzzacott P, Denoble P. Thirty years of American cave diving fatalities. *Diving and Hyperbaric Medicine*. 2016 September;46(3):150-154.)

Introduction: Cave divers enter an inherently dangerous environment that often includes little visibility, maze-like passageways and a ceiling of rock that prevents a direct ascent to the surface in the event of a problem.

Methods: Reports of cave diving fatality cases occurring between 01 July 1985 and 30 June 2015 collected by Divers Alert Network were reviewed. Training status, safety rules violated, relevancy of the violations, and root causes leading to death were determined.

Results: A total of 161 divers who died were identified, 67 trained cave divers and 87 untrained. While the annual number of cave diving fatalities has steadily fallen over the last three decades, from eight to less than three, the proportion of trained divers among those fatalities has doubled. Data regarding trained cave divers were divided into two equal 15-year time periods. Trained cave divers who died in the most recent time period were older but little else differed. The most common cause of death was asphyxia due to drowning, preceded by running out of breathing gas, usually after getting lost owing to a loss of visibility caused by suspended silt. An overwhelming majority of the fatalities occurred in the state of Florida where many flooded caves are located.

Conclusion: Even with improvements in technology, the greatest hazards faced by cave divers remain unchanged. Efforts to develop preventative interventions to address these hazards should continue.

Key words

Deaths; recreational diving; technical diving; root cause analysis; epidemiology; DAN – Divers Alert Network

Introduction

Cave divers enter an inherently dangerous environment that includes little visibility, maze-like passageways and a ceiling of rock that prevents a direct ascent to the surface in the event of a problem. In 1966, an American report contained 11 cave and spring diving fatalities out of 86 documented skin and scuba diving fatalities.[1] Since then, hundreds of recreational divers have died in US caves.[2] In 1979, Sheck Exley published the first cave diving instructional text, called *Basic cave diving: blueprint for survival,* that provided safe cave diving guidelines and used accident analysis to illustrate the effectiveness of these practices.[3] At that time, training agencies reached a consensus that most cave diving deaths were caused by breaking one or more of the following guidelines:[4]

- always limit penetration into the cave to one-third of the starting amount of gas;
- always have a continuous guideline to the surface;
- always dive at, or shallower than, a safe depth for the gas being used.

To round out the five safe cave diving rules that make up most of today's training courses, two more rules were added five years later:[5]

- all divers entering a cave must have cave diver training;
- every diver should have three light sources, each having the ability to burn for the entire scheduled dive time.[5]

The five are known as the 'Golden Rules' of cave diving.

Previous cave diving fatality research compared trained with untrained divers but the continued relevance of the five rules has not been examined since they were finalised in 1984.[2] Technology has advanced remarkably in recent decades in all fields of engineering and scuba diving equipment is no exception. In 1997, AP Valves released the first production closed circuit rebreather (CCR) marketed for recreational diving, which soon gained popularity in the technical diving community including among cave divers. A rebreather essentially recycles exhaled gas by removing carbon dioxide and topping up metabolised oxygen. This enables a diver to stay longer underwater without carrying additional tanks of breathing gas. There are various types of CCR available today and hazards associated with them have been described previously.[6] In this paper 'rebreather' refers to any form of scuba that recycles exhaled gas, including semi-closed rebreathers, CCRs, electronic and manual rebreathers.

Once the exclusive preserve of military divers, long-range diver propulsion vehicles (DPV) are now commercially available, enabling greater distance penetrations into caves, as are dive lights with greatly improved times before failure, heated dry suit undergarments enabling longer dives in cold water and other technological advances. If and how these advances may have affected the hazards modern cave divers face has not been previously explored. The aim of this study was to review characteristics of recent mortality among trained cave divers in the USA, and to provide a foundation upon which to build new preventative interventions if needed, or to reinforce existing efforts.

Methods

Divers Alert Network (DAN) collects information about recreational scuba diving fatalities and maintains a database. An individual case file is created for each fatality and these case files may include medical examiner or coroner's reports, autopsies, witness statements, recovery divers' reports, news clippings, information from the next of kin and/or the dive buddy, dive profiles downloaded from dive computers, court transcripts, sheriff's reports or any other relevant information. From this database, cave diving fatality cases occurring between 01 July 1985 and 30 June 2015 were extracted and reviewed. Cave diver training status was determined, (trained, untrained or unknown) and, after describing the trend in proportions trained or untrained, the unknown and untrained divers were removed and only trained cave divers were further considered. The study protocol was approved by the Institutional Review Board of the Divers Alert Network (approval number 011−14).

ROOT CAUSE ANALYSIS – ALL YEARS

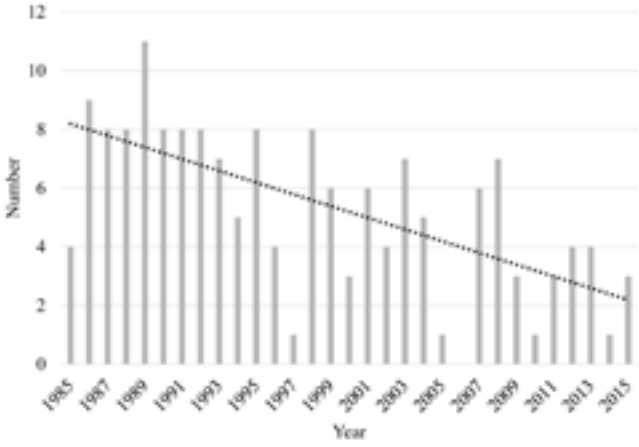
The causes of each fatality were classified into four consecutive steps, as described previously in diving fatality root cause analyses.[2,7,8] The 'medical cause of death' was accepted as established by a medical examiner. Based on available evidence, root causes were classified as: 'second tier', a mutually exclusive binary classification based on common circumstances associated with each cause of death (e.g., ran out of gas: yes/no); the 'harmful action' that was thought to have led to the second tier status, and finally the 'trigger', the reason the harmful action happened (the most significant contributing factor). While each causal path usually involves many possible contributing factors, this analysis considered the most common and relevant factors in each cause of death (e.g., running out of gas is the most common event that precedes drowning). The available evidence was queried following a causal taxonomy instrument developed in 2007.[2] This method has been shown to have high inter-rater agreement. Reviewers for this study were both trained and active cave divers. The classification instrument was then reduced to include root causes in only trained cave diver fatalities in the USA and divided into two 15-year groups. The early group included fatalities that occurred between 01 July 1985 and 30 June 2000, the late group between 01 July 2000 and 30 June 2015.

As all divers in this sub-analysis were trained, the training rule was met for each case. As well as classifying the root causes, violations of any of the other four safe-cave-diving rules were noted. Each rule broken was then deemed relevant or irrelevant to the fatality based on whether or not the violation directly affected the outcome.

CHARACTERISTICS – EARLY AND LATE GROUPS

Data were stored in an Excel® spreadsheet and analysed using SAS version 9.4 (Cary, NC). The trend for cave diving fatalities to increasingly involve trained cave divers was tested for significance with a Cochran-Armitage test. The linear variables age and distance into the cave were tested for normality (Proc Univariate). Age was normally distributed (skewness 0.55, kurtosis -0.21). Distance was not and so a fitted lognormal distribution was tested using Anderson-Darling, Cramér-von Mises and Kolmogorov-Smirnov tests. At $\alpha > 0.10$ significance level, all tests supported that the lognormal distribution provided a good model for the distribution of distance into the cave. Student's *t*-tests were then used to assess differences in age and log-distance between early and late groups. Logistic regression was used to test for differences in binary outcomes between these groups, (sex, DPV use, use of closed circuit). Significance in all cases was accepted at $P < 0.05$.

Figure 1
Annual USA cave diving fatalities 1985−2015 with trend line



Results

A total of 161 divers were initially identified, 67 trained and 89 untrained in cave diving, with five divers having an undetermined training status. While the number of cave diving fatalities has steadily fallen over the last three decades (Figure 1), the proportion of trained divers among those fatalities has steadily increased. Table 1 presents the training status of the fatalities in each group. There was an almost complete reversal of trained and untrained proportions between the two time periods (two-sided Cochran-Armitage trend test $P < 0.0001$).

Sixty-one of the 67 cave-trained fatalities occurred in the state of Florida. The Devil's system led with 14 deaths. Jackson Blue Spring, Little River Spring, and Peacock Springs followed, accounting for five deaths each. Four deaths took place in the Eagle's Nest system and three deaths occurred at Madison Blue Springs.

Table 2 summarises the demographics of the divers, details of the dives and the equipment used. Trained cave diver fatalities in the most recent time period were older ($P = 0.002$). While the latter group included double the

Table 1
Cave diving fatalities 1985–2015 by training status; *n* (%); * $P < 0.0001$

	Untrained	Trained	Total
July 1985–June 2000	66 (69)	30 (31)*	96 (62)
July 2000–June 2015	23 (38)	37 (62)*	60 (38)

Table 2
Characteristics of trained cave divers, dive data and equipment used by time period; † data sources used feet; DPV – diver propulsion vehicle; * $P = 0.002$

	Early group (*n* = 30)	Later group (*n* = 37)	Overall (*n* = 67)
Age (years) mean (SD; *n*)	36 (11; 30)	45 (12; 36)*	40 (12; 66)
Male/female ratio	28/2	32/5	60/7
Depth (feet†) mean (SD; *n*)	122 (78; 29)	102 (71; 27)	112 (74; 56)
Distance (feet†) mean (SD; *n*)	698 (850; 24)	1,029 (1,043; 27)	873 (962;51)
Breathing circuit (*n*)			
Open	28	29	57
Closed	1	6	8
Single or double (*n*)			
Single fatality	28	32	60
Double fatality	2	5	7
DPV used (*n*)	6	11	17

percentage of females of the earlier group, this was not significantly different ($P = 0.37$). Recent deaths occurred further into the cave ($P = 0.06$). DPV use increased non-significantly from six of 30 divers in the early group to 11 of 37 in the latter group ($P = 0.50$). The majority of fatalities from both periods occurred wearing open-circuit cylinders on the back and four in each period were diving with the cylinders in side-mount configuration. The number of fatalities using CCRs increased non-significantly from one to seven ($P = 0.11$).

Rules broken and those which were considered by the two reviewers to have been relevant to the outcome are presented in Table 3. At least one rule was broken by 13 of the 30 divers in the early group and 14 of the 37 in the later group. The rule of thirds was most commonly broken ($n = 20$) and most commonly relevant to the outcome ($n = 11$), followed by the line rule and gas rule (Table 3). The light rule was not considered relevant to any fatalities.

The causal chain of each trained cave diver fatality is shown in the taxonomy of cave diving fatalities flowchart in Figure 2. The most common cause of death was asphyxia due to drowning ($n = 41$). In 28 of those, the second tier was running out of gas, and the most common harmful action preceding this was getting lost ($n = 12$). Triggers for getting

Table 3
Summary of broken rules and relevancy by time period; *n* (%)

	Early group (*n* = 30)	Later group (*n* = 37)	Overall (*n* = 67)
Rules broken			
Thirds rule	6	8	14
Gas rule	4	5	9
Line rule	6	2	8
Light rule	1	2	3
Broken and relevant			
Thirds rule	3	8	11
Line rule	5	2	7
Gas rule	2	2	4
Light rule	0	0	0

lost included loss of visibility due to suspended silt (LVSS) ($n = 6$), taking a wrong turn in a complex cave system ($n = 3$) and entering a cave without a continuous guideline back to safety ($n = 2$).

Eleven drownings occurred due to other harmful actions: seven had witnessed convulsions (seizures) at depth; in at least four of those, the harmful action was using the wrong tank with a breathing gas mix which was toxic at the dive depth and a fifth diver had old oxygen sensors in his rebreather. For two divers, the remaining gas was not known (Figure 2) and there were two more divers who appeared to have suffered CNS seizures; one in which there was no medical examiner's report or death certificate, so the case was classed as 'unknown', and one where the cause of death was determined to be arterial gas embolism, following the harmful action of a rapid ascent caused by oxygen toxicity.

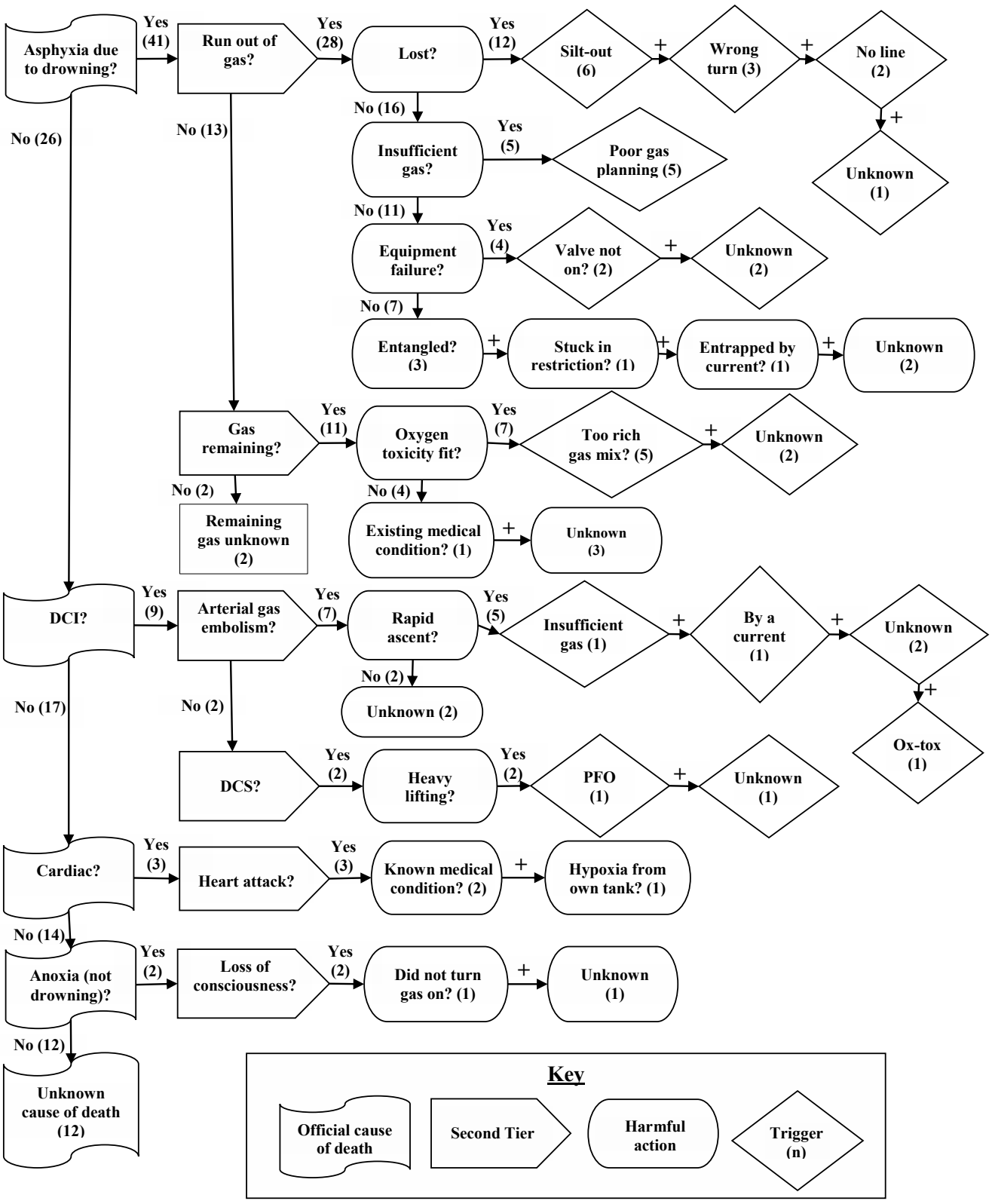
Also notable are two divers who apparently did not trust the direction of line arrows indicating the direction towards the nearest exit and swam further into the cave, while the surviving buddies followed the direction of the arrows to a safe exit. The cause of death in two further divers was reported as 'anoxia' (not drowning); one in which the diver did not open the valve of his rebreather oxygen cylinder and the other where the diver remained in a coma for two weeks before dying.

Discussion

The apparent annual decrease in cave diving fatalities in the US and that fewer were untrained may be because of the increased availability of cave diver training and restricted access to caves for untrained divers. However, this is somewhat speculative in the absence of known denominators. The average age of fatalities among trained cave divers has increased at a comparable rate to that among recreational diving fatalities generally, by approximately two years in every four.[9] Concurrently, the proportion of females among the fatalities has doubled but remains

Figure 2

Taxonomy of USA cave diving fatalities in divers trained in cave diving techniques; Ox-tox – oxygen toxicity



relatively small and statistically insignificant. Whether or not the proportion of women fatalities observed in this study is commensurate with the proportion of women who cave dive, or the proportion of cave dives made by women, cannot be determined from this study alone. Aside from increasing age, there is little difference in anthropometrics between the early and late groups of cave diving fatalities.

When it comes to the five golden rules, two, in particular, have emerged as crucial to survival: the line rule and the thirds rule. Maintaining a continuous guideline to the surface remains as essential as ever. The logic behind turning the dive when no more than a third of the total gas reserve has been spent is that any solo diver or pair of divers would have the minimum gas required to exit even if they were to lose half their total gas at the point of maximum penetration. Among the cave-diving-trained fatalities in this study for whom breaking the thirds rule was thought relevant, all but one ran out of gas, whereas among those for whom breaking the thirds rule was not considered relevant ($n = 56$), 19 died owing to other circumstances (e.g., entangled in line or stuck in a restriction) and nonetheless ran out of gas. Solo cave divers and buddy pairs especially may want to consider if the rule of thirds is adequately conservative for their intended dive. While the thirds rule aims to mitigate a catastrophic loss of gas, it may not adequately account for unintended delays such as loss of visibility from suspended silt, entanglement or entrapment in a restriction.

As in a larger study that included untrained cave divers, drowning was the most common cause of death.[2] In both studies, the commonest cause of drowning was running out of air due to loss of visibility. Since most oxygen toxicity seizures are preventable, cave diver training agencies should also continue to reinforce the rule "*always dive at, or shallower than, a safe depth for the gas being used*". Promoting the analysis of all breathing gases before every dive and clear marking of the cylinders is also important for diving safety. Four divers breathed an oxygen-rich gas at depth that was intended for decompression and a fifth diver is thought to have been using a rebreather with out-of-date oxygen sensors and a malfunctioning solenoid. This combination may have raised the inspired partial pressure of oxygen without alerting the electronic alarm system. Individual variation in susceptibility to oxygen toxicity may also be a key factor, possibly contributing to four more cases, when coupled with additional factors such as exercise.

Conclusions

The proportion of divers dying in caves in the US who were not trained for cave diving has steadily fallen over the last three decades. The average age of trained cave divers who died, as with recreational divers in general, has increased. Fatalities involving DPVs, rebreathers and greater distance penetrations are also on the rise, though none statistically significantly, given the relatively small numbers. Use of these new types of equipment and styles of diving are not specifically covered by the five historic safe cave diving rules and should only be adopted after careful personal consideration, for example, with regards to DPV redundancy. The line rule and thirds rule are as relevant as ever and we recommend that cave divers pay particular attention to gas planning and use of a continuous guideline. We recommend that divers do not get off the guideline, particularly during loss of visibility, as well as doing double and triple checks that the gases they are breathing are appropriate for their intended dive depths.

References

1 Webster DP. Skin and scuba diving fatalities in the United States. *Public Health Rep*. 1966;81:703-11.
2 Buzzacott P, Zeigler E, Denoble P, Vann R. American cave diving fatalities 1969-2007. *International Journal of Aquatic Research and Education*. 2009;3:162-77.
3 Exley S. *Basic cave diving: a blueprint for survival*. Brandford, FL: National Speleological Society Cave Diving Section; 1979.
4 Zumrick JL, Prosser JJ, Grey HV, editors. *NSS Cavern Diving Manual*. 1st ed. Branford, FL: National Speleological Society Cave Diving Section; 1988.
5 Jablonski J. *Beyond the daylight zone: The fundamentals of cave diving*. High Springs, FL: Global Underwater Explorers; 2001.
6 Fock AW. Analysis of recreational closed-circuit rebreather deaths 1998-2010. *Diving Hyperb Med*. 2013;43:78-85.
7 Denoble PJ, Caruso JL, Dear GL, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med*. 2008;35:393-406.
8 Lippmann J, Lawrence CL, Wodak T, Fock A, Jamieson S, Walker D, Harris R. Provisional report on diving-related fatalities in Australian waters 2010. *Diving Hyperb Med*. 2015;45:154-75.
9 Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA, Vann RD. Scuba injury death rate among insured DAN members. *Diving Hyperb Med*. 2008;38:182-8.

Acknowledgements

The authors wish to thank the many agencies that assist DAN in diving fatality research, and DAN fatality researchers Jeanette Moore and Brittany Trout.

Conflicts of interest: nil

Submitted: 04 December 2015; revised 14 March, 05 May and 24 July 2016
Accepted: 25 July 2016

Leah Potts[1,2], Peter Buzzacott[1,3], Petar Denoble[1]

[1] Divers Alert Network, Durham, North Carolina, USA
[2] Department of Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, USA
[3] School of Sports Science, Exercise and Health, University of Western Australia, Crawley, Australia

Address for correspondence:
Peter Buzzacott
Divers Alert Network
6 West Colony Place
Durham, 27705, USA
pbuzzacott@dan.org

Safety of transport and hyperbaric oxygen treatment in critically-ill patients from Padua hospitals into a centrally-located, stand-alone hyperbaric facility

Gerardo Bosco, Giacomo Garetto, Alessandro Rubini, Antonio Paoli, Prachiti Dalvi, Devanand Mangar and Enrico M Camporesi

Abstract

(Bosco G, Garetto G, Rubini A, Paoli A, Dalvi P, Mangar D, Camporesi EM. Safety of transport and hyperbaric oxygen treatment in critically-ill patients from Padua hospitals into a centrally-located, stand-alone hyperbaric facility. *Diving and Hyperbaric Medicine*. 2016 September;46(3):155-159.)

Introduction: Some patients admitted to the intensive care unit (ICU) might require repetitive hyperbaric oxygen treatment (HBOT) while receiving critical care. In such cases, the presence of a hyperbaric chamber located inside or near an ICU is preferable; however, this set-up is not always possible. In Padua, the "*Associazione Tecnici IPerbarici*" hyperbaric centre is a stand-alone facility outside of a hospital. Despite this, selected ICU patients receive HBOT at this facility.

Methods: We retrospectively reviewed the medical records from 2003 to 2013 of 75 consecutive, critically-ill patients, 28 of whom were initially intubated and mechanically ventilated whilst undergoing HBOT. We evaluated the methods adopted in Padua to guarantee the safety and continuity of care during transfer for and during HBOT in this specially-equipped multiplace chamber.

Results: The 75 patients collectively received 315 HBOT sessions, 192 of which were with the patients intubated and mechanically ventilated. The diagnoses ranged from necrotizing fasciitis to post-surgical sepsis and intracranial abscess. We obtained full recovery for 73 patients. Two deaths were recorded not in close time relation to HBOT.

Conclusions: With meticulous monitoring, efficient transport and well-trained personnel, the risks associated with transportation and HBOT can be acceptable for the referring physician.

Key words

Hyperbaric oxygen therapy; intensive care medicine; infectious diseases; fasciitis, necrotizing; transport; clinical audit

Introduction

It is well accepted that high oxygen tension can provide multiple benefits to some critically-ill patients, from rapid inhibition of the production of necrotizing toxins to reduction of the hypoxic marginal zone after a period of acute ischaemia. The raised oxygen tension modulates oedema and cellular infiltration which normally extends deep into the viable tissue. The inflammatory process is, thus, held to a minimum.[1]

In this retrospective study, we investigated the safety of sending ICU patients to receive hyperbaric oxygen treatment (HBOT) to an external facility in the city of Padua. We describe, from both the medical and nursing viewpoints, how to prepare the patient for transfer to the hyperbaric centre and the methods adopted at the "*Associazione Tecnici IPerbarici*" (ATIP) Hyperbaric Medical Centre to ensure continuity of care to critically-ill patients during the administration of HBOT in a multiplace chamber.[2] We reviewed the complications and outcomes experienced during transport and HBOT treatment.[3] ATIP sees all of the most critically-ill patients in the area; thus, the medical professionals are well-acquainted with treatment regimens for critically-ill patients. Three separate ICU facilities from surrounding hospitals can refer patients to ATIP for HBOT. Therefore, cases are varied, from severe soft-tissue infections, post-surgical complications, severe multiple trauma, and the complications of serious systemic infections. These are all pathologies that require a multi-disciplinary approach, and benefit from HBOT starting as soon as possible.[4,5]

Materials and methods

The study was a retrospective chart review approved by the Institutional Review Board of the Biomedical Department at the University of Padua (audit approval number: 12) of 75 consecutive patients (56 male and 19 female; age range 35–55 y; BMI 27–31 $kg \cdot m^{-2}$) referred for HBOT from ICUs at three Padua hospitals from 2003 to 2013. For each patient, disease-related data, number of sessions, duration and pressures of HBOT, clinical outcomes, side effects, and degree of compliance to therapy were collected.

Prior to transfer, each patient was thoroughly evaluated to ensure they were appropriate candidates for HBOT.[6] The patient was first evaluated by an ATIP anesthesiologist in the ICU to assess their clinical status to ensure the absence of contraindications to HBOT and to help ward doctors and nurses to prepare the patient for therapy.[7] A proper clinical evaluation is critical for avoiding complications during HBOT and minimizing risks to the patient.[8] Their history was thoroughly reviewed to identify any potential past conditions that might contraindicate HBOT. Organs and apparatuses affected by an increase in ambient pressure or partial pressure of oxygen were given careful consideration.

Absolute contraindications included: the presence of an untreated pneumothorax, a history of spontaneous pneumothorax, history or diagnosis on admission of sub-pleural emphysematous bullae, a history of retinal detachment, or unstable angina. Relative contraindications can often be evaluated and temporarily managed during transport such as to not delay HBOT.[9,10]

EVALUATION OF THE STATE OF CONSCIOUSNESS

A patient's state of consciousness is evaluated at the bedside since not all patients coming from the ICU have a compromised level of consciousness. This is an important consideration when determining air breaks at pressure and pre-HBOT procedures to be performed (e.g., bilateral myringotomy). In the ICU, the patient may require pharmacological sedation with drugs whose administration must continue during HBOT.[11]

CARDIOVASCULAR EVALUATION

Cardiovascular function is often impaired in sepsis and interferes with the ability to transport the patient out of the ICU. We ensured that both blood pressure and heart rate were maintained within reasonable limits with the use of vasopressors. Systemic venous return and diuresis were evaluated on a daily basis. Heart rate was monitored and history or presence of valvular disease or angina was noted. Patients were also examined for presence and functionality of implanted defibrillators and pacemakers and their compatibility with the hyperbaric environment was evaluated.[12]

RESPIRATORY EVALUATION

Patients coming from the ICU may or may not be breathing spontaneously. If the patient was mechanically ventilated, he/she was assessed to determine if they were completely or partially dependent on the ventilator. In our hands, transport and HBOT require maintaining neuromuscular paralysis combined with adequate sedation for the intubated patient with appropriate drugs. Most patients could be transported on an inspired oxygen fraction (FiO_2) of 0.4.

Pulmonary function tests were evaluated, if available. Chest X-rays were important to verify the integrity of the structures, to confirm the absence of pneumothorax and the correct placement of the endotracheal (ETT) or tracheostomy tube. During HBOT, special attention was given to the ascent phase if the patient required positive end-expiratory pressure (PEEP) to prevent any gas trapping and the subsequent risk of pulmonary barotrauma. Thus, a holistic approach is used in assessing patient eligibility for HBOT. The assessment was conducted to determine both our capacity and ability to manage the patient while simultaneously ensuring continuity of care and minimizing risk to our patients.

The following checklist is commonly completed at the time of initiating transfer:

- Identify the number of infusion pumps and check sufficient quantity of drugs in the syringe(s) for the duration of treatment and any potential delays in transportation.
- Prepare administration of additional drugs to infuse via an IV infusion, as necessary.
- Discontinue unnecessary medication or infusions.
- Provide adequate pain relief for the duration of therapy.
- Suspend parenteral nutrition and whole blood or packed red blood cell infusions to simplify patient management in the chamber.
- Provide access for monitoring arterial blood pressure.
- If the ICU monitoring equipment is compatible with that of the hyperbaric unit, use the arterial line.
- If the monitoring equipment is not compatible, flush the arterial line with diluted heparin and close off.
- Ensure care of the endotracheal tube; nasal intubation rather than oral intubation is preferred because it is more stable and secure.
- Avoid use of a laryngeal mask.
- For tracheostomy tubes, ensure the connections are compatible with the chamber equipment.
- Provide free drainage of a nasogastric tube.
- Assess surgical drains for compatibility (most are) and control the shut-off position.
- Replace ileostomy and urinary drainage bags with fresh ones before sending for HBOT.

The physician and nurse team will continue to take care of the patient inside the pressure chamber. Both team members are ICU credentialed and HBOT trained.

TRANSFER PROTOCOL AND EQUIPMENT

The management of ambulance transport for these critically ill patients has evolved over the years, from manual ventilation with an Ambubag™ for intubated patients in the early years to an Oxylog 2000™ (Dräger) transport ventilator, always under the direct supervision of a critical-care-trained anesthesiologist. During transport, patient monitoring includes ECG, BP (either via an arterial line or non-invasively) and $SatHbO_2$ with a Propaq 106EL (Protocol System Inc.) from 2003 to 2007, then with a Siemens SC9000XL monitor. Drug infusions were continued during transport to the extent and in the manner agreed with the anesthesiologist at the hyperbaric centre, using Fresenius PILOTE C™ infusion pumps. Equipment used in transport and inside the hyperbaric chamber are routinely serviced to ensure all are in ideal working condition.[12]

HYPERBARIC UNIT PROCEDURES

All equipment in the chamber is assembled and tested prior to the patient's arrival to minimize time from leaving the ICU to beginning HBOT. At the ATIP Medical Centre, a hyperbaric

Table 1
Summary of the principal diagnoses; numbers of hyperbaric oxygen treatments (HBOT), including those with patients intubated and ventilated; other treatments and outcomes in 75 patients; DIC - disseminated intravascular coagulopathy; ETT - endotracheal tube

Diagnosis	Patients (*n*)	Initial notes	Other therapy	HBOT sessions intubated and ventilated	HBOT sessions post extubation	Outcomes
Perineal fasciitis	20	5 ETT 3 septic shock	Antibiotics; surgical debridement/drainage; myringotomies	26	15	19 full recovery 1 death
Cervical fasciitis	8	5 ETT 1 tracheostomy 3 septic shock	Antibiotics; surgical debridement/drainage; fasciotomies; myringotomies	20	13	8 full recovery
Gas gangrene	6	All ETT 6 septic shock Further surgery	Antibiotics; surgical debridement	20	35	2 amputations
Abdominal fasciitis (myositis)	15	4 ETT 3 tracheostomies 5 septic shock	Antibiotics; surgical debridement; myringotomies	20	13	15 full recovery
Dehiscent surgical wound	8	2 ETT 1 septic shock	Antibiotics; surgical debridement; myringotomies	23	13	8 full recovery
Mediastinitis	4	2 ETT 1 septic shock	Antibiotics; myringotomies	15	8	4 full recovery
Multiple trauma; acute ischaemia	12	2 ETT 1 septic shock Multiple surgeries	Antibiotics; surgical debridement; myringotomies	30	26	12 full recovery
Intracranial abscess	1	ETT	Antibiotics; myringotomies	20	-	1 full recovery
Meningitis; DIC	1	ETT	Antibiotics; myringotomies	25	-	1 death
Total	75			192	123	73 full recovery 2 deaths

physician received and re-evaluated the patients, transferred the monitoring and infusion systems, and assisted with ventilation by adapting the systems to be compatible with the hyperbaric environment. The mechanical ventilator and perfusion systems used at ATIP were a Siemens Servo 900 E ventilator and two Fresenius Pilote Hyperbaric, both of which were tested for use in hyperbaric environments and resulted in full compliance with European standards.[12] Patients were placed on the ventilator in controlled-volume mode, sedated and paralyzed. The level of PEEP set in the ICU was maintained during HBOT except during decompression when it was decreased to avoid any risk of pulmonary barotrauma and was then immediately restored to its previous level on exiting the chamber.

HBOT was provided in a large multiplace chamber compressed with air (Galeazzi, Zingonia-Italy). All patients were accompanied by an experienced physician who remained inside the chamber throughout the treatment. Oxygen was inhaled through a cuffed ETT or tracheostomy tube. The cuff of the tube was filled with air during HBOT, changing the amount of air in the cuff while changes in chamber pressure occurred to prevent leakage past the cuff or undue pressure on the mucosal lining of the trachea.

The standard HBOT protocol includes a pressure of 254–284 kPa on a daily basis for up to several weeks.[13] Conscious, spontaneously-breathing patients inhaled pure O_2 from a demand-regulated mask for three 25-min periods, interrupted by two 5-min air breaks to minimize the risks of O_2 pulmonary toxicity. For intubated, mechanically ventilated patients, no air breaks were administered. For patients with severe necrotizing soft-tissue infections (NSTIs), the protocol was modified to initiate treatment with five closely-spaced sessions over 48 hours at 284 kPa.[5,8] The precise therapeutic schema was modified on a case-by-case

basis to suit the disease being treated as well as the clinical response achieved. Arterial oxygen saturations before and after HBOT were also monitored.

Results

A summary of the findings is reported in Table 1. Twenty-eight patients were first treated while intubated and mechanically ventilated, and received myringotomies. Subsequently, they received HBOT while breathing spontaneously after extubation.[11] A total of 315 HBOT were given to the 75 patients reviewed, 192 whilst the patients were intubated and ventilated. We did not consider 25 patients rejected for absolute contraindications to HBOT in the same time frame.

Twenty-six patients had NSTIs, of whom 20 had necrotizing fasciitis of the buttock/perineal region and six gas gangrene (GG) of a limb. The diagnosis of GG was made on the basis of fever, tachycardia, severe pain, septic shock, odour, crepitation of tissues, and the presence of gas on X-ray. The finding of Gram-positive rods in a Gram stain confirmed the diagnosis. The patients required placement of multiple decompressive drains and fasciotomies while in the ICU and then they were transferred into the hyperbaric chamber. Surgical debridement with removal of infected and dead tissue was performed prior to HBOT exposure.[14] In 15 patients with abdominal fasciitis, incision and drainage were carried out in the ICU and a temporary colostomy was performed in the operating room to protect the perineal area before HBOT to avoid the passage of stool through the anus and contamination of the perineal wounds.

Eight patients were treated with HBOT for other types of poorly healing surgical wounds. These patients had recently undergone a thoracotomy or a laparotomy and, at the time of surgery, were immunosuppressed. They underwent repeated surgical debridements and subsequently healed. Nine of the thirteen patients with Fournier's syndrome received concomitant antibiotic therapy and surgical debridement(s). The twelve multiple trauma patients were treated with HBOT for ischaemia and/or compartment syndrome. Eight patients with cervical fasciitis and four with mediastinitis were treated with HBOT after surgical debridement. The one patient with disseminated intravascular coagulation suffered from a bacterial meningitis. One patient was diagnosed with an intracranial abscess. The most serious NSTI cases received an initial series of treatments with HBOT at 283 kPa, five times in 48 hours.

All in all, complete recovery was achieved in 73 of the 75 patients. No complications or untoward events occurred during transport or during HBOT. The median time for transportation from the hospital ICU to ATIP in Padua was 21 min (range: 16–29 min). Complications post-therapy included a pneumothorax discovered after return to the ICU. Two deaths from cardiac arrest occurred in patients with Waterhouse-Friderichsen syndrome a few hours after leaving the hyperbaric centre. To 2013, no other in-hospital deaths were reported in this group of patients.

Discussion

The ideal is for the recompression chamber to be situated in or close to the ICU; however, most medical facilities responsible for treating critically-ill patients are not equipped with hyperbaric chambers. Hyperbaric facilities, even if located inside the hospital, are often at some distance from the ICU. Complications compromising patient safety are a major potential risk whilst transporting ICU patients to and fro for remote investigations (e.g., radiological procedures) or treatment such as HBOT. Careful management, using well-established protocols for monitoring and ventilator care by a team skilled in treating ill patients and knowledgeable of the possible complications of HBOT, as in the Padua experience, are pivotal for patient safety.[10]

Critically-ill patients are at increased risk of morbidity and mortality during transport. The transport process itself is associated with a risk of physiological deterioration and adverse events. The incidence of adverse events is proportional to the duration of the transfer, to the pre-transfer severity of illness or injury and to the inexperience of the medical escorts. Risk can be minimized and outcomes improved with careful planning, qualified personnel and appropriate equipment.[15] Many recommendations are available from expert opinion identifying effective 'protective' factors related to the patients, such as equipment checks, accurate preparation of the patient, correct use of protocols, and diagnostic and therapeutic units located within easy reach of the emergency department or ICU.[16] Furthermore, good clinical commonsense is required to decrease adverse events during transport and the risk has to be balanced against the expected benefits of the HBO procedure.

In the present study, the patients were monitored by an intensive-care trained anesthesiologist/hyperbaric specialist at all times during transport, HBOT and return to the ICU. Since none of the patients in this study experienced any transport-related challenges or complications, the ATIP's HBOT protocol has the potential to serve as a prototype for hyperbaric medical centres. Thus, with meticulous monitoring, efficient transport, and well-trained personnel, the risks of transportation and HBOT can be acceptable for the referring physician.

Conclusions

Hyperbaric oxygen treatment can be administered safely to most critically-ill patients in a multiplace chamber provided they are monitored closely with appropriately trained, experienced personnel present. Although the ATIP Medical Centre in Padua is a stand-alone facility, the time of transport

to the intervention was kept short by thorough preparation. No clinical complications during either transport or HBOT were reported in 75 consecutive patients reviewed over a decade, of whom all but two who died made a full recovery.

References

1 Camporesi EM, Bosco G. Mechanisms of action of hyperbaric oxygen therapy. *Undersea Hyperb Med*. 2014;41:247-52.

2 Eke N. Fournier's gangrene: a review of 1726 cases. *Br J Surg*. 2000;87:718-28.

3 Edlich RF, Cross CL, Dahlstrom JJ, Long WB. Modern concepts of the diagnosis and treatment of necrotizing fasciitis. *J Emerg Med*. 2010;39:261-5.

4 Weaver LK. Critical care of patients needing hyperbaric oxygen. In: Thom SR, Neuman T, editors. *The physiology and medicine of hyperbaric oxygen therapy*. Philadelphia: Saunders/Elsevier; 2008. p. 117-29.

5 Weaver LK. Hyperbaric oxygen in the critically ill. *Crit Care Med*. 2011;39:1784-91.

6 Mathieu D, Ratzenofer-Comenda B, Kot J. Hyperbaric oxygen therapy for intensive care patients medications and risk-benefit balance. *Diving Hyperb Med*. 2015;45:42-6.

7 Lind F. A pro/con review comparing the use of mono and multiplace chambers for critical care. *Diving Hyperb Med*. 2015;45:56-60.

8 Lind F, Ohlen G, Linden V, Eriksson B, Frostell C. *Treatment with hyperbaric oxygen (HBO) at the Karolinska University Hospital. A Stockholm County Council report on the clinical practice and evidence basis of hyperbaric medicine*. [cited 2016 July 07]. Stockholm: Stockholms Lans Landsting; 2011. Available at: http://www.hyperbaricoxygen.se

9 Soh CR, Pietrobon R, Freiberger JJ, Chew ST, Rajgor D, Gandhi M, et al. Hyperbaric oxygen therapy in necrotizing soft tissue infections: a study of patients in the United States Nationwide Inpatient Sample. *Intens Care Med*. 2012;38:1143-51.

10 Willy C, Rieger H, Vogt D. [Hyperbaric oxygen therapy for necrotizing soft tissue infections: contra.] Chirurg 2012;83:960- 72. German.

11 SIAARTI / SIMSI/ ANCI. *Linee guida sulle indicazioni all'ossigenoterapia iperbarica Medicina Subacquea ed iperbarica* 1, Rome: Marzo; 2007. Italian.

12 J Kot. Medical equipment for multiplace hyperbaric chambers. *Diving Hyperb Med*. 2006;7:29-31.

13 Levett D, Bennett MH, Millar I. Adjunctive hyperbaric oxygen for necrotizing fasciitis. *Cochrane Database Syst Rev*. 2015 Jan 15;1:CD007937.

14 Shupak A, Shoshani O, Goldenberg I, Barzilai A, Moskuna R, Bursztein S. Necrotizing fasciitis: an indication for hyperbaric oxygenation therapy? *Surgery*. 1995;118:873-8.

15 Parmentier-Decrucq E, Poissy J, Favory R, Nseir S, Onimus T, Guerry MJ, et al. Adverse events during intrahospital transport of critically ill patients: incidence and risk factors. *Ann Intensive Care*. 2013;3:10. doi: 10.1186/2110-5820-3-10.

16 Warren J, Fromm Jr RE, Orr RA, Rotello LC, Horst HM. American College of Critical Care Medicine. Guidelines for the inter-and intrahospital transport of critically ill patients. *Crit Care Med*. 2004; 32:256-62.

Acknowledgements

We wish to thank all our ATIP and hospital medical, nursing and technical colleagues for their skill and professionalism in caring for the patients presented in this report.

Conflicts of interest: nil

Submitted: 07 December 2015; revised 29 February, 05 May and 01 July 2016
Accepted: 13 July 2016

Gerardo Bosco[1], Giacomo Garetto[2], Alessandro Rubini[1], Antonio Paoli[1], Prachiti Dalvi[3], Devanand Mangar[4], Enrico M Camporesi[5]

[1] Department of Biomedical Sciences, University of Padua, Padua, Italy
[2] Associazione Tecnici IPerbarici (ATIP) Hyperbaric Medical Centre, Padua, Italy
[3] TeamHealth Anesthesia, Tampa General Hospital, Tampa, Florida, USA
[4] Department of Surgery and TeamHealth Anesthesia, Tampa General Hospital, Tampa, Florida, USA
[5] Department of Surgery and Anesthesiology, University of South Florida, Tampa, Florida ; TeamHealth Anesthesia, Tampa General Hospital, USA

Address for correspondence:
Enrico M Camporesi
1 Tampa General Hospital Circle, Suite A327
Tampa
Florida 33606, USA
ecampore@health.usf.edu

Hyperbaric oxygen therapy in the treatment of sudden sensorineural hearing loss: a retrospective analysis of outcomes

Susannah Sherlock, Kenneth Thistlethwaite, Mohsina Khatun, Christopher Perry and Alexis Tabah

Abstract

(Sherlock S, Thistlethwaite K, Khatun M, Perry C, Tabah A. Hyperbaric oxygen therapy in the treatment of sudden sensorineural hearing loss: a retrospective analysis of outcomes. *Diving and Hyperbaric Medicine*. 2016 September;46(3):160-165.)

Objective: To analyse predictive factors affecting outcome after treatment with hyperbaric oxygen (HBOT) in patients with idiopathic sudden sensorineural hearing loss (ISSHL).

Methods: This is a retrospective audit of outcome in 77 consecutive patients referred for consideration of HBOT for ISSHL for either adjunctive treatment or after failure of steroid therapy. The hearing measured from the pre- and post-HBOT pure-tone audiogram (PTA_4) at four frequencies; 500 Hz, 1 kHz, 2 kHz and 4 kHz, was averaged and compared. The PTA_4 score was classified into three groups: complete improvement (≤ 25 dB residual hearing loss); moderate improvement (11–50 dB gain) and no improvement (≤ 11dB gain). Data were also analysed using mean residual loss on completion as the outcome measure.

Results: Seventy-six patients underwent 1,029 HBOT sessions. Twenty five of 78 ears (33%) had complete resolution of deafness after HBOT. A further 31 (40%) had a significant improvement in PTA_4. Delay (> 28 days) and older age were associated with worse outcomes in PTA_4 improvement. Those with less severe hearing loss and short delay (< 15 days) had the best outcome (mean residual loss 28 dB). Eight of nine patients who were delayed > 28 days had no improvement in PTA_4.

Conclusions: Fifty-six of 76 (74%) patients had complete (25) or moderate (31) improvement in hearing loss after HBOT. Short delay to HBOT, a severer degree of hearing loss and younger age were the best predictive factors of improved PTA_4. Outcome was poor if treatment was delayed over 28 days. Well-designed randomised controlled trials are needed to clarify the role of HBOT and steroids.

Key words

ENT; inner ear; risk factors

Introduction

The diagnosis, incidence, pathology, treatment and natural history of idiopathic sudden sensorineural hearing loss (ISSHL) are all areas of controversy. It is defined by the National Institute on Deafness and Other Communications Disorder (NIDOCD) as the "*sudden loss of hearing over three contiguous pure-tone frequencies of 30 dB or more that develops over 72 hours or less*".[1] Due to the high number of potential causative agents, including ischaemia, it is not surprising that many therapies have been tried: among them hyperbaric oxygen treatment (HBOT), rheological agents, antiviral agents, acupuncture, vitamins and steroids.[2–4]

The American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) recently released clinical practice guidelines suggesting HBOT could be useful up to three months after onset of symptoms; however, the hyperbaric literature suggests best outcomes if utilised within two weeks of symptoms.[5,6] On the basis of this discrepancy we conducted a retrospective audit to identify patient factors affecting outcome.

BACKGROUND

ISSHL was first described in 1944.[7] The reported incidence of 160 per 100,000 may be an underestimation because up to 65% of cases resolve spontaneously usually within two weeks.[8,9] This high rate has been disputed by others and may be as little as 25%.[10] However, spontaneous resolutions are acknowledged to be rare beyond two weeks.[11] Recently published work suggests 72% of ISSHL cases are idiopathic.[12] Most cases are unilateral. Bilateral disease has a poorer prognosis and should raise suspicion of serious systemic aetiology.[13] The recurrence rate is quoted as being 5%.[14] ISSHL is considered to be a medical emergency by many (though not all) ear, nose and throat (ENT) surgeons and can have a profound impact on a patient's ability to communicate, especially when it is bilateral.[15] However, despite its importance, the optimum management remains unclear.

A Cochrane review of the use of anti-viral agents to treat ISSHL concluded their use was questionable.[16] AAO-HNS clinical practice guidelines suggest they should not be routinely prescribed. Corticosteroids have traditionally been considered the gold standard treatment but there is considerable debate about the level of effectiveness, dosing, timing and route of administration. A Cochrane review suggests their usefulness on the basis of randomised, controlled trials (RCTs) is not proven.[17] HBOT has been advocated as salvage treatment when steroids have failed.[18] When HBOT is employed, there is inconsistency in previous publications on the timing, treatment depth and number

of treatments. A Cochrane review of the use of HBOT for ISSHL concluded that "*for people with acute ISSHL, the application of HBOT significantly improved hearing, but the clinical significance remains unclear.*"[19]

In a survey of the clinical management of ISSHL by otorhinolaryngologists in the UK, 96% recommend corticosteroids, 45% recommend antiviral therapy and only 4% recommend HBOT. [3] Despite supportive evidence for HBOT, it is not recommended as first-line treatment but, rather, as salvage therapy when other medical therapies have failed.[8,20]

HBOT RATIONALE

HBOT was first recommended in the treatment of ISSHL in the 1960s to improve cochlear ischaemia by reducing cochlear oedema. Auditory cells and peripheral nerve fibres have no direct vascular supply and are dependent on oxygen diffusion through the perilymph and cortilymph. This is likely to be improved by circulating arterial oxygen tensions over 1,500 mm Hg produced by HBOT at 243 kPa. Treatment at 152 kPa has been shown to be of no benefit after unsuccessful steroid therapy.[21] Furthermore, HBOT has been demonstrated to have immunomodulatory and anti-inflammatory effects, to improve local haemodynamics and induce angiogenesis.[22,23] HBOT is considered a relatively safe treatment. The most common reported side effect is barotrauma of the tympanic membrane, mild and self-limiting in most cases, (overall incidence often quoted as 17.8%) which can complicate therapy, especially if continued treatment requires grommet insertion.[24]

Methods

We conducted a retrospective review of all the patients treated with HBOT for ISSHL at a quaternary referral hospital, the Royal Brisbane and Women's Hospital, between 01 January 2012 and 30 June 2014. This study is reported in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines.[25] The project was exempted from full ethics review as a low- and negligible-risk research project by the Royal Brisbane and Women's Hospital Human Research Ethics Committee (HREC/15/QRBW/55).

Patient records were identified from the local database with the code "*hearing loss*". Only patients with the strict definition of ISSHL as used by the NIDOCD were included. The pre- and post-HBOT audiograms were extracted and general demographics collected such as date of birth, gender and previous medical history. Possible predictors of outcome recorded included age, sex, affected ear, severity of hearing loss, delay until HBO treatment and number of treatments.

HBOT consisted of 90 mins daily at 243 kPa for 10 treatments, then repeat audiogram. If the audiogram had improved less than 11 dB, treatment was ceased. If 11 dB or more, five further HBOT were offered. The audiogram was repeated after every five HBOT until no improvement was noted, at which point treatment ceased. The hearing measured from pure-tone audiogram (PTA_4) at four frequencies (500 Hz, 1 kHz, 2 kHz and 4 kHz) was averaged and compared. All data were de-identified and extracted to an Excel™ file to be analysed by an independent statistician.

To explore potential factors associated with outcome, we defined the following categorical variables: severe (> 60 dB) and moderate (≤ 60 dB) pre-treatment hearing loss; age with ≤ 50 years and > 50 years. Number of treatments was categorised as ≤ 10 or > 10. Delay in presentation was categorized as early (within 14 days), moderately delayed (15–28 days) and late (> 28 days). In the absence of consensus in the literature, these categories were defined arbitrarily using categories published by other groups. Mean residual losses were compared by the delay in presentation for treatment accounting for severity of pre-treatment PTA_4 score using the F-test statistic.

Improvement in the PTA_4 score (before/after HBOT) was categorized into three groups; complete recovery, moderate improvement (11–50 dB gain) and no improvement (≤ 10 dB gain). Complete recovery was defined as a hearing loss of ≤ 25 dB (below predicted) at the end of treatment as defined by the NIDOCD and the World Health Organisation.[1,26]

STATISTICS

General linear modelling was applied to examine the unadjusted and adjusted association of patient demographic and clinical characteristics with the absolute change in hearing after treatment (dB). The change in hearing was calculated taking the difference between post- and pre-treatment PTA_4 score. The results were rounded to the nearest whole number. Selection of potential characteristics for the adjusted analysis was based on the unadjusted association with P-value < 0.10. A stepwise, backward selection process was applied to find the parsimonious model with all the significant covariates. The estimated marginal mean values were presented and the results were evaluated using 95% confidence intervals (CI) and the P-values. A P-value less than 0.05 was accepted as statistically significant.

Results

There were 77 patients with 79 affected ears (two bilateral). One patient with unilateral loss was excluded as they did not meet the definition of ISSHL. The remaining 76 patients underwent a total of 1,029 patient compressions (Table 1). Nine patients suffered self-limiting tympanic barotrauma and two required grommet insertion to complete therapy. There were no major complications. All patients had been prescribed oral corticosteroids at the specialist's discretion of

Table 1

Patient demographics (n = 78), hyperbaric oxygen treatment (HBOT) and hearing loss pre and post HBOT; * P < 0.001

Patient characteristics	Mean	(95% CI)
Pre-treatment hearing loss (dB)	69	(64, 75)
Post-treatment hearing loss (dB)	47	(40, 53)
Mean gain in hearing post HBOT (dB)	23	(19, 27)*
Age (year)	52	(48, 56)
Male/Female	42/36	
Ear treated (left/right)	41/37	
Delay to HBOT (day)	13	(11, 16)
No. of HBOT	14	(12, 15)
Smoker (n = 50)		
Ever smoker	20	
Never smoker	19	
Unknown	11	
Heavy alcohol use (n = 50)		
Yes	5	
No	33	
Unknown	12	

Figure 1

Treatment outcomes relative to the delay in presentation

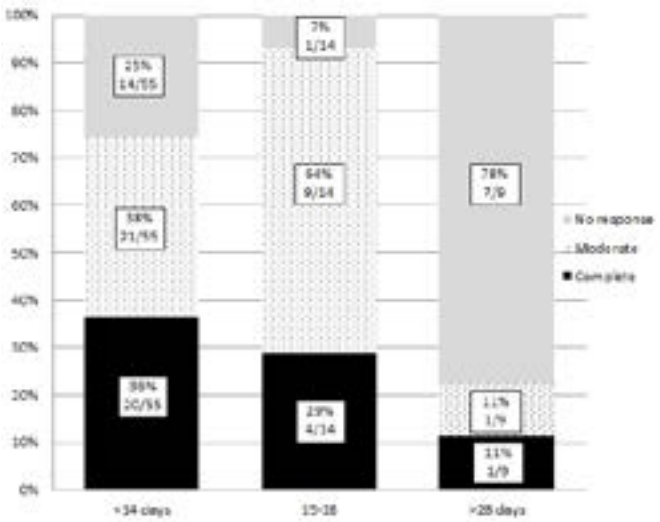


Table 2

Pure-tone audiogram PTA_4 (dB) scores after treatment for two levels of pre-treatment PTA_4 and delay at presentation; mean (95% CI)

		Post-treatment PTA_4 loss				
Pre-treatment PTA_4		**≤ 60 dB**		**> 60 dB**		
Delay to presentation	(n)	Mean	(95% CI)	Mean	(95% CI)	P-value
< 15 days	55	28	(21, 34)	59	(47, 71)	≤ 0.001
15–28 days	14	30	(16, 44)	55	(35, 75)	0.151
> 28 days	9	50	(31, 69)	63	(30, 95)	0.280
Mean (95% CI)	76	31	(25, 36)	59	(50, 68)	
P-value		0.027		0.911		

dose, most commonly 1 mg·kg^{-1} prednisone, prior to referral. All patients had an MRI scan to exclude retrocochlear malignancy.

Among the four continuous variables: age; mean gain in hearing and post-treatment hearing loss all followed a normal distribution. Pre-treatment hearing loss did not, and should be more correctly shown as a median score since it was moderately skewed (skewness = 0.685). Also, delay in presentation was positively skewed. However, the mean score of delay in presentation was 13 days and the median was 12 days (interquartile range, IQR 4, 17), which are not much different from each other. For consistency with other mean values in Table 1, the mean values for this variable with 95% CI are shown.

Figure 1 compares the percentage of people who benefitted from HBOT (measured by improvement in PTA_4) between groups classified by delay to HBOT. Delay over 28 days meant no improvement with HBOT for seven of the nine patients in this category. One patient had complete recovery with delayed presentation compared to 20 patients in the < 14 day group.

Fifty-six (73%) of 78 ears with ISSHL had complete or moderate improvement in hearing loss when HBOT was added to conventional steroid therapy. Improvement was moderate in 31 patients after HBOT, whilst 24 (25 ears; 32%) were considered to have normal hearing post treatment, according to the definition of the NIDOCD. Nine patients had minor worsening of PTA_4 (range -7 dB to -1 dB deterioration) which was not considered a significant change on the audiogram.

Table 2 demonstrates mean residual hearing loss after treatment among the patients with different delay times and accounting for different levels of pre-treatment PTA_4 scores. Results show a significant effect on poor outcome for delay to HBOT but only for the moderate hearing loss afflicted patients (P = 0.027). Delay did not show a statistically significant association in those with > 60 dB loss at presentation (P = 0.911). Of those with greater impairment,

Table 3
Unadjusted and adjusted means (95% CI and *P*-values) of the change in hearing after hyperbaric oxygen treatment by the patient's demographic and clinical features

		Change in hearing after the treatment (dB)					
		Unadjusted			Adjusted		
Selected characteristics	(*n* = 78)	Mean	(95% CI)	*P*-value	Mean	(95% CI)	*P*-value
Pre-treatment PTA_4 (dB)							
≤ 60	34	18	(12, 24)	0.032	16	(9, 22)	0.029
60+	44	27	(21, 32)		25	(18, 31)	
Age (y)							
≤ 50	37	27	(21, 33)	0.086	24	(17, 30)	0.043
50+	41	19	(14, 25)		16	(10, 22)	
Sex							
Male	42	25	(19, 30)	0.393			
Female	36	21	(15, 27)				
Ear							
Left	41	19	(14, 25)	0.071	16	(10, 22)	0.071
Right	37	27	(21, 33)		23	(17, 30)	
Number of treatments							
≤ 10	33	21	(15, 28)	0.566			
10+	45	24	(18, 29)				
Delay in presentation							
Early presentation	55	24	(20, 29)	0.036	24	(19, 28)	0.028
Moderately delayed	14	26	(17, 36)		27	(18, 36)	
Late presentation	9	8	(-4, 20)		9	(-3, 20)	

even early intervention with HBOT was less likely to be of benefit when examined with respect to final PTA_4 rather than absolute change in PTA_4 ($P < 0.001$). Early or moderately delayed presentation showed significant benefit compared to late presentation ($P = 0.028$).

Age also became a significant prognostic indicator in the adjusted analysis ($P = 0.043$), showing younger patients derived more dB gain. The unadjusted and adjusted association with the absolute change in hearing (dB improvement) after the treatment is presented in Table 3. In the adjusted analysis, patients with severe hearing loss (> 60 dB) had a significantly greater improvement (25 dB) compared to patients with moderate hearing loss (16 dB) ($P = 0.029$).

Discussion

In this study of patients with ISSHL treated with HBOT we found that delay to treatment was strongly correlated with poor outcome, which is consistent with previous reports.[27] Delay in receiving HBOT of more than four weeks significantly reduced any perceived benefit of HBOT; indeed, successful treatment of ISSHL by any modality after four weeks is rare. Our data does not support the AAO-HNS guidelines that HBOT should be considered up to three months after onset of sudden deafness. We would suggest HBOT beyond four weeks has little benefit but should be considered on a case-by-case basis.

Younger age, hearing loss > 60 dB and early HBOT were significant prognostic indicators of a greater improvement in PTA_4. The best hearing outcome, when defined as mean residual hearing loss post treatment, was achieved in younger patients with a hearing loss < 60 dB who presented early. This group achieved a mean residual loss of 28 dB which approaches the adult defined limits of normal hearing at -25 dB. Severe loss and younger age have been reported to be good prognostic indicators of success in patients treated with steroids.[28] This may be because those with a greater hearing loss have more to gain and the young have less vascular disease. Reports on age-related effects on responses to treatment have been conflicting when comparing different therapies.[16,29] Our results support younger age as a good prognostic indicator of response to HBOT.

However, when analysing the data using the more patient-centred outcome measure of mean residual loss after treatment as the outcome measure rather than the overall improvement in PTA_4, the results were different. Those with a loss < 60 dB achieved better outcomes ($P \leq 0.001$). And even more interestingly, delay had a statistically significant negative effect on outcome in the group with a loss < 60 dB ($P = 0.027$). The same effect from delay to treatment was not reflected in the group with an initial loss > 60dB. We hypothesise that the evolution of the injury involves an additional pathology that causes a more severe audiological impairment and resistance to treatment with HBOT. This may simply represent a

more severe ischaemic insult with secondary oedema and inflammation and is worthy of further investigation.

This highlights the importance of choice of outcome measure when assessing improvement. Residual hearing loss after treatment is arguably more functionally important than absolute change in PTA_4 from presentation. A patient with profound loss may have a marked measured improvement in PTA_4 but still have a severe hearing deficit resistant to amplification. We believe residual mean loss is the better outcome measure. Those who presented with profound loss but gained some hearing improvement may still have benefitted from HBOT. This level of gain can functionally change a non-aidable level of deafness to a level that can be improved with a hearing aid. However, the numbers in the delayed group were small, so interpretation of statistical significance should be cautious.

Definitions of what constitutes a response to treatment differ widely in the literature. Improvement is usually defined as greater than 10 dB improvement in pure-tone average (PTA) but other definitions and mathematical formulae have been used in different studies. In our analysis a change of 10 dB or less was considered no improvement. Some studies have also used speech discrimination score (SDS) as a measurement of improvement. We chose to measure PTA_4 to assess response as it is simple, repeatable and robust. This is an easier marker than SDS for the hyperbaric physician to interpret and to tailor treatment duration by. PTA_4 and SDS usually reflect each other; however, some authors consider the mean PTA_4 to be a more objective measurement of outcome than SDS.[4,30] Future studies should include SDS and PTA_4 plus a functional assessment such as the (modified) Amsterdam Inventory for Auditory Disability and Handicap and a quality of life score such as that developed by Hawthorne.[30,31] No trials to date have assessed the functional impact of any measured improvements in PTA_4.

In the natural history of ISSHL described for 88 patients, only five patients had a good recovery after 14 days.[9] This study had a variety of interventions including conservative management and there was no difference shown between those who received drugs and those who did not. In our study, 13 of the 14 patients referred between 15 to 28 days after onset showed complete or moderate recovery. This is important since spontaneous improvement is reported in the ENT literature to be unlikely beyond two weeks. Interestingly, this group had the highest percentage of overall responders. This needs to be interpreted with caution as the smaller number of patients in this group decreases the power of the calculation. This may suggest that ischaemia reversal is not solely responsible for improvement. The mechanism may be due to reduction of oedema or blunting of secondary ischaemia due to reperfusion injury or may even indicate that HBOT has a better chance of success after steroid priming.

If the suggested pathology in patients who improve with HBOT is considered to be ischaemia, it would seem reasonable to institute therapy as early as possible. When delay was over 28 days, our small sample (nine patients) suggested reduced benefit from HBOT. This sample size is too small to determine the therapeutic window for HBOT. However the association with delay and worse outcome is very strong in the analysis using mean residual loss in those with ≤ 60 dB (34 patients) and reached high statistical significance ($P = 0.027$). Delay to HBOT is often due to misdiagnosis and being unable to access an ENT surgeon in a timely fashion. This should be addressed so patients get urgent referral for specialist care.

The incidence of barotrauma was similar to that reported in a French study and lower than previously reported in other series.[24,32]

There are limitations to the present study; most importantly that it is a retrospective, single-cohort study without a control group. In addition, the lack of inclusion of SDS scores and the risk of chance associations owing to the small numbers of patients in each group may be important. Most patients were referred promptly (early presentation) whilst still taking steroids rather than after failure of primary treatment. This makes it difficult to discriminate between HBOT and steroid effectiveness or a potential synergistic interaction between the two treatments in the early presenters. A randomised controlled trial comparing the effectiveness of steroids, HBOT alone or in combination is warranted to determine the most appropriate treatment for ISSHL.

Conclusion

Fifty-six (73%) of 78 ears with ISSHL had complete or moderate improvement in hearing loss when HBOT was added to conventional steroid therapy. Shorter delay prior to commencing HBOT and being younger than 50 years old were the best predictors of good outcome. In those with < 60 dB loss on presentation, delay to treatment impacted negatively on outcome whether the outcome measure was overall improvement in dB gain or mean residual loss at the end of treatment. This study has not established clearly a role for HBOT in ISSHL but the outcomes do appear to be improved compared to the literature on currently accepted treatments. Therefore, there is an urgent need for a large randomised controlled trial to fully elucidate the best treatment of ISSHL, a highly debilitating condition.

References

1 National Institute on Deafness and Other Communication Disorders. *Sudden deafness*. [cited 2016 May 25]. Available from: http:www.nidcd.nih.gov/health/Pages/sudden.aspx.

2 Kaya H, Koc AK, Sayin I, Gunes S, Altintas A, Yegin Y, et al. Vitamins A, C, and E and selenium in the treatment

of idiopathic sudden sensorineural hearing loss. *Euro Arch Otorhinolaryngol*. 2015;272:1119-25.
3 Stobbs N, Goswamy J, Ramamurthy L. How are we managing sudden sensorineural hearing loss in the United Kingdom?: our experience. *Clin Otolaryngol*. 2014;39:385-8.
4 Seggas I, Koltsidopoulos P, Bibas A, Tzonou A, Sismanis A. Intratympanic steroid therapy for sudden hearing loss: a review of the literature. *Otol Neurotol*. 2011;32:29-35.
5 Stachler RJ, Chandrasekhar SS, Archer SM, Rosenfeld RM, Schwartz SR, Barrs DM, et al. Clinical practice guideline: sudden hearing loss. *Otolaryngol Head Neck Surg*. 2012;146:S1-35.
6 Murphy-Lavoie H, Piper S, Moon RE, Legros T. Hyperbaric oxygen therapy for idiopathic sudden sensorineural hearing loss. *Undersea Hyperb Med*. 2012;39:777-92.
7 De Kleyn A. Sudden complete or partial loss of function of the octavus system in apparently normal persons. *Acta Otolaryngol*. 1944 32:407-29.
8 Stew BT, Fishpool SJ, Williams H. Sudden sensorineural hearing loss. *Br J Hosp Med* (London). 2012;73:86-9.
9 Mattox DE, Simmons FB. Natural history of sudden sensorineural hearing loss. *Ann Otol Rhinol Laryngol*. 1977;86:463-80.
10 Schuknecht HF, editor. *Pathology of the ear*. Philidelphia; Lea and Febiger; 1993. p. 524-9.
11 Kumar A, Sinha A, Al-Waa AM. Resolution of sudden sensorineural hearing loss following a roller coaster ride. *Indian J Otolaryngol Head Neck Surg*. 2011;63:104-6.
12 Chau JK, Cho JJ, Fritz DK. Evidence-based practice: management of adult sensorineural hearing loss. *Otolaryngol Clin North Am*. 2012;45:941-58.
13 Sara SA, Teh BM, Friedland P. Bilateral sudden sensorineural hearing loss: review. *J Laryngol Otol*. 2014;128(Suppl 1):S8-15.
14 Wu CM, Lee KJ, Chang SL, Weng SF, Lin YS. Recurrence of idiopathic sudden sensorineural hearing loss: a retrospective cohort study. *Otol Neurotol*. 2014;35:1736-41.
15 Huy PT, Sauvaget E. Idiopathic sudden sensorineural hearing loss is not an otologic emergency. *Otol Neurotol*. 2005;26:896-902.
16 Awad Z, Huins C, Pothier DD. Antivirals for idiopathic sudden sensorineural hearing loss. *Cochrane Database of Systematic Reviews*. 2012;8:CD006987. doi: 10.1002/14651858.CD006987.pub2.
17 Wei BP, Stathopoulos D, O'Leary S. Steroids for idiopathic sudden sensorineural hearing loss. *Cochrane Database of Systematic Reviews*. 2013;7:CD003998. doi: 10.1002/14651858.CD003998.pub3.
18 Muzzi E, Zennaro B, Visentin R, Soldano F, Sacilotto C. Hyperbaric oxygen therapy as salvage treatment for sudden sensorineural hearing loss: review of rationale and preliminary report. *J Laryngol Otol*. 2010;124:e2.
19 Bennett MH, Kertesz T, Perleth M, Yeung P, Lehm JP. Hyperbaric oxygen for idiopathic sudden sensorineural hearing loss and tinnitus. *Cochrane Database of Systematic Reviews*. 2012;10:CD004739. doi: 10.1002/14651858.CD004739.pub4.
20 Cekin E, Cincik H, Ulubil SA, Gungor A. Effectiveness of hyperbaric oxygen therapy in management of sudden hearing loss. *J Laryngol Otol*. 2009;123:609-12.
21 Kau RJ, Sendtner-Gress K, Ganzer U, Arnold W. Effectiveness of hyperbaric oxygen therapy in patients with acute and chronic cochlear disorders. *ORL J Otorhinolaryngol Relat Spec*.1997;59:79-83.
22 Drenjancevic I, Kibel A. Restoring vascular function with hyperbaric oxygen treatment: recovery mechanisms. *J VascRes*. 2014;51:1-13.
23 Thom SR. Hyperbaric oxygen: its mechanisms and efficacy. *Plast Reconstr Surg*. 2011;127(Suppl 1):131S-41S.
24 Plafki C, Peters P, Almeling M, Welslau W, Busch R. Complications and side effects of hyperbaric oxygen therapy. *Aviat Space Environ Med*. 2000;71:119-24.
25 von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet*. 2007;370(9596):1453-7.
26 Clark JG. Uses and abuses of hearing loss classification. *ASHA*. 1981;23:493-500.
27 Caers D, Lafère P, Vanhoutte D, Germonpré P. Retrospective analysis of 101 deafness cases treated with hyperbaric oxygen therapy. In: Kot J, editor. *37th Annual Meeting of the European Underwater and Baromedical Society* (EUBS); 2010 24th-27th August, 2011. Gdansk: EUBS; 2011.
28 Fetterman BL, Saunders JE, Luxford WM. Prognosis and treatment of sudden sensorineural hearing loss. *Am J Otol*.1996;17:529-36.
29 Topuz E, Yigit O, Cinar U, Seven H. Should hyperbaric oxygen be added to treatment in idiopathic sudden sensorineural hearing loss? *Eur Arch Otorhinolaryngol*. 2004;261:393-6.
30 Meijer AG, Wit HP, TenVergert EM, Albers FW, Muller Kobold JE. Reliability and validity of the (modified) Amsterdam Inventory for Auditory Disability and Handicap. *Int J Audiol*. 2003;42:220-6.
31 Hawthorne G, Hogan A. Measuring disability-specific patient benefit in cochlear implant programs: developing a short form of the Glasgow Health Status Inventory, the Hearing Participation Scale. *Int J Audiol*. 2002;41:535-44.
32 Bessereau J, Tabah A, Genotelle N, Francais A, Coulange M, Annane D. Middle-ear barotrauma after hyperbaric oxygen therapy. *Undersea Hyperb Med*. 2010;37:203-8.

Conflicts of interest: nil

Submitted: 20 February 2016; revised 02 June and 26 July 2016
Accepted: 07 August 2016

Susannah Sherlock[1,4], Kenneth Thistlethwaite[1], Mohsina Khatun[2], Christopher Perry[3], Alexis Tabah[1,4]

[1] Hyperbaric Medicine Unit, Royal Brisbane and Women's Hospital (RBWH), Brisbane, Queensland, Australia
[2] School of Public Health, Faculty of Medicine and Biomedical Sciences, The University of Queensland, Brisbane, Australia
[3] Queensland Institute of Medical Research, Brisbane
[4] Burns, Trauma, and Critical Care Research Centre, RBWH and University of Queensland

Address for correspondence:
Dr Susannah Sherlock
Royal Brisbane and Women's Hospital
Hyperbaric Medicine Unit
Butterfield Street
Herston QLD 4026
Australia
susannah.sherlock@health.qld.gov.au

The effect of general anaesthesia and neuromuscular blockade on Eustachian tube compliance: a prospective study

Akeelesh Mungur, Guy Cochard, Yves Ozier and Pierre Lafère

Abstract

(Mungur A, Cochard G, Ozier Y, Lafère P. The effect of general anaesthesia and neuromuscular blockade on Eustachian tube compliance: a prospective study. *Diving and Hyperbaric Medicine*. 2016 September;46(3):166-169.)

Objective: The most common complications of hyperbaric oxygen treatment (HBOT) are related to pressure changes on gas-containing cavities. Therefore, inability to auto-inflate the middle ear may result in transient or permanent hearing loss. However, it seems that middle ear barotrauma (MEBt) does not develop more often in mechanically ventilated patients than in ambulatory patients. This might be explained by deep sedation of these patients. Therefore, the aim of this study was to determine whether anaesthesia and/or neuromuscular blockade can influence Eustachian tube (ET) function.

Methods: Forty patients who were undergoing surgery under general anaesthesia were enrolled in this prospective study. ET function was evaluated by tympanography performed three times: before induction of general anaesthesia (baseline), after induction with sufentanyl/propofol and after full blockade was achieved with a long-acting neuromuscular blocking agent.

Results: There were no differences in ear volume ($P = 0.19$) and ear pressure ($P = 0.07$). There was a significant variation in compliance on tympanography after the induction of general anaesthesia ($P = 0.009$). Compared to the baseline, this variation was characterized by an increase after induction of anaesthesia ($24 \pm 7.13\%$, $P < 0.01$) and neuromuscular blockade ($23 \pm 8.9\%$, $P < 0.05$). The difference between after induction and after neuromuscular blockade was not statistically significant ($P = 0.13$).

Discussion: the findings of this trial suggest that the administration of hypnotic drugs associated with opioids improves ET compliance. Therefore it may have favourable prophylactic effects on MEBt in ventilated intensive care unit patients scheduled for HBOT.

Key words

Tympanometry; middle ear; ear barotrauma; ENT

Introduction

Multiple studies have examined the use of hyperbaric oxygen treatment (HBOT) in several acute pathologies with mixed results. Therefore, every few years, the European Committee for Hyperbaric Medicine publishes its recommendations concerning the clinical indications for HBOT. Several proposed conditions, such as iatrogenic gas embolism, decompression sickness, carbon monoxide poisoning and necrotizing soft tissue infections may require intensive care (ICU) hospitalisation and mechanical ventilation.[1,2]

The most common complications of HBOT are due to the effects of pressure changes on the gas-containing cavities of the body. Failure to equalize the pressure gradient between the affected body cavity and the external environment during chamber operation results in barotrauma, most commonly middle ear barotrauma (MEBt).[3] Known risk factors for MEBt include female sex, older age, artificial airways (intubation) and a history of Eustachian tube (ET) dysfunction or the inability to auto-inflate the middle ear such as sedated and ventilated ICU patients who are unable to perform a Valsalva manoeuvre to prevent MEBt. Damage to the components of the auditory system (ossicular chain, tympanic membrane in case of MEBt) may result in transient or permanent impairment, such as hearing loss and tinnitus.[4,5]

According to the literature, reported incidences of MEBt after HBOT range from 8% to 68.7% and up to 91% in patients unable to auto-inflate their middle ear.[3,6–8] However, in a recent study, although the incidence was twice as high in the intubated group compared to the conscious group of patients (24.4% vs. 12.4%), this result was not statistically significant. In this particular 'acute-only' setting, there was no influence of age, sex or mechanical ventilation on the occurrence of MEBt.[9] This might be explained by deep sedation of the patients while HBOT was performed, as it may have helped the relaxation of the tube-opening muscles (*m. tensor* and *m. levator veli palatini*) and unconscious pressure equalization.

We conducted the present prospective study to determine whether or not anaesthesia/sedation and/or neuromuscular blockade (NMB) could influence ET compliance.

Methods

This was a prospective, observational study conducted on 40 patients who were undergoing surgery under general anaesthesia. After local ethics committee approval, EudraCt registration (2015-003022-14) and obtaining written informed consent, patients were subjected to otolaryngological examination to rule out any disorder affecting hearing and ET function. Patients with a history of recent ear discharge, abnormal external auditory canal, acute infections of the ear or a perforated tympanic membrane were excluded. We also excluded patients in whom a rapid sequence induction was indicated.

Tympanometry analysis was done using an AT 235 impedance meter (Interacoustics, Assens, Denmark). A small probe was inserted which emits a sound of low frequency (226 Hz) via a tube into the auditory canal and a continuous change of positive and negative pressure was created by the pump of the instrument in the external auditory canal in front of the tympanic membrane. The compliance was measured simultaneously. This measurement was done three times: before induction (Baseline), after injection of hypnotic drugs (Induction) and after NMB, once full blockade was achieved (no response to 'train-of-four' stimulation of a peripheral nerve). Demographic data were recorded for each patient including age, sex, height, weight and ASA classification.

To avoid any bias related to the anaesthetic procedure, it was standardized with propofol 4 $mg \cdot kg^{-1}$ preceded by sufentanyl 0.3 $\mu g \cdot kg^{-1}$ and followed by atracurium 0.5 $mg \cdot kg^{-1}$ administered through a 18g intravenous cannula in the patient's antecubital fossa. NMB was monitored by acceleromyography. Since it has been demonstrated that the use of nitrous oxide as an anaesthetic gas can increase middle ear pressure, which may theoretically result in expulsion of middle ear fluid through an open ET, nitrous oxide was not used. Also, to avoid any effective volume variation of the middle ear (fluid displacement), no positive pressure ventilation was applied between the first (Baseline) and second (Induction) tests.

STATISTICAL ANALYSIS

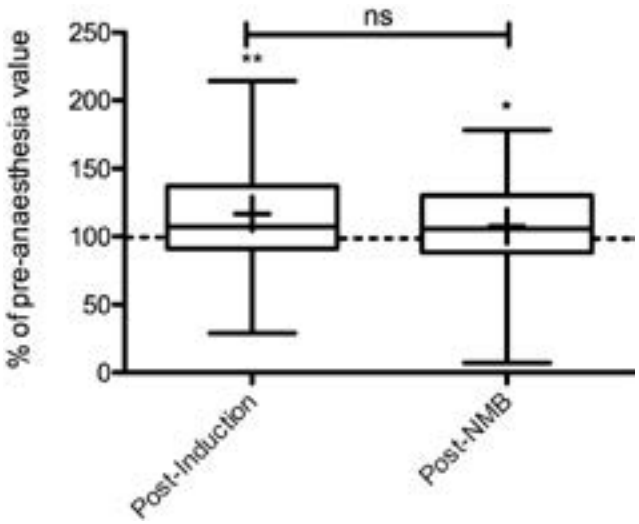
All tests were performed using a standard computer statistical package, GraphPad Prism version 5.00 for Mac (GraphPad Software, San Diego California USA). Since each candidate was their own control, a power analysis indicated that a sample size of 66 ears was required to detect a difference in ET compliance with an effect size of at least 20% (= 0.05, (1 -) = 0.95).

The Kolmgorov-Smirnov normality test was used to determine whether the data were normally distributed. A Gaussian distribution could be assumed for heart rate, mean arterial pressure (MAP), diastolic pressure and patient demographics. For these parameters, a one-way analysis of variance was used. Post-hoc comparisons were then made using Bonferroni's multiple comparison tests.

In all other cases (compliance, ear volume and pressure, systolic blood pressure), a Friedman test with Dunn's multiple comparison tests or Wilcoxon matched-pairs signed rank tests were used. Compliance changes were expressed as a percentage (median and 25–75 interquartile range) of the baseline value recorded during the pre-induction phase before any drugs were injected. This has allowed an appreciation of the magnitude of change rather than the absolute values. A threshold of $P < 0.05$ was considered statistically significant.

Figure 1

Box and whisker plots of variation in middle ear compliance compared to the value recorded before induction of anaesthesia (dotted line = 100%), indicating median, 25–75 percentiles and minimum and maximum observations; "+" marked in the boxes indicate the means; NMB – neuromuscular blocking agent; ns – not significant; * $P < 0.05$; ** $P < 0.01$ (Dunn's test)



Results

All subjects were selected from a large surgical population in order to obtain a group of comparable health status (ASA I and II). There was no variation of heart rhythm ($P = 0.21$), a 15% drop of the blood pressure after the injection of hypnotic drugs was observed (systolic BP: 136 ± 19 to 115 ± 19mmHg; diastolic BP: 75 ± 13 to 66 ± 13mmHg; MAP: 98 ± 13 to 83 ± 14mmHg). There was no further variation after injection of NMB agents.

Of the 80 tested ears, 12 data sets were excluded because of incomplete results leaving 68 ears available for analysis. The loss of data was mostly due to leaking during the compliance measurement and the inability for the operator to correct the problem before intubation was mandatory.

There were no statistically significant differences in ear volume ($P = 0.19$) or pressure ($P = 0.07$) during the different measurements. There was a significant change in compliance (Figure 1) after the induction of general anaesthesia ($P = 0.009$, Friedman test). Compared to Baseline, this variation is characterized by an increase in middle ear compliance after induction of anaesthesia to 107% (91–137%, Dunn's test $P < 0.01$) and after NMB 106% (88–130%, Dunn's test $P < 0.05$). However, the difference between post induction and after NMB was not statistically significant ($P = 0.13$, Wilcoxon matched-pairs signed rank test).

Discussion

The physiological role of the ET is threefold: to protect the middle ear from sources of disease, to help drain

secretions away and to ventilate the middle ear. Although the physiological mechanisms involved in these functions are multiple, the role of ET patency is certain in the pressure equilibration process; however, it is probably not the only one involved.[10,11] Indeed, the anatomic structure of the ET is highly complex in that the lumen is surrounded by several muscular, cartilaginous, fat and connective tissue elements and is bounded by fluid-coated mucosal tissue. Therefore ET dysfunction may be due to anatomic and/or mechanical abnormalities. However, the precise mechanisms by which these structural properties alter ET opening phenomena have not been investigated.[12,13]

In healthy individuals, the tubes are physiologically closed at rest, and open primarily by synergistic action of the palatine muscles. This opening occurs during swallowing, when muscle contraction deforms the surrounding soft tissue resulting in an increase in the cross-sectional area of the lumen and a reduction in the resistance to airflow.[14] Several investigators have demonstrated that paralysis of the *tensor veli palatini* muscle, the primary muscle associated with ET function, results in negative middle ear pressures[15] and a significant decrease in the compliance or elastic properties of the ET.[16,17]

Other investigations have suggested that the elastic and viscoelastic properties of the cartilage and/or fat and connective tissue may also be important determinants of ET function.[18,19] Middle ear gas hyperoxia, which is a consequence of HBOT, has been shown to down-regulate the ET ventilatory function in patients. This has been confirmed in young adult female cynomolgus monkeys breathing either room air or 100% normobaric oxygen; higher opening, closing, and steady state pressures were observed under systemic hyperoxia.[20]

Both hyperoxia and inability to use the peritubal muscles in order to equalize ear pressure are present in mechanically ventilated patients undrgoing HBOT. This might explain why 94% of the intubated patients in one study developed MEBt, and 61% required placement of tympanostomy tubes.[21] However, these results were not supported in a recent study.[9] This might be explained by the fact that the earlier series included patients treated for head and neck surgical and radiation side effects, whereas the recent study did not. This would be in line with the hypothesis of the role of viscoelastic properties of soft tissues surrounding the ET. One other factor suggested by our results might be the deep sedation of the patients and not the effects of NMB agents, as it may have helped relaxation of the ET-opening muscles and unconscious pressure equalization.

Two aspects must be considered, a direct effect of either or both of the induction agents, sufentanyl and propofol, or an indirect effect through hypotension. Propofol was initially approved for use as an induction and maintenance hypnotic agent; however, its clinical uses have expanded over the last decades to also include intensive care sedation, although it is also known for its haemodynamic effects. Indeed, in several studies, the overall incidence of hypotension is 15.7% with 77% of the episodes recorded within 10 min of induction of anaesthesia.[22–24] Our results are in accord with these findings. However, it is less clear whether or not hypotension could have an effect on ET function. Although we cannot formally exclude this hypothesis, an extensive literature search failed to demonstrate any correlation between blood pressure and ET dysfunction.[13,25]

The muscle-relaxing mechanisms of intravenous anaesthetics, especially propofol, have been investigated in several studies.[26–28] A central mechanism (cortical and spinal cord) has been proposed to describe muscle-relaxing properties of propofol.[26–28] Bolus propofol administration impairs the central part of the motor system by decreasing α-motor neuron excitability as shown by a decreased spinal F wave.[26] Other authors have described a peripheral mechanism, reporting that anaesthetic doses of propofol decrease diaphragmatic contractility in dogs;[27] whilst inhibition of human skeletal muscle sodium channels in a voltage-dependent manner has also been described.[28] This mechanism may contribute to the reduction in muscle excitability. Contrary to the actions of propofol, sufentanil is more prone to induced muscle rigidity.[29]

Since we did not apply positive pressure ventilation between the first two tests, and others have reported that anaesthesia per se can modify the shape of the tympanogram in 30% of cases (from type B to type A),[30] we cannot be sure that the improvement in compliance was related to an improvement in ET patency. However, these tympanometric changes were mostly demonstrated in the presence of middle-ear effusion, which was not the case in our settings since we excluded all patients with a previous medical ear history or any active ear pathology. Moreover, manual ventilation of the patients prior to the injection of a NMB agent to ensure that ventilation was possible before intubation did not modify ear compliance, ear volume or ear pressure further. Therefore, it is possible to assume that the change in compliance was most probably, although not necessarily exclusively, related to ET function.

Conclusion

This trial suggests that the administration of hypnotic drugs associated with opioids may improve Eustachian tube compliance. Therefore, it may have a favourable prophylactic effect on MEBt in intubated, ventilated patients scheduled for HBOT.

References

1 Kot J, Mathieu D. Controversial issues in hyperbaric oxygen therapy: a European Committee for Hyperbaric Medicine Workshop. *Diving Hyperb Med*. 2011;41:101-4.

2 Goulon M, Wattel F, Bitterman N, Hamilton-Farell M, Lind

F, Messimeris T, et al. No title. In: Bakker D, Marroni A, Mathieu D, editors. *7th European consensus conference on hyperbaric medicine*. Lille: European Committee for Hyperbaric Medicine; 2004. p. 20.
3 Karahatay S, Yilmaz YF, Birkent H, Ay H, Satar B. Middle ear barotrauma with hyperbaric oxygen therapy: incidence and the predictive value of the nine-step inflation/deflation test and otoscopy. *Ear Nose Throat J*. 2008;87:684-8.
4 Cave KM, Cornish EM, Chandler DW. Blast injury of the ear: clinical update from the global war on terror. *Mil Med*. 2007;172:726-30.
5 Dougherty AL, MacGregor AJ, Han PP, Viirre E, Heltemes KJ, Galarneau MR. Blast-related ear injuries among U.S. military personnel. *J Rehabil Res Dev*. 2013;50:893-904.
6 Blanshard J, Toma A, Bryson P, Williamson P. Middle ear barotrauma in patients undergoing hyperbaric oxygen therapy. *Clin Otolaryngol Allied Sci*. 1996;21:400-3.
7 Igarashi Y, Watanabe Y, Mizukoshi K. Middle ear barotrauma associated with hyperbaric oxygenation treatment. *Acta Otolaryngol*. 1993;504(Suppl):143-5.
8 Beuerlein M, Nelson RN, Welling DB. Inner and middle ear hyperbaric oxygen-induced barotrauma. *Laryngoscope*. 1997;107:1350-6.
9 Bessereau J, Tabah A, Genotelle N, Francais A, Coulange M, Annane D. Middle-ear barotrauma after hyperbaric oxygen therapy. *Undersea Hyperb Med*. 2010;37:203-8.
10 Llewellyn A, Norman G, Harden M, Coatesworth A, Kimberling D, Schilder A, et al. Interventions for adult Eustachian tube dysfunction: a systematic review. *Health Technol Assess*. 2014;18:1-180, v-vi.
11 Sproat R, Burgess C, Lancaster T, Martinez-Devesa P. Eustachian tube dysfunction in adults. *BMJ*. 2014;348. doi: http://dx.doi.org/10.1136/bmj.g1647.
12 Sheer FJ, Swarts JD, Ghadiali SN. Three-dimensional finite element analysis of Eustachian tube function under normal and pathological conditions. *Med Eng Phys*. 2012;34:605-16.
13 Swarts JD, Alper CM, Luntz M, Bluestone CD, Doyle WJ, Ghadiali SN, et al. Panel 2: Eustachian tube, middle ear, and mastoid anatomy, physiology, pathophysiology, and pathogenesis. *Otolaryngol Head Neck Surg*. 2013;148(4 Suppl):E26-36. doi: 10.1177/0194599812472631.
14 Beery QC, Doyle WJ, Cantekin EI, Bluestone CD, Wiet RJ. Eustachian tube function in an American Indian population. *Ann Otol Rhinol Laryngol Suppl*. 1980;89(3 Pt 2):28-33.
15 Casselbrant ML, Cantekin EI, Dirkmaat DC, Doyle WJ, Bluestone CD. Experimental paralysis of tensor veli palatini muscle. *Acta Otolaryngol*. 1988;106:178-85.
16 Ghadiali SN, Banks J, Swarts JD. Finite element analysis of active Eustachian tube function. *J Appl Physiol*. 2004;97:648-54.
17 Ghadiali SN, Swarts JD, Doyle WJ. Effect of tensor veli palatini muscle paralysis on eustachian tube mechanics. *Ann Otol Rhinol Laryngol*. 2003;112:704-11.
18 Ishijima K, Sando I, Balaban CD, Miura M, Takasaki K. Functional anatomy of levator veli palatini muscle and tensor veli palatini muscle in association with eustachian tube cartilage. *Ann Otol Rhinol Laryngol*. 2002;111:530-6.
19 Kaneko A, Hosoda Y, Doi T, Tada N, Iwano T, Yamashita T. Tubal compliance changes with age and in tubal malfunction. *Auris Nasus Larynx*. 2001;28:121-4.
20 Shupak A, Tabari R, Swarts JD, Bluestone CD, Doyle WJ. Effects of systemic hyperoxia on eustachian tube ventilatory function. *Laryngoscope*. 1997;107:1409-13.
21 Presswood G, Zamboni WA, Stephenson LL, Santos PM. Effect of artificial airway on ear complications from hyperbaric oxygen. *Laryngoscope*. 1994;104:1383-4.
22 Hug CC Jr, McLeskey CH, Nahrwold ML, Roizen MF, Stanley TH, Thisted RA, et al. Hemodynamic effects of propofol: data from over 25,000 patients. *Anesth Analg*. 1993;77(Suppl):S21-9.
23 Claeys MA, Gepts E, Camu F. Haemodynamic changes during anaesthesia induced and maintained with propofol. *Br J Anaesth*. 1988;60:3-9.
24 Smith I, White PF, Nathanson M, Gouldson R. Propofol. An update on its clinical use. *Anesthesiol*. 1994;81:1005-43.
25 Gelardi M, Marchisio P, Caimmi D, Incorvaia C, Albertario G, Bianchini S, et al. Pathophysiology, favoring factors, and associated disorders in otorhinosinusology. *Pediatr Allergy Immunol*. 2012;23 Suppl 22:5-16. doi: 10.1111/j.1399-3038.2012.01323.x.
26 Dueck MH, Oberthuer A, Wedekind C, Paul M, Boerner U. Propofol impairs the central but not the peripheral part of the motor system. *Anesth Analg*. 2003;96:449-55.
27 Fujii Y, Hoshi T, Takahashi S, Toyooka H. Propofol decreases diaphragmatic contractility in dogs. *Anesth Analg*. 1999;89:1557-60.
28 Haeseler G, Stormer M, Bufler J, Dengler R, Hecker H, Piepenbrock S, et al. Propofol blocks human skeletal muscle sodium channels in a voltage-dependent manner. *Anesth Analg*. 2001;92:1192-8.
29 Yuan YH, Xu PF, Ge HQ, Lu ZH, Xu M. Sufentanil induced muscle rigidity identified by ventilator graphics in medical intensive care unit. *Chin Med J* (England). 2013;126:3396.
30 Fish BM, Banerjee AR, Jennings CR, Frain I, Narula AA. Effect of anaesthetic agents on tympanometry and middle-ear effusions. *J Laryngol Otol*. 2000;114:336-8.

Conflicts of interest: nil

Submitted: 15 February 2016; revised 10 July 2016
Accepted: 24 July 2016

Akeelesh Mungur[1], Guy Cochard[2], Yves Ozier[1,3], Pierre Lafère[1,2,3]

[1] Department of Anaesthesiology, Hôpital de la Cavale Blanche, Brest, France
[2] Unit of Hyperbaric Oxygen Therapy, Hôpital de la Cavale Blanche
[3] Laboratoire ORPHY, Université de Bretagne Occidentale, Brest

Address for correspondence:
Laboratoire ORPHY, EA 4324
Université de Bretagne Occidentale
6 avenue Le Gorgeu, CS 93837
29238 Brest Cedex
France
pierre.lafere@chu-brest.fr

Remote ischaemic conditioning in a rat model subjected to decompression stress

Nikolaj Hjort Schmidt, Kasper Hansen, Henrik Lauridsen, Annie Vesterby, Jens Randel Nyengaard, Alf Brubakk and Michael Pedersen

Abstract

Schmidt NH, Hansen K, Lauridsen H, Vesterby A, Nyengaard JR, Brubakk A, Pederson M. Remote ischaemic conditioning in a rat model subjected to decompression stress. *Diving and Hyperbaric Medicine*. 2016 September;46(3):170-175.)

Introduction: Vascular bubble formation after decompression has been associated with inflammation, necrosis, and platelet activation. This study evaluates remote ischaemic conditioning (RIC), performed before or after decompression, on bubble formation, platelet activation and ischaemic brain lesions.

Methods: Forty-two female Wistar rats were pressurised to 600 kPa air pressure for 45 min followed by linear decompression (50 kPa·min^{-1}). Rats received RIC (5 min ischaemia followed by 5 min reperfusion, repeated four times) one day before (pre-RIC, n = 10) or immediately after an air-dive (post-RIC, n = 10). The other animals served as air-dived sham rats (n = 11) or non-dived controls (n = 11). Bubbles were evaluated by ultrasonography of the pulmonary artery for 140 min after the dive. Blood was collected before and after the dive to evaluate platelet and metabolic changes (i.e., pH, lactate, glucose, free calcium ions, oxygen and carbon dioxide tensions, haemoglobin and haemoglobin oxygen saturation). Rats were euthanized two days after the dive to investigate potential brain infarctions evaluated by 2,3,5-triphenyltetrazolium chloride (TTC) staining.

Results: Pre-RIC and sham rats exhibited a similar bubble response. In contrast to this, post-RIC animals had significantly higher bubble grades that lasted for ~40 min longer than the sham group. Additionally, a 50% mortality was noted for post-RIC animals. No significant platelet or metabolic changes were observed and the dive profile did not produce TTC-verifiable cerebral ischaemic changes in any groups.

Conclusion: Pre-conditioning does not alter the response to decompression contrary to post-conditioning which seems to aggravate the bubble response.

Key words

Decompression sickness; venous gas embolism; platelets; metabolism; central nervous system; ischaemic preconditioning

Introduction

During decompression to the surface following a dive, if the tissue supersaturation of inert gas exceeds a certain threshold, bubbles may form to restore gas equilibrium within the body.[1,2] Gas bubbles have served as a biomarker for development of decompression profiles because no bubbles or very low bubble grades after decompression are correlated with a low probability of decompression sickness (DCS).[3]

Intravascular bubbles have the potential to obstruct blood vessels, which results in inflammation, platelet activation and depletion and development of ischaemia/necrosis in the adjacent tissue.[4–9] Prevention of DCS or attenuation of the pathophysiological responses to decompression ('decompression stress') through pre-dive procedures has been sought for decades through different conditioning procedures.[10] A novel idea is to evaluate the effects of remote ischaemic conditioning (RIC), which implies that short non-lethal periods of ischaemia in a remote bodily structure (e.g., a leg) protect against longer lasting harmful periods of ischaemia in another bodily structure/organ (e.g., the brain). RIC has provided impressive pre-clinical as well clinical results, e.g., pre-hospital salvage of myocardium in patients with suspected acute myocardial infarction;[11] improved glomerular filtration rate and renal perfusion after kidney transplantation in pigs;[12] and reduced cerebral infarction after transient middle cerebral artery occlusion in rats.[13]

The nomenclature pre-, per-, and post-RIC, denotes whether RIC is performed before, during, or after the insult. RIC can be performed with a blood pressure cuff non-invasively.[14] Therefore, if RIC demonstrates a protective effect against 'decompression stress' this could be a promising future adjuvant pre-hospital DCS treatment in a practical diving context. Accordingly, the objective of this study was to investigate whether RIC performed prior to (pre-RIC) or immediately after (post-RIC) simulated dives reduces bubble formation, platelet activation, and/or diminishes ischaemic insults in the brain in a decompression-stressed rat model.

Methods

Forty-two female Wistar rats (Taconic, Ry, Denmark), body mass 0.252 ± 0.001 (mean ± SE) kg, were randomly assigned to the following groups: control, not dived (n = 11); sham, a 'dived control' group, i.e., not receiving RIC (n = 11); pre-dive RIC (n = 10) or post-dive RIC (n = 10). Two pre-RIC rats were subsequently excluded from the study due to pressure chamber malfunction. Rats were housed at 24.1 ± 0.04^{O}C, relative humidity of 49.6 ± 0.8% and a 12/12 h day/night cycle with free access to food and

water. All experiments were approved by the national animal experimental inspectorate (license: 2014-15-0201-00101) and conducted in accordance with the Danish Ministry of Environment and Food animal research act.

STUDY DESIGN

The study was designed as a randomised block experiment and each rat was handled for four consecutive days (Figure 1). Primary endpoints were bubble grade, platelet fluctuations, and ischaemic brain lesions. Secondary endpoints were mortality, cardiac output (CO) and stroke volume (SV), and blood pH, lactate, glucose, free calcium ions, oxygen (O_2) and carbon dioxide (CO_2) tensions, haemoglobin and haemoglobin oxygen saturation.

Day 1: 23 h prior to simulated diving, all groups were anaesthetised for 1 h. Anaesthesia was induced with a subcutaneous injection (3 mL·kg^{-1}) of hypnorm (fentanyl 0.315 mg·mL^{-1} and fluanisone 10 mg·mL^{-1}) mixed with midazolam (5 mg·mL^{-1}) and sterile water (ratio 1:1:2), with a maintenance dose (1.5 mL·kg^{-1}) injected after 20 min.

Pre-RIC was initiated 15 min following injection of the anaesthetic induction dose and was performed with a custom-made tourniquet fitted around the upper part of the right hind leg, a method of temporary ischaemia previously used and validated.[13,15] One cycle consisted of 5 min of ischaemia followed by 5 min of reperfusion, repeated four times (Figure 1). Sufficient restriction of the blood supply during ischaemia was validated in pilot studies by ultrasonography of leg vessels distal to the tourniquet, and by paw pulse oximetry (data not shown). Furthermore, the paw turned blue during the ischaemic period, which subsequently changed to a deep red from hyperaemia after release of the tourniquet.

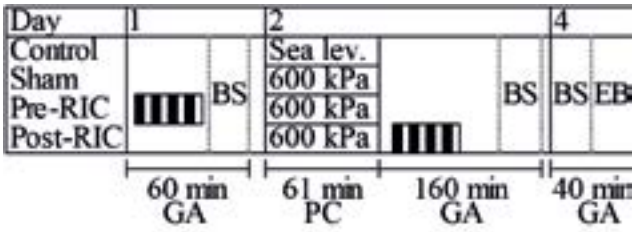
Heart rate (HR), respiratory frequency (RF) and temperature (T) were measured and displayed in real-time using the Vevo 2100 (FujiFilm VisualSonics, Toronto, ON, Canada) imaging system's physiologic monitoring equipment (Vevo Imaging Station) consisting of four electrodes mounted to the rat's paws, and a rectal probe. One hour after the anaesthetic induction, HR, RF, and T were recorded. Subsequently, venous (~0.5 mL) and arterial (~0.5 mL) blood samples were withdrawn from the tongue and tail, respectively. The venous blood samples were collected in EDTA-coated tubes (Microvette 500 K3E, Sarstedt, Nümbrecht, Germany) and analysed for platelets and haemoglobin. Arterial blood samples were obtained in heparin-coated syringes (Pico 50, Radiometer, Brønshøj, Denmark) and analysed for pH, lactate, glucose, free calcium ions, O_2- and CO_2 tension, and haemoglobin oxygen saturation using an ABL 700 (Radiometer, Brønshøj, Denmark).

Day 2: Sham, pre- and post-RIC animals were subjected to a simulated air-dive in an automated pressure chamber

Figure 1

Study design; animals were handled under general anaesthesia (GA), but were awake in the pressure chamber (PC); blood samples (BS) were taken at the end of each anaesthetic period; brains were removed after euthanasia (EB); Sea lev. - sea level pressure

▮▮▮▮ – repetitive remote ischemic conditioning



system (volume ≈ 3 L). A continuous airflow through the chamber of 1.5 L·min^{-1} was maintained while a rat was in the chamber. Awake rats were compressed over 6 min with atmospheric air to 600 kPa, which was maintained for 45 min, and followed by linear decompression of 50 kPa·min^{-1} to ambient pressure (Figure 1), representing moderate to severe exposure with a previously described 33% mortality following such an air-dive.[16] Animals in the control group stayed in the chamber at sea level pressure for 61 min.

Using the same anaesthetic agent and doses as described for day 1, each rat was anesthetised immediately following return to sea level and received maintenance doses 40 and 80 minutes later. The post-RIC group received RIC at 11.5 min after anaesthesia. Ultrasonography of the pulmonary artery was performed 20 min after return to sea level and continued for 130 min, and was acquired using the previously described Vevo 2100 imaging system fitted with a 21 MHz linear array transducer (frame rate 210 min^{-1}). The pulmonary artery was visualised through the parasternal longitudinal axis view. In B-mode, 420 frames were obtained every 20 min using a trigger mechanism; hence, the images were acquired independently of bubbles observed by the operator. Vascular bubbles in the pulmonary artery were graded according to the Eftedal-Brubakk (EB) scale.[17] Three consecutive cycles of four beats were evaluated, and the average bubble grade reported.

Similarly to Day 1, HR, RF and T were measured. After the last bubble scan, CO was calculated by multiplying HR with SV; the latter was estimated in the expiratory phase through three consecutive heart cycles by measuring the pulmonary arterial diameter distal to the pulmonary valves along with the velocity time integral (VTI) derived from pulse-waved Doppler measurements. All ultrasound data were analysed with the observer blinded to the type of exposure.

Following ultrasonic evaluation, both venous and arterial blood samples were obtained as previously described. For pain relief, buprenorphine (0.05 mg·kg^{-1}) was injected subcutaneously 2 h after return to sea level and further

administered through the drinking water (7.5 mg·L^{-1}) for the remainder of the experiment.

Day 4: After 43 h of recovery, surviving rats were anaesthetised, had blood withdrawn for analysis, and were euthanized by an intra-cardiac injection of pentobarbital (50 mg·mL^{-1}). The brain was immediately removed from the skull and cut according to the systematic uniform random sampling technique;[18] i.e., first coronal cut was randomly positioned between 0 to 2 mm from end of the frontal lobes. Hereafter, a new cut was positioned every 2 mm caudally. The slices where then placed in a pre-heated (37^{O}C) 2% 2,3,5-triphenyltetrazolium chloride (TTC) solution (Sigma-Aldrich Chemie GmbH, Steinheim, Germany) for 3 h under constant stirring in an incubator (37^{O}C). The brain slices were subsequently transferred to 4% formaldehyde and stored in the refrigerator for later histological processing. The olfactory bulb and cerebellum were removed prior to histological examination. Each brain slice (~7 per brain) was placed on the caudal side in a vibratome (Vibratome Series 3000 Plus) and 390 µm tissue was initially removed from the rostral side. Next, a 65 µm section was prepared and mounted for later analysis with bright-field microscopy.

STATISTICS

All data are reported as median (interquartile range). The number of animals allocated to each group was based on previous conditioning studies.[19,20] Because most data were not normally distributed, non-parametric Wilcoxon rank sum tests were used for analysis with the control, pre-RIC and post-RIC groups compared to the sham group individually. The Kruskal-Wallis test was used to evaluate baseline platelet levels across groups. Mortality was evaluated using 2x2 tables with Fisher's exact test. $P < 0.05$ was considered statistically significant. All data analyses were performed in Stata 13 (StataCorp LP, TX, USA).

Results

PHYSIOLOGY

Pre-RIC animals had a significantly higher RF on Day 1 compared to the sham group ($RF_{pre\text{-}RIC}$ = 72 (67.5–92) min^{-1}; RF_{sham} = 53 (47.5–61) min^{-1}; $P = 0.03$), and the control group had a slightly higher T 20 min after return to sea level on Day 2 compared to the sham group ($T_{control}$ = 37.0 (36.5-37.1)^{O}C; T_{sham} = 36.0 (36.0-36.6)^{O}C; $P = 0.02$). For the remaining observation points at Day 1 and 2, pre-RIC and control animals exhibited no differences with respect to HR, RF, T, CO, and SV when compared individually to the sham group.

HR in the post-RIC group was significant higher on Day 1 compared to the sham group ($HR_{post\text{-}RIC}$ = 476 (444.5–492.5) min^{-1}; HR_{sham} = 420 (408.5–440) min^{-1}; $P = 0.02$), which was also observed on Day 2 at 20 min ($HR_{post\text{-}RIC}$ = 483 (475–505) min^{-1}; HR_{sham} = 440 (426–465.5) min^{-1}; $P = 0.003$), 60 min ($HR_{post\text{-}RIC}$ = 505 (493–512) min^{-1}; HR_{sham} = 453 (438.5–471.5) min^{-1}; $P = 0.007$) and 100 min ($HR_{post\text{-}RIC}$ = 507.5 (501.8-514.8) min^{-1}; HR_{sham} = 465 (444–488.5) min^{-1}; $P = 0.03$) after chamber exit. At 40, 80, 120 and 140 min after chamber exit on Day 2, similar but insignificant differences were observed. Comparable T were observed between post-RIC and sham both Day 1 and 2.

Generally, RF values were comparable between the post-RIC and the sham group over the entire observation period except 20 min after chamber exit on Day 2 ($RF_{post\text{-}RIC}$ = 79 (70–90) min^{-1}; RF_{sham} = 52 (36.5–67.5) min^{-1}; $P = 0.03$). CO was identical between the post-RIC and sham groups; however, SV was all but significantly lower in post-RIC animals compared to the sham group on Day 2 ($SV_{post\text{-}RIC}$ = 137.2 (112.1–202.4) mm^{3}; SV_{sham} = 234.0 (196.8–304.8) mm^{3}; $P = 0.05$).

BUBBLE GRADES AND MORTALITY

Comparing control with sham, the bubble grades were significantly elevated in the entire observation period, except for the last scan 140 min after return to sea level (data not shown, since no bubbles were observed in control rats). Generally, pre-RIC animals had lower bubble grades (n.s.) and the variation among rats (i.e., the bubble range) was smaller compared to the sham group. Post-RIC animals exhibited a significantly elevated bubble response at 100 min ($P = 0.04$), with a similar trend at 120 min ($P = 0.07$), after return to sea level when compared to the sham group. At all other time points the medians were statistically identical (Figure 2).

The maximum bubble grade observed in each rat across the observation period is presented in Table 1 for the various groups, i.e., if a rat exhibited grade 2 bubbling at most time points during the observation period and then at one time point exhibited grade 4, then grade 4 is reported in the table, thus each rat only appears once in the table.

There were no deaths in the control group. One of 11 rats died in the sham dive group, two of eight in the pre-RIC group and five of 10 in the post-RIC group. These differences in mortality were not statistically significant, although there may have been a trend of higher mortality in the post-RIC group ($P = 0.06$). When pooled for survival, rats that died during follow-up had a median maximum bubble grade of 4, compared to a median maximum grade of 1 in the sham, pre- and post-animals that survived the recovery period and were euthanized on Day 4.

BLOOD ANALYSES

No differences were observed between the control, pre-RIC, and post-RIC groups compared to the sham group,

Figure 2
Bubble grades (Eftedal-Brubakk (EB) scale[17]), median + interquartile ranges; A) Sham (black squares) vs. pre-RIC (grey circles). B) Sham (black squares) vs. post-RIC (grey triangles). * $P < 0.05$

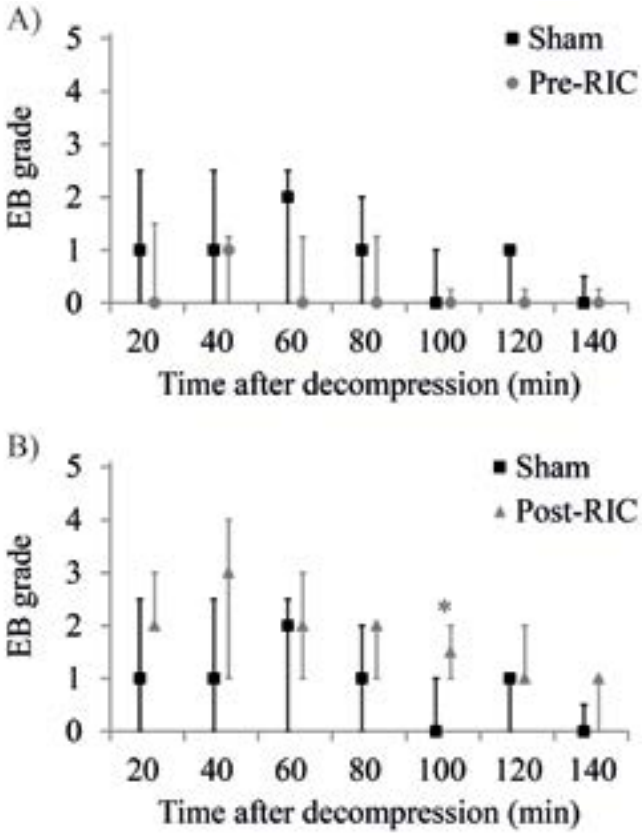


Table 1
Maximum bubble grade (Eftedal-Brubakk scale[17]) observed at some point for (*n*) rats in the individual groups across the 140-min observation period

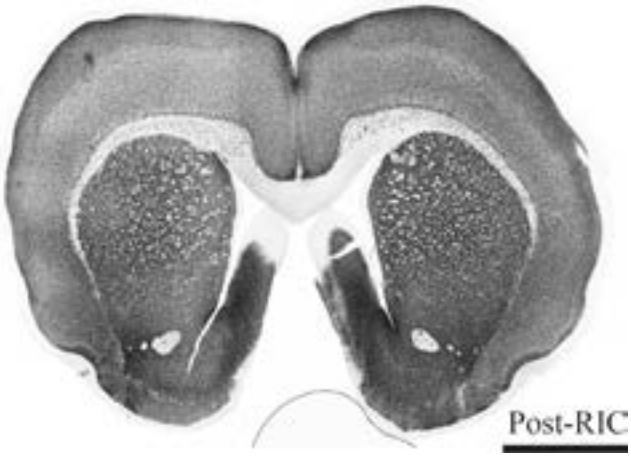
EB grade	Control	Sham	Pre-RIC	Post-RIC
0	11	4	4	3
1	0	0	2	0
2	0	3	0	1
3	0	1	1	1
4	0	1	1	4
5	0	2	0	1

respectively, with regard to platelets, pH, lactate, glucose, free calcium-ions, O_2- and CO_2-tension, haemoglobin and haemoglobin oxygen saturation on Days 1, 2 or 4.

HISTOLOGY

Five control and five sham animals, the latter selectively chosen as the animals displaying the highest bubble grades, and all pre- and post-RIC animals were evaluated microscopically, but no signs of ischaemic lesions were found in any of the samples. A representative example of a post-RIC 65 µm section (grey-scale) is shown in Figure 3.

Figure 3
Representative post-RIC 2,3,5-triphenyltetrazolium chloride (TTC) stained coronal brain section. Scale bar = 3 mm. Optical magnification x 40 (grey-scale image)



Discussion

The present study evaluated the effects of both pre- and post-RIC in a rat model subjected to 'decompression stress'. No differences in the physiological, metabolic or haematological parameters measured were observed, nor were ischaemic brain lesions seen. In the post-RIC group, maximum bubble counts were significantly higher than in the sham dive group, but the lack of a significant difference in bubble grades between the sham and pre-RIC animals suggests that the study probably had insufficient strength (i.e., a Type II error) to detect any difference that might have been present.

Unlike in previous studies, the present dive profile did not produce changes in platelet numbers.[7] This may be explained by the lesser decompression stress of the 600 kPa exposure in the present study compared to the 1,000 kPa exposure used previously.[7] Thus, we are unable to say if RIC attenuates decompression-induced changes in platelets.

Administration of a NO-donor prior to pressurisation has been reported to lower the median EB bubble grade from 5 to 0, when compared with dived controls.[20] Thus, it is surprising that we were not able to demonstrate a similar effect based on the observation that early-phase nitric oxide (NO) and nitrite release has been associated with remote ischaemic conditioning.[21,22] However, RIC has been described to be highly time-dependent comprising of both an early (minutes) and long-term (days) phase of protection, depending on the assessed organ.[14] Thus, as it has been seen with exercise prior to decompression, we cannot preclude the possibility that different timing of the RIC-procedure would mediate a different response. Furthermore, differences in

number and duration of RIC cycles may mediate different protective responses against global cardiac ischaemia.[15] Thus, it seems possible that an alternative RIC-protocol to the one used in this study would mediate an altered decompression stress response.

Post-RIC rats exhibited an elevated bubble response, and the elevated RF, HR and reduced SV post-dive on Day 2 may reflect compromised cardio-respiratory function due to bubble filtering in the lungs and circulatory stress from intravascular bubbles, as previously described.[23] However, the post-RIC HR were already elevated on Day 1 when compared to the sham animals HR, although the two groups had been treated identically at this point. We cannot comment on the SV and CO Day 1, but it may be that the post-RIC group, by chance, were more susceptible to 'decompression stress' due to their altered cardiovascular status at enrolment. We also speculate whether muscle trauma, mediated by the tourniquet during the RIC procedure, may have been the cause of the elevated bubble response seen in post-RIC animals as suggested previously.[24]

Mortality may have been greater in the post-RIC group but, again, the study probably had insufficient strength to confirm this despite the size of the study being based on previous similar work. The 25% mortality in the pre-RIC group is similar to that in a previous comparable study.[16] It is possible that the elevated bubble grade observed in post-RIC animals is the cause of the increased mortality in this group, as an increased bubble grade has been associated with early mortality in other rodent studies.[16,20]

No necrotic brain lesions were detected, as was also the case in a previous study.[16] TTC has successfully been used as a marker for ischaemic brain lesions in a rat stroke model, where pre- or per-RIC significantly reduced the infarcted area when compared to controls.[13] Therefore, despite our negative findings, we expect TTC to be useful in identifying cerebral gas embolisms following a more radical dive profile. However, the use of opioid analgesia in our study may have blunted potential cerebral ischaemic damage since opioids have been found to contribute to the neurogenic pathway for RIC protection against brain infarction.[25]

Impressive multi-tissue protection has been documented for RIC in various organs and intervention models.[11–13,26] Thus, if RIC provides a similar protection against the systemic adverse effect of DCS, RIC could be a useful technique for diving purposes, since it can be performed simply and non-invasively with a blood pressure cuff. However, in the light of the present results, further research is needed before RIC could become a future tool in the pre-hospital treatment of divers with DCS.

Conclusions

Remote ischaemic pre-conditioning conducted 23 h prior to a simulated 600 kPa air-dive did not significantly affect pulmonary bubble load in rats. Instead, remote ischaemic post-conditioning performed immediately after the dive worsened the bubble response and possibly increased mortality. No metabolic or platelet changes were observed in RIC-treated animals compared to sham dive animals, nor were cerebral ischaemic changes demonstrated using TTC staining.

References

1 Randsoe T, Hyldegaard O. Threshold altitude for bubble decay and stabilization in rat adipose tissue at hypobaric exposures. *Aviat Space Environ Med*. 2013;84:675-83.

2 Yang M, Milovanova TN, Bogush M, Uzun G, Bhopale VM, Thom SR. Microparticle enlargement and altered surface proteins after air decompression are associated with inflammatory vascular injuries. *J Appl Physiol*. 2012;112:204-11.

3 Eftedal OS, Lydersen S, Brubakk AO. The relationship between venous gas bubbles and adverse effects of decompression after air dives. *Undersea Hyperb Med*. 2007;34:99-105.

4 Mollerlokken A, Gaustad SE, Havnes MB, Gutvik CR, Hjelde A, Wisloff U, et al. Venous gas embolism as a predictive tool for improving CNS decompression safety. *Eur J Appl Physiol*. 2012;112:401-9.

5 Flick MR, Perel A, Staub NC. Leukocytes are required for increased lung microvascular permeability after microembolization in sheep. *Circ Res*. 1981;48:344-51.

6 Nyquist PA, Dick EJ, Jr., Buttolph TB. Detection of leukocyte activation in pigs with neurologic decompression sickness. *Aviat Space Environ Med*. 2004;75:211-4.

7 Pontier JM, Vallee N, Bourdon L. Bubble-induced platelet aggregation in a rat model of decompression sickness. *J Appl Physiol*. 2009;107:1825-9.

8 Palmer AC, Calder IM, Yates PO. Cerebral vasculopathy in divers. *Neuropathol Appl Neurobiol*. 1992;18:113-24.

9 Schneeweis C, Fleck E, Gebker R. Myocardial infarction after scuba diving. *Eur Heart J*. 2012;33:2224.

10 Gempp E, Blatteau JE. Preconditioning methods and mechanisms for preventing the risk of decompression sickness in scuba divers: a review. *Res Sports Med*. 2010;18:205-18.

11 Botker HE, Kharbanda R, Schmidt MR, Bottcher M, Kaltoft AK, Terkelsen CJ, et al. Remote ischaemic conditioning before hospital admission, as a complement to angioplasty, and effect on myocardial salvage in patients with acute myocardial infarction: a randomised trial. *Lancet*. 2010;375:727-34.

12 Soendergaard P, Krogstrup NV, Secher NG, Ravlo K, Keller AK, Toennesen E, et al. Improved GFR and renal plasma perfusion following remote ischaemic conditioning in a porcine kidney transplantation model. *Transpl Int*. 2012;25:1002-12.

13 Hahn CD, Manlhiot C, Schmidt MR, Nielsen TT, Redington AN. Remote ischemic per-conditioning: a novel therapy for acute stroke? *Stroke*. 2011;42:2960-2.

14 Kanoria S, Jalan R, Seifalian AM, Williams R, Davidson BR. Protocols and mechanisms for remote ischemic preconditioning: a novel method for reducing ischemia reperfusion injury. *Transplantation*. 2007;84:445-58.

15 Johnsen J, Pryds K, Salman R, Lofgren B, Kristiansen SB, Botker HE. The remote ischemic preconditioning algorithm: effect of number of cycles, cycle duration and effector organ mass on efficacy of protection. *Basic Res Cardiol*. 2016;111:10.

16 Havnes MB, Wideroe M, Thuen M, Torp SH, Brubakk AO,

Möllerlökken A. Simulated dive in rats lead to acute changes in cerebral blood flow on MRI, but no cerebral injuries to grey or white matter. *Eur J Appl Physiol*. 2013;113:1405-14.
17 Eftedal O, Brubakk AO. Agreement between trained and untrained observers in grading intravascular bubble signals in ultrasonic images. *Undersea Hyperb Med*. 1997;24:293-9.
18 Muhlfeld C, Nyengaard JR, Mayhew TM. A review of state-of-the-art stereology for better quantitative 3D morphology in cardiac research. *Cardiovasc Pathol*. 2010;19:65-82.
19 Wisloff U, Richardson RS, Brubakk AO. NOS inhibition increases bubble formation and reduces survival in sedentary but not exercised rats. *J Physiol*. 2003;546:577-82.
20 Wisloff U, Richardson RS, Brubakk AO. Exercise and nitric oxide prevent bubble formation: a novel approach to the prevention of decompression sickness? *J Physiol*. 2004;555:825-9.
21 Pickard JM, Botker HE, Crimi G, Davidson B, Davidson SM, Dutka D, et al. Remote ischemic conditioning: from experimental observation to clinical application: report from the 8th Biennial Hatter Cardiovascular Institute Workshop. *Basic Res Cardiol*. 2015;110:453.
22 Rassaf T, Totzeck M, Hendgen-Cotta UB, Shiva S, Heusch G, Kelm M. Circulating nitrite contributes to cardioprotection by remote ischemic preconditioning. *Circ Res*. 2014;114:1601-10.
23 Butler BD, Hills BA. The lung as a filter for microbubbles. *J Appl Physiol.* 1979;47:537-43.
24 Harvey EN. Decompression sickness and bubble formation in blood and tissues. *Bull N Y Acad Med*. 1945;21:505-36.
25 Zhou Y, Fathali N, Lekic T, Ostrowski RP, Chen C, Martin RD, et al. Remote limb ischemic postconditioning protects against neonatal hypoxic-ischemic brain injury in rat pups by the opioid receptor/Akt pathway. *Stroke*. 2011;42:439-44.
26 Kim YH, Yoon DW, Kim JH, Lee JH, Lim CH. Effect of remote ischemic post-conditioning on systemic inflammatory response and survival rate in lipopolysaccharide-induced systemic inflammation model. *J Inflamm* (London). 2014;11:16.

Acknowledgements

We would like to acknowledge Anette Funder, Helene Andersen and Maj-Britt Lundorf for their indispensable histological assistance.

Funding

The work was supported by The Danish Council for Independent Research (Grant-ID: DFF – 4004-00472B). The Centre for Stochastic Geometry and Advanced Bioimaging is supported by the Villum Foundation.

Conflicts of interest: nil

Submitted: 05 November 2015; revised 24 April and 29 June 2016
Accepted: 01 July 2016

Nikolaj Hjort Schmidt[1], Kasper Hansen[1], Henrik Lauridsen[1], Annie Vesterby[2], Jens Randel Nyengaard[3], Alf Brubakk[1], Michael Pedersen[1]

[1]Department of Clinical Medicine – Comparative Medicine Lab, Aarhus University, Aarhus N, Denmark
[2]Department of Forensic Medicine, Aarhus University
[3]Stereology and Electron Microscopy Laboratory, Centre for Stochastic Geometry and Advanced Bioimaging, Department of Clinical Medicine, Aarhus University, Denmark

Address for correspondence:
Nikolaj H Schmidt
Department of Clinical Medicine – Comparative Medicine Lab
Aarhus University, Palle Juul-Jensens Boulevard 99
DK-8200 Aarhus N
Denmark
schmidt@clin.au.dk

The World as it is

Requests for emergency hyperbaric oxygen treatment for carbon monoxide poisoning in Ankara, Turkey

Münïre Kübra Özgök-Kangal, Iclal Karatop-Cesur, Gökhan Akcalı, Senol Yildiz and Günalp Uzun

Abstract

(Özgök-Kangal MK, Karatop-Cesur I, Akcalı G, Yildiz S, Uzun G. Requests for emergency hyperbaric oxygen treatments for carbon monoxide poisoning in Ankara, Turkey. *Diving and Hyperbaric Medicine*. 2016 September;46(3):176-180.)

Background: Carbon monoxide (CO) poisoning is common in Turkey. Our department is the main provider of emergency hyperbaric oxygen therapy (HBOT) in Ankara and neighboring cities. In this study, we analyzed the characteristics of CO-poisoned patients who were referred by phone to our department for emergency HBOT.

Methods: We retrospectively reviewed the records of phone consultations with emergency departments regarding the need for treatment of CO-poisoned patients with HBOT between 14 January 2014 and 14 January 2015. The following information was extracted from medical records: age, gender, CO source, exposure duration, carboxyhemoglobin (COHb) level, symptoms, electrocardiography (ECG) findings, cardiac enzymes, pregnancy, the distance of referring hospital to our centre, time between admission and consultation and HBOT decision.

Results: Over the one-year period, 562 patients with CO poisoning were referred for HBOT. We recommended HBOT for 289 (51%) patients. HBOT was recommended for 58% (n = 194) of the patients with COHb ≥ 25%, 72% (n = 163) of the patients with a history of syncope, 67% (n = 35) of the patients with ECG abnormality, and 67% (n = 14) of pregnant patients. Patients for whom HBOT was not recommended despite having positive signs of severe poisoning were referred significantly later compared to patients for whom HBOT was recommended.

Conclusion: We found that the duration from admission to an emergency department to HBOT consultation affected our decision-making.

Key words

Toxicity; transport; hyperbaric medicine; clinical audit

Introduction

Carbon monoxide (CO) poisoning is a leading cause of morbidity and mortality worldwide.[1–6] According to Social Security Agency records, in 2010 10,154 patients presented to emergency departments (ED) in Turkey for CO poisoning. A frequency of 14/100,000 and a mortality rate of 5/10,000,000 was calculated. However, these rates may be an underestimate of the actual figures considering the misdiagnosis of these cases at EDs and the people deceased at the scene who never reach an ED.[7]

CO strongly binds to oxygen-binding sites on haemoglobin and forms carboxyhaemoglobin (COHb) which eventually causes tissue hypoxia by reducing the oxygen-carrying capacity of the blood. The CO-haemoglobin bond can be reversed by supplemental oxygen therapy. Normobaric oxygen therapy with a non-rebreathing face mask is the standard treatment for CO poisoning. Hyperbaric oxygen treatment (HBOT) is recommended in severe cases to minimise long-term and permanent neurocognitive dysfunction.[8–10]

Currently, there is no clear consensus on HBOT indications for CO poisoning. According to the Undersea and Hyperbaric Medical Society (UHMS), patients with serious CO poisoning (as manifested by transient or prolonged unconsciousness, abnormal neurologic signs, cardiovascular dysfunction, or severe acidosis) or patients who are 36 years of age or older, those exposed to CO for 24 hours or more (including intermittent exposures), pregnant patients or those with COHb level of 25% or more are recommended to receive HBOT.[11] Similarly, the European Committee for Hyperbaric Medicine (ECHM) recommends HBOT to patients with a high risk of immediate or long-term complications. Unconsciousness at or before admission, clinical neurological, cardiac, respiratory or psychological symptoms or signs and pregnancy were identified as high risk factors. If a patient's symptoms have ceased and HBOT was delayed beyond 24 hours after the last exposure, HBOT is not generally recommended.[12] On the other hand, the American College of Emergency Physicians does not mandate any particular practice.[13]

Our department is the main provider of emergency HBOT in Ankara and neighboring cities in Turkey. We have an on-call team for emergency referrals 24/7. Our on-call team decides whether to accept a patient for emergency HBOT based on the information provided by the referring hospital on the phone. Our department does not have predefined criteria

for HBOT in CO poisoning, although we take into account the recommendations of UHMS and ECHM. Owing to the limited availability of HBOT centres in Turkey, patients must to be transferred between hospitals, even between cities, for emergency HBOT. Thereby, transportation-related risks and the distance between a hospital and HBOT facility are other important factors that should be considered for HBOT decisions.

In this study, we analyzed the characteristics of CO-poisoned patients who were referred to our department for emergency HBOT. Additionally, we evaluated the frequency for which HBOT was recommended for each criterion. No attempt to assess clinical outcome was made in this review.

Methods

We retrospectively reviewed the records of telephone consultations with EDs regarding the need for HBOT for CO-poisoned patients between 14 January 2014 and 14 January 2015. The study protocol was approved by the Institutional Ethics Committee for Clinical Research. Informed consent was not required since the telephone consultation records were anonymous. The following information was extracted from the phone consultation records: patient's age and gender, CO source, exposure duration, COHb level, symptoms, electrocardiography (ECG) findings, cardiac enzymes and pregnancy. The distance of the referring hospital to our centre and the elapsed time between emergency admission and HBOT consultation were also analyzed.

The data are reported as *n* (%) or mean ± standard deviation (SD). The patients with missing data for some parameters were not excluded. The missing data were taken into account while calculating the percentages and reported separately. For statistical analysis, we used independent samples *t*-tests for continuous variables and chi-square tests for categorical variables. A value of $P < 0.05$ was accepted as statistically significant. We used SPSS® Statistics Version 21 (IBM Corp., Armonk, NY) for statistical analysis.

Results

The telephone consultation records included 562 patients over the one-year period. Of these, 177 (31%) were female, and 241 (43%) were male, while the gender information was missing for 144 (26%) patients. The mean age of the patients was 28.6 ± 22.4 years (range: 0.1–88 years). The mean COHb level of the patients was 27.6% (range: 0.4%–70%), while the COHb level was unknown in 32 patients. The mean CO exposure duration was 7 ± 6 hours ($n = 109$; range: 1–24 h). The mean elapsed time between emergency unit admission and HBO consultation was 3h 22 min ± 3h 14 min (range: 15 min–19 h 40 min). The clinical characteristics of referred patients are summarised in Table 1.

Table 1
Clinical characteristics of patients referred for hyperbaric oxygen treatment (HBOT)

	n	(%)
Most common symptoms		
History of syncope	225	(40)
Headache	86	(15)
Nausea/vomiting	56	(10)
Dizziness	28	(5)
Other neurological symptoms		
Confusion	26	(5)
Lethargy	26	(5)
Loss of consciousness (+ respiratory difficulties)	18	(3)
Loss of consciousness	14	(2.5)
Seizure	9	(1.6)
Incontinence	8	(1.4)
ECG abnormalities		
Yes	52	(9)
No	431	(77)
Not available	79	(14)
Cardiac enzyme abnormalities		
Yes	70	(13)
No	327	(58)
Not available	165	(29)
Pregnancy		
Yes	21	(4)
% Carboxyhemoglobin		
0–24%	195	(34.7)
≥ 25%	335	(59.6)
Not available	32	(5.7)

Among all consultations, 10% were from our institution, 58% were from other hospitals in Ankara and 31% were from 24 other cities. The average distance between consulting cities and Ankara was 285 ± 127 km (range: 80–737 km). The patients were mostly referred in the winter months of December through February (58%) and after working hours (63%). The most frequent CO sources were heating systems including stoves (53%) and combi gas boilers (27%).

We recommended HBOT for 289 (51%) patients. The mean COHb level of the patients for whom HBOT was recommended was 30.4% (± 10.7%; range:1%–70%) and was significantly higher than in those for whom HBOT was not recommended (24.8% ± 9.2%, range: 0.4%–53.0%; $P = 0.029$). When the patients were grouped according to their COHb level, 58% of the patients with COHb ≥ 25%, were recommended to receive HBOT whilst 40% of the patients with COHb ≤ 25% were recommended to receive HBOT ($P < 0.001$).

A history of syncope was present in 40% ($n = 225$) of patients and 72% ($n = 163$) of them were recommended to receive HBOT ($P < 0.001$; Table 2). Among the patients ($n = 108$)

Table 2
The rate of recommendation for hyperbaric oxygen treatment (HBOT) based on commonly used criteria

	HBOT		No HBOT		*P* value
Age group (years)					
0–35	184	(52)	168	(48)	0.331
>35	92	(48)	100	(52)	
History of syncope					
Yes	163	(72)	62	(28)	<0.001
No	126	(37)	211	(63)	
Other neurological symptoms					
Yes	89	(82)	19	(18)	<0.001
No	200	(44)	254	(56)	
ECG abnormalities					
Yes	35	(67)	17	(33)	0.006
No	204	(47)	227	(53)	
Cardiac enzyme abnormalities					
Yes	34	(49)	36	(51)	0.681
No	150	(46)	177	(54)	
Carboxyhemoglobin (mean% ± SD)	30.4	±10.7	24.8	±9.2	0.029

with other neurological symptoms, 82% ($n = 89$) of patients were recommended to receive HBOT ($P < 0.001$).

Chest pain was present in one patient and hypotension in two; however, the ECG was normal in these patients. HBOT was recommended for all three of these patients with other indications for HBOT pregnancy ($n = 1$); coma ($n = 1$); cardiac enzyme abnormality ($n = 1$). ECG data were available in 483 patients. Of these, 11% ($n = 52$) had abnormal ECG findings including ischaemic changes (ST abnormalities, T negativity, non-ST myocardial infarction, left bundle branch block), atrial fibrillation, extra-systoles, tachycardia, right axis deviation, and prolonged QT. HBOT was recommended for 67% ($n = 35$) of patients with ECG abnormalities ($P = 0.006$; Table 2).

There were 21 pregnant patients with CO poisoning, of whom we recommended HBOT for 14 whose average COHb level was 24.1 ± 5.3%. The average COHb level of the seven pregnant patients who were not recommended HBOT was 17.5 ± 10.3%. Of these, five had no history of syncope, neurological symptoms, cardiovascular symptoms, ECG abnormality or cardiac enzyme abnormality. The status of their foetus was reported as normal by obstetric consultants. However, two other pregnant patients had a history of syncope. One of these patients was referred from Konya from where transportation takes two hours to our institution, and the elapsed time between hospital admission and HBOT consultation was eight hours. The other patient was referred from Karabük where transportation takes three hours to our institution and the elapsed time was four hours.

Eight patients had 24 hours of CO exposure and four of them were advised to receive HBOT. One of them was pregnant and others had headache, dizziness or weakness. The remaining four patients, who were not advised to receive HBOT, did not have positive symptoms, ECG abnormality or cardiac enzyme abnormality.

Table 3
The relationship between clinical characteristics and elapsed time (h) to hyperbaric referral according to whether the patient received hyperbaric oxygen treatment (HBOT/No HBOT)

	HBOT (h)	No HBOT (h)	*P* value
History of syncope	3.8 ± 6.8	8.4 ± 23.5	0.005
Other neurological	4.8 ± 8.3	18.5 ± 40.0	<0.001
ECG abnormalities	4.3 ± 8.5	7.1 ± 11.5	0.305
Pregnancy	1.1 ± 0.6	6.0 ± 5.9	0.001

We found that patients who were not recommended for HBOT despite a history of syncope, presence of neurologic symptoms at admission or pregnancy had longer delays to HBOT consultation (Table 3).

Discussion

HBOT decisions in patients with CO poisoning can be challenging. In the present study, we found that COHb levels, history of syncope, neurological symptoms, and ECG abnormality were linked to our HBOT decisions. In addition, we found that patients who had been referred after a considerable delay were not accepted for HBOT even if they had a history of syncope, presence of neurologic symptoms at admission or pregnancy.

In one study, HBOT was used in 14 (12.1%) of 116 patients admitted to an ED over a 14-year period.[14] However, 60% of the patients were classified as mild according to a poisoning severity score/clinical score (European Association of Poison Centres and Clinical Toxicologists/International Programme on Chemical Safety). This may explain the low proportion of HBOT recommendations.

Only 19% of all CO poisoning patients presenting to one Taiwanese ED were treated with HBOT in that institution's hyperbaric medicine department.[15] The authors reported that the National Health Insurance of Taiwan did not cover the cost of HBOT and that there was no standard HBOT indication for such cases in Taiwan. This may explain this low referral rate for HBOT despite their institution having a 24/7 HBOT service.

In Jerusalem, 21% of patients with CO poisoning admitted to an ED were referred for HBOT. COHb levels were lower than 25% in 71% of the patients; patients who had convulsions, loss of consciousness or respiratory failure were referred for HBOT.[5] Of 325 paediatric CO poisoning cases admitted to an ED in another study, 81 (24%) received HBOT.[16] The authors classified the patients according to COHb level (10–30% mild, 30–40% moderate, 40–60% severe),

with 254 of the 325 patients (78%) classified as mild intoxication unlikely to be referred for HBOT. In another two-year study of paediatric patients, 107 were diagnosed as acute CO poisoning and 55 (51%) received HBOT.[17] This high frequency may be due to the fact that 54 of 74 CO poisoning patients had a COHb > 20%. Similarly, HBOT was recommended for 289 patients (51%) who were referred from 25 different cities in the present study.

According to the UHMS/CDC CO poisoning surveillance programme, the mean COHb level was 23.4% (range 0.1–77.0%) among the patients who received HBOT.[18] In the Jerusalem series, the average COHb level in patients who received HBOT was 22 ± 8% and 16 ± 7% in the group of patients who received conservative treatment ($P > 0.5$),[5] whereas in the present study, the difference in the mean COHb level between patients recommended for HBOT and those who were not was statistically significant ($P = 0.029$).

In two earlier studies, the incidence of syncope was 9% and 23% respectively compared to 40% in our study.[17,19] It is important to realize that our study population differs from many other studies in that only moderate or severe CO poisoning patients were included.

Currently, there is no consensus about the maximum delay to the initiation of HBOT.[18,20] Many of the CO-poisoning-related pathological processes are time dependent and the time window for HBOT in humans remains unknown.[21] Animal studies suggest that lipid peroxidation can be prevented when HBOT is initiated 45 minutes after CO exposure,[22] and that HBOT has a time-dependent protective effect with the highest efficiency being between three and four hours after poisoning.[23] Unfortunately, the efficiency of administering HBOT beyond six hours is not clearly known. Most HBOT practitioners do not recommend HBOT beyond a delay of 24 hours.[20]

The present audit has limitations. We analyzed the phone consultation records of a single HBOT centre; therefore, our results may not be generalizable. Multicentre studies may increase our understanding of how HBOT is used in CO poisoning in real life and help to identify problems. Due to the retrospective design of the study, we rely on only the data available in the records

Another limitation of our study was the lack of information on the discharge status or long-term outcome of patients. Long-term outcome is the most important outcome measure in CO poisoning.[10] We could not follow up the patients after HBOT because our centre covers such a wide area (almost 280,000 km^2) and only a small minority of the patient referrals (10%) came from our own institution. After the end of all HBOT sessions, patients were transported back to their referring hospitals. Lastly, looking at outcome was not the prime purpose of this audit.

Conclusions

In this study, we found that COHb levels, history of syncope, neurological symptoms and ECG abnormalities were related to HBOT decisions. In addition, we found that patients who were referred after a significant delay were not accepted for HBOT despite a history of syncope, presence of neurologic symptoms at admission or pregnancy. CO poisoning remains an important public health problem in our country and the role of HBOT is still not clearly defined. Our study revealed that a significant time was lost before HBOT consultations. Due to this delay, many patients did not receive HBOT despite having criteria defined by the UHMS and ECHM. The reasons for such delay should be investigated in future studies and reliable outcome data obtained.

References

1 Hampson NB, Weaver LK. Carbon monoxide poisoning: a new incidence for an old disease. *Undersea Hyperb Med*. 2007;34:163-8.

2 Average annual number of deaths and death rates from unintentional, non-fire related carbon monoxide poisoning, by sex and age group - United States, 1999–2010. *Morbidity and Mortality Weekly Report*. 2014;63(3):65.

3 Iqbal S, Clower JH, King M, Bell J, Yip FY. National carbon monoxide poisoning surveillance framework and recent estimates. *Public Health Rep*. 2012;127:486-96.

4 Dianat I, Nazari J. Characteristics of unintentional carbon monoxide poisoning in Northwest Iran – Tabriz. *Int J Inj Contr Saf Promot*. 2011;18:313-20.

5 Salameh S, Amitai Y, Antopolsky M, Rott D, Stalnicowicz R. Carbon monoxide poisoning in Jerusalem: epidemiology and risk factors. *Clin Toxicol*. 2009;47:137-41.

6 Li F, Chan HC, Liu S, Jia H, Li H, Hu Y, et al. Carbon monoxide poisoning as a cause of death in Wuhan, China: a retrospective six-year epidemiological study (2009–2014). *Forensic Sci Int*. 2015;253:112-8.

7 Metin S, Yildiz S, Cakmak T, Demirbas S. [Frequency of carbon monoxide poisoning in Turkey in 2010.] TAF *Prev Med Bull*. 2011;10:587-92. Turkish.

8 Hampson NB, Hauff NM. Risk factors for short-term mortality from carbon monoxide poisoning treated with hyperbaric oxygen. *Crit Care Med*. 2008;36:2523-7.

9 Hampson NB, Piantadosi CA, Thom SR, Weaver LK. Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. *Am J Respir Crit Care Med*. 2012;186:1095-101.

10 Weaver LK, Hopkins RO, Chan KJ, Churchill S, Elliott CG, Clemmer TP, et al. Hyperbaric oxygen for acute carbon monoxide poisoning. *N Engl J Med*. 2002;347:1057-67.

11 Weaver LK. Carbon monoxide poisoning. Weaver LK, editor. *Hyperbaric oxygen therapy indications*, 13th ed. Florida: Best Publishing Company; 2014.

12 Wattel F, Bitterman N, Hamilton-Farell M, Lind F, Messimeris T, Roque F, et al. Carbon monoxide (CO) intoxication. In: Bakker D, Marroni A, Mathieu D, editors. Abstract. *Proceedings of 7th European Consensus Conference on Hyperbaric Medicine*; 2014 Dec 3–4; Lille, France: European Committee for Hyperbaric Medicine; 2004. p. 7.

13 Wolf SJ, Lavonas EJ, Sloan EP, Jagoda AS. Clinical policy:

critical issues in the management of adult patients presenting to the emergency department with acute carbon monoxide poisoning. *Ann Emerg Med*. 2008;51:138-52.
14 Arici AA, Demir O, Ozdemir N, Unverir P, Tuncok Y. [Carbon monoxide exposures admitted to emergency department: fourteen years analysis.] *DEU Tıp Fakultesi Dergisi*. 2010:24:25-32. Turkish.
15 Ku CH, Hung HM, Leong WC, Chen HH, Lin JL, Huang WH, et al. Outcome of patients with carbon monoxide poisoning at a far-east poison center. *PLoS One*. 2015:10:e0118995. doi:10.1371/journal.pone.0118995
16 Boztepe H, Yalaki Z, Bilge YD. [Evaluation of neurological and cardiological findings in carbon monoxide poisoning in children.] *Turk Pediatri Ars*. 2014;49:314-22. Turkish.
17 Yarar C, Yakut A, Akin A, Yildiz B, Dinleyici EC. [Analysis of the feature of acute carbon monoxide poisoning and hyperbaric oxygen therapy in children.] *Turk J Pediatr*. 2008;50:235-41. Turkish.
18 Hampson NB, Dunn SL, Yip FY, Clower JH, Weaver LK. The UHMS/CDC carbon monoxide poisoning surveillance program: three-year data. *Undersea Hyperb Med*. 2012;39:667-85.
19 Akköse S, Türkmen N, Bulut M, Akgöz S, Isçimen R, Eren B. An analysis of carbon monoxide poisoning cases in Bursa, Turkey. *East Mediterr Health J*. 2010;16:101-6.
20 Hampson NB, Little CE. Hyperbaric treatment of patients with carbon monoxide poisoning in the United States. *Undersea Hyperb Med*. 2005;32:21-6.
21 Weaver LK. Hyperbaric oxygen in carbon monoxide poisoning. Conflicting evidence that it works. *BMJ*. 1999;319:1083-4.
22 Thom SR. Antagonism of carbon monoxide-mediated brain lipid peroxidation by hyperbaric oxygen. *Toxicol Appl Pharmacol*. 1990;105:340-4.
23 Brvar M, Luzar B, Finderle Z, Suput D, Bunc M. The time-dependent protective effect of hyperbaric oxygen on neuronal cell apoptosis in carbon monoxide poisoning. *Inhal Toxicol*. 2010;22:1026-31.

Submitted: 06 October 2015; revised 19 July and 01 August 2016
Accepted: 03 August 2016

Münïre Kübra Özgök-Kangal, Iclal Karatop-Cesur, Gökhan Akcali, Senol Yildiz, Günalp Uzun

Department of Underwater and Hyperbaric Medicine, Gülhane Military Medicine Academy, Ankara, Turkey

Address for correspondence:
M K Özgök-Kangal
Gülhane Askeri Tıp Akademisi,
Sualtı Hekimliği ve Hiperbarik Tıp A.D.
Etlik, Ankara
Turkey
kubra_ozgk@hotmail.com

Letter to the Editor

Carbon dioxide absorbents for rebreather diving

Firstly I would like to thank SPUMS members for making me a Life Member of SPUMS; I was surprised and greatly honoured by the award.

I also want to confirm and expand on the findings on carbon dioxide absorbents reported by David Harvey et al.[1]

For about 35 years, I was the main player in deciding which absorbent went into Australian Navy and Army diving sets. On several occasions, suppliers of absorbents to the anaesthesia market tried to supply the Australian military market. On no occasion did they provide absorbent that came close to the minimum absorbent capacity required, generally being 30–40% less efficient than diving-grade absorbents. Because I regard lives as being more important than any likely dollar saving, the best absorbent was always selected unless two suppliers provided samples with the same absorbent capacity. On almost every occasion, there was a clear winner and cost was never considered.

I suggest the same argument for the best absorbent should be used by members and their friends who dive using rebreather sets. I make this point because of my findings on a set that was brought to me after the death of its owner. The absorbent was not the type or grain size recommended by the manufacturer of the set and did not resemble any of the diving grade absorbents I knew of. I suspected by its appearance that it was anaesthetic grade absorbent. When I tested the set, the absorbent system failed very quickly so it is likely that carbon dioxide toxicity contributed to his death. The death was not the subject of an inquest and I have no knowledge of how the man obtained the absorbent. Possibly there was someone from an operating theatre staff who unintentionally caused their friend's death by supplying him with 'borrowed absorbent'. I make this point as I would like to discourage members from making a similar error.

Reference

1 Harvey D, Pollock NW, Gant N, Hart J, Mesley P, Mitchell SJ. The duration of two carbon dioxide absorbents in a closedcircuit rebreather diving system. *Diving Hyperb Med*. 2016;46:92-7.

John Pennefather, Consultant to the School of Underwater Medicine, Royal Australian Navy, Mosman NSW
john.pennefather1@defence.gov.au

Key words
Rebreathers/closed circuit; rebreathers/semi-closed circuit; risk factors, letters (to the Editor)

A day in the life of a diabetic diver: the Undersea and Hyperbaric Medical Society/Divers Alert Network protocol for diving with diabetes in action

Rebecca Johnson

Abstract

(Johnson R. A day in the life of a diabetic diver: the Undersea and Hyperbaric Medical Society/Divers Alert Network protocol for diving with diabetes in action. *Diving and Hyperbaric Medicine*. 2016 September;46(3):181-185.)
Some people with well-managed insulin-dependent diabetes can dive safely. Those cleared to participate should control tightly the variables that impact blood glucose levels, including activity, timing, food and insulin. Honest self-assessment is critical. A diabetic diver should cancel a dive if seasick, unusually anxious, or following significant high or low blood glucose levels in the preceding 24 hours. The diver should enter the water with a blood glucose level above 8.3 mmol·L^{-1} and below 14 mmol·L^{-1} with a stable or rising trend in blood glucose established with glucose tests at 90, 60, and 30 minutes prior to a dive. The diver should carry emergency glucose at all times and brief dive buddies about hypoglycaemia procedures. This is a personal account of the author's experience diving with type 1 diabetes and details how the UHMS/DAN recommendations are put into practice on dive days. Key elements of the self-assessment process, long- and rapid-acting insulin adjustments, meal timing, responses to blood glucose trends, handling hypoglycaemia and approaching multi-dive days are described. Some considerations for people using insulin pumps are also briefly discussed.

Key words
Scuba diving; health status; exercise; blood glucose level; endocrinology; safety

Introduction

Many people with well-managed insulin-dependent diabetes mellitus (IDDM) are highly self-aware, disciplined and able to manage risk; traits that set them in good stead to be excellent divers. Indeed, dive medicine bodies recognise that "*some individuals with insulin-requiring diabetes may be able to dive with an acceptable level of risk.*"[1] The Undersea and Hyperbaric Medical Society (UHMS) and Divers Alert Network (DAN) provide a comprehensive series of recommendations for selection and surveillance, scope of diving, and glucose management on the day of diving. The proceedings of the meeting through which the guidelines were developed includes individual papers, discussion, and the consensus guidelines.[2] An executive summary including the 19-point guidelines can be found in the proceedings and was reprinted in this journal.[3] The guidelines have been adopted by a number of dive medicine bodies, including the South Pacific Underwater Medicine Society (SPUMS).[1]

Medical evaluation to ensure 'fitness to dive' and scope of diving are critical pieces of the UHMS/DAN guidelines, but are beyond the scope of this paper. Here, my personal experience of diving with type 1 diabetes and details of how I put the UHMS/DAN recommendations into practice on dive days are related. Key elements of the self-assessment process, long- and rapid-acting insulin adjustments, meal timing, responses to blood glucose trends, handling hypoglycaemia, and approaching multi-dive days are considered. Also briefly discussed are some considerations for people using insulin pumps. Readers are encouraged to refer to the complete guidelines for additional information.[2,3]

Managing type 1 diabetes

Diagnosed with type 1 diabetes in 2001, when I was 17 years old, I currently follow a regimen of multiple daily injections (MDI) using analogue long- and rapid-acting insulins (detemir and lispro). I generally inject long-acting insulin (morning and night) and up to four, small rapid-acting insulin doses for meals and corrections during the day. I eat a low-carbohydrate diet which keeps my blood glucose very stable; eliminating carbohydrate-based foods reduces both post-prandial glucose excursions and the amount of insulin I need, which minimises error margins in dose calculations. I am very active, which keeps me insulin-sensitive, and I use both a continuous glucose monitoring system (CGMS; Dexcom Inc, San Diego, USA) and now 'flash' monitoring (Freestyle Libre, Abbot Diabetes Care, UK) to fine-tune my overall management. I choose not to use an insulin pump because I am comfortable and confident with MDI and consistently achieve HbA1c values around mid-5 mmol·L^{-1} with my approach.

Diving with type 1 diabetes

I learned to dive in 2007, certifying as a PADI Divemaster in 2008. Armed with a history of excellent HbA1c values and good hypoglycaemia awareness, I passed the dive medical and became certified in Thailand and Honduras rather than in Australia, where people with type 1 have difficulty accessing dive training. The access issue in Australia is due primarily to a position statement issued in 1994 by the Australian Diabetes Society (ADS) declaring diabetes to be contraindicated for diving, which is at odds with positions

on diving with diabetes in the United Kingdom, the USA and a number of European countries. The ADS statement was withdrawn for review in April 2015, and at the time of writing (20 August 2016), people with diabetes in Australia await an updated statement.

When I learned to dive, I was not aware of the UHMS/DAN protocols and I established my own safe blood glucose management strategies based on logic and years of learning about blood glucose management for sports. My approach was in essence similar to the UHMS/DAN protocols: I tested frequently in the lead up to a dive, dived with slightly elevated blood glucose levels in order to manage hypoglycaemia risk, briefed my dive buddy about diabetes and always carried hypoglycaemia treatment. Now, a clear set of strategies for blood glucose management on dive days is available and accessible for people with diabetes to follow, with support from both health care professionals and peers.[2,3]

Goals on dive days

Diving with type 1 diabetes requires careful planning and management, with the main aim of avoiding underwater hypoglycaemia. A secondary aim is to minimise anxiety about blood glucose – I would rather be captivated by a beautiful reef than worrying about my levels – so my approach is to control all the variables in play to make the outcomes as predictable as possible.

CONTROLLING THE VARIABLES

The four major variables that influence blood glucose are activity, timing, food and insulin. This is what I have learned about the four variables in relation to diving:

Activity

The type, intensity, and duration of physical activity impacts blood glucose. When making predictions about this variable, I need to consider factors like water temperature, likelihood of current and purpose of the dive (e.g., relaxing and drifting, or active and intense). I can generally predict that a combination of the fall in temperature from immersion in water and constant slow kicking will drop my blood glucose level by 2–3 $mmol \cdot L^{-1}$ over a 50-minute dive. If I am kicking into a current and working hard, it may drop more.

However, on rare occasions this does not hold true: if I have a particularly intense or exciting dive, I can emerge from the water with elevated blood glucose because adrenalin causes my liver to release glycogen. This is important to keep in mind for anxious or novice divers with diabetes as it can explain unexpected high blood glucose levels after diving.

Timing

Like many people with diabetes, I experience the "*dawn phenomenon*" which is a sharp increase in blood glucose early in the morning and subsequent insulin resistance that lasts until about 11:00 am. I become more sensitive to insulin as the day progresses. This means mornings are the ideal time to dive for me, as it is the time when I am naturally well protected from hypoglycaemia.

If I am scheduled to dive in the afternoon or evening, I plan around my increased insulin sensitivity. Because I know diving generally causes my blood glucose to drop, I can manage my hypoglycaemia risk by either reducing the rapid-acting insulin I take with my lunch and running my glucose level slightly high until dive time, or (my preferred method) raise my blood glucose slightly by eating two to four glucose tablets (8–16 grams of carbohydrate) about 45 minutes prior to diving.

Insulin

Understanding insulin is essential for the diabetic diver, and healthcare professionals are key to educating people with diabetes about insulin pharmacodynamics and pharmacokinetics. If people with diabetes understand insulin time/action profiles, absorption rates and mechanisms of action, they can work with their diabetes care teams to select the most appropriate insulins for their lifestyles, eating habits and physical activity pursuits.

Changing my long-acting insulin, for example, has helped me dive and exercise safely. When I moved from human to analogue insulins, I was started on glargine insulin. Glargine precipitates into an insoluble depot of insulin in the tissues at the injection site, which gradually becomes soluble and moves into the bloodstream. I found I sometimes experienced hypoglycaemia when I was physically active as activity increased blood flow around the insulin depot and, therefore, increased the speed at which the insulin was released into my bloodstream. I switched to insulin detemir, which binds to albumin in the blood and slowly dissociates, giving it a more stable absorption profile which I have found protects me from hypoglycaemia during exercise.[3]

Information about long-acting insulins is important for people on MDI only; knowing rapid-acting insulin time/action profiles is essential for people on both MDI and insulin pumps. Rapid-acting insulins have intense rises and peaks, generally becoming effective within 15–20 minutes of injection, peak after 60–90 minutes, and are active for around three hours. I find having rapid-acting insulin in my system when I exercise can make me prone to hypoglycaemia, so I never dive with active rapid-acting insulin on board. This strategy impacts meal timing when diving.

Food

As I prefer to dive with a system clear of rapid-acting insulin, I do not eat meals in the three hours prior to diving. I generally do morning dives in a fasted state, eat a late breakfast/early lunch for afternoon diving, and

leave my evening meal until after a night dive. Controlling my variables like this means I can minimise my risk of hypoglycaemia and dive with confidence. More generally, as dietary carbohydrate has a profound impact upon blood glucose, I minimise it. My diet generally consists of non-starchy vegetables, quality protein and healthy fats which keeps my blood glucose stable and predictable.

A note on insulin pumps

Insulin pumps only use rapid-acting insulin, so people on pumps must strike a fine balance between having some rapid-acting insulin on board to prevent hyperglycaemia, but not so much as to cause hypoglycaemia. Pumpers could manage hypoglycaemia risk by reducing their basal insulin delivery rate 2 to 5 hours prior to diving, and/or ingesting some fast-acting carbohydrate such as glucose tablets in the 45 minutes before diving. As with MDI regimens, controlling the four variables on pumps helps manage blood glucose. Not diving within three hours of a meal and insulin bolus, i.e., diving with only basal insulin on board and fine tuning with glucose tablets only, is a strategy some people employ to make levels more predictable.

Insulin pumps cannot be taken more than 1 metre below the surface, so pumps need to be disconnected prior to diving. Insulin will remain in a person's system for approximately three hours after a pump is disconnected. The amount of active insulin on board (bolus insulin only) can be obtained from most new pumps. Combined with a good understanding of rapid-acting insulin time/action profiles, insulin-on-board information will help a diver decide the best time to disconnect his/her pump prior to diving. Pumps should be reconnected upon surfacing, immediately after testing blood glucose levels to ensure the diver is not hypoglycaemic.

Blood glucose management on diving days

The UHMS/DAN guidelines give a series of recommendations about how to approach dive days with diabetes. This section outlines how I put these recommendations into practice.

SELF-ASSESSMENT

UHMS/DAN recommends that divers with diabetes assess themselves in a general sense prior to diving, and cancel a dive "*if* [the diver] *is uncomfortable, unduly anxious, unwell in any way (including seasickness), or blood glucose control is not in its normal stable pattern.*"[2]

I need three hours' notice at a minimum to do a dive; generally I prefer my self-assessment to begin about eight hours before a dive. My overnight blood glucose is generally stable, but if I am diving in the morning, ideally I use my flash monitor or CGMS overnight, which involves a sensor inserted under my skin that transmits and records my glucose levels every five minutes. CGMS transmitters cannot be taken more than 1 metre below the surface so I need to disconnect the transmitter and tape the sensor site before diving. Alternatively, I test my blood glucose before bed and rise to test at least three hours before the dive. If I am diving in the afternoon or evening, I test six to eight times during the day. If my blood glucose has been elevated (above 10 $mmol \cdot L^{-1}$) for more than three hours or if I have a significant hypoglycaemic event (below 3 $mmol \cdot L^{-1}$) in the lead-up to a dive, then I call it off.

Seasickness is a particular issue if the diver has chosen to manage hypoglycaemia risk by ingesting carbohydrate rather than reducing insulin; if the diver vomits s/he will have active insulin on board but no carbohydrate for it to act upon, which may lead to hypoglycaemia. A diabetic diver who becomes seasick should not dive, and glucose replacement to counteract active insulin is crucial. In my experience, a way to counteract hypoglycaemia when vomiting with active rapid-acting insulin on board is to frequently sip small amounts of fluids containing sugar, as at least some sugar will be absorbed before the fluid is rejected. The 'sick day' procedures from the diver's diabetes team should be followed in relation to issues like ketone management.

MINIMUM BLOOD GLUCOSE AND TREND

The UHMS/DAN protocol recommends establishing a blood glucose level of at least 8.3 $mmol \cdot L^{-1}$ (SPUMS recommends 9 $mmol \cdot L^{-1}$) and both recommend ensuring blood glucose is either stable or rising before entering the water.[1,2] Assuming long-acting/basal insulin doses are correct and remain unchanged, achieving the target minimum blood glucose level requires either reducing rapid-acting insulin for any meal eaten prior to diving, or ingesting carbohydrate. As I prefer to avoid dosing and eating meals before diving, I may need to increase my blood glucose level with a small, controlled amount of carbohydrate such as two to four glucose tablets (totalling 8–16 grams of carbohydrate which normally raises my blood glucose by 2–3 $mmol \cdot L^{-1}$) in order to reach a level where I am safe to dive. I generally do this about 45 minutes before diving. I test my blood glucose 90, 60 and 30 minutes and immediately prior to the dive to establish that I am entering the water with a stable or slightly rising blood glucose trend. The 90-minute test is additional to the UHMS/DAN guidelines.

MAXIMUM BLOOD GLUCOSE

The reason I eat very few carbohydrates and use only small amounts of glucose for corrections is because it is very easy to raise blood glucose levels too much. The protocol states that corrections with carbohydrate to raise blood glucose should not result in a level higher than 14 $mmol \cdot L^{-1}$, and diving should be cancelled if levels reach 16 $mmol \cdot L^{-1}$ or higher. High blood glucose increases the risks of dehydration, cramps and ketone accumulation.

If blood glucose levels are within the target range recommended for diving (8.3 [or 9]–14 mmol·L^{-1}) then they are higher than the ideal range of 4–8 mmol·L^{-1}. I aim to maintain levels of 8.5–10 mmol·L^{-1} when diving. I am comfortable running my blood glucose levels slightly higher than usual in order to dive safely; however, I need to drink extra water in order to counteract the dehydration I feel when I do this.

CARRYING EMERGENCY GLUCOSE AND HYPOGLYCAEMIA PROCEDURES

I try to ensure my risk of hypoglycaemia is remote by the choices in the lead-up to a dive; however, as recommended by UHMS/DAN, I always carry glucose in my buoyancy compensator (BCD) just in case. The most durable and easily ingestible form of glucose I have found for diving is gel shots, sold in cycling and running shops. I usually give one gel shot to my dive buddy, and inform him or her that I also have gel shots in the pocket of my BCD. The UHMS/DAN guidelines also recommend having glucagon available at the surface.

I brief my dive buddy thoroughly about diabetes and what to do if I have a hypoglycaemia event. I have never experienced low blood glucose underwater during a dive, but I have experimented in swimming pools in order to better understand my hypoglycaemia symptoms in water; I know that a sudden, acute awareness of cold and a feeling of weakness are my main symptoms. If I were to feel hypoglycaemic underwater, I would signal "*L*" with index finger and thumb for "*Low*" to my buddy, surface with him or her, establish positive buoyancy, ingest glucose on the surface and leave the water.

The worst case scenario is loss of consciousness underwater, in which case the only additions needed to a standard rescue procedure are administration of parenteral glucagon if available, and notifying emergency services that the rescued diver has diabetes.

AFTER DIVING

I always check my blood glucose immediately after diving, and have noticed that my pattern of a 2–3 mmol·L^{-1} drop is very predictable and I generally emerge between 5.5 and 8 mmol·L^{-1}. If we are due to do another dive, I avoid eating and taking rapid-acting insulin during the surface interval so I can remain in tight control of my variables. If I need to correct my blood glucose level to bring it up to a level that is safe for a second dive, I do so with glucose tablets only. As with all sustained exercise, if I have a particularly active day diving I need to be cautious about delayed hypoglycaemia, which I manage for eight to ten hours after diving, with regular blood tests or my CGMS. Finally, UHMS/DAN recommends logging blood glucose levels, diabetes interventions and dives. Ensuring blood glucose meter date and time settings are correct is important (and often overlooked when replacing batteries or changing meters) in case records need to be corroborated at a later date.

Table 1
The major principles of management for safe scuba diving for a person with type 1 diabetes

- People with well-managed insulin-dependent diabetes can dive safely.
- Divers with diabetes should tightly control the variables that impact blood glucose levels, including activity, timing, food and insulin.
- Honest self-assessment is critical. A diver with diabetes should cancel a dive if seasick, unusually anxious, or if s/he has had significant high or low blood glucose levels in the preceding 24 hour period.
- Enter the water above 8.3 mmol·L^{-1} and below 14 mmol·L^{-1} with a stable or rising trend in blood glucose established with glucose tests at 90, 60, and 30 minutes prior to a dive.
- Carry emergency glucose at all times and brief dive buddies about hypoglycaemia procedures.
- Use the online diabetes community for support and practical advice about reaching physical activity goals with insulin dependent diabetes.

The future: new technology

'Flash monitoring' is a new system that monitors interstitial glucose through a subcutaneous sensor that transmits a tethered radio signal to a receiver came to market recently in Australia. The sensor is scanned by the receiver to provide an instantaneous glucose reading and the glucose level trend for the previous eight hours. No finger pricks are needed to calibrate the device and it is considerably cheaper than existing continuous glucose monitors on the market. I now use a flash monitor regularly. The sensor is not supposed to be submerged deeper than 3 m but I took it on a 18 m dive and it survived and remained accurate post dive (compared to finger prick glucose measurements). I then went on several 15 m dives with the receiver in a jury-rigged pressure-proof camera housing. The system gave me what appeared to be accurate in-dive readings, corroborated on the surface immediately post dive. Research on the sensor's pressure tolerances and its accuracy at depth would seem well worthwhile pursuing. With a custom housing, such new technology potentially promises much for divers with diabetes to obtain glucose information while diving.

Conclusions

Diving with insulin-dependent diabetes presents some challenges, but it is certainly achievable for those medically cleared, capable, and motivated to participate. It is crucial for diabetic divers to identify, understand and control

the variables that impact blood glucose in order to dive safely (Table 1). My approach is simple: I minimise risk by avoiding rapid-acting insulin and meals prior to diving and adhere to the UHMS/DAN recommendations on dive days. The UHMS/DAN recommendations can be tailored to suit different diabetes regimens and preferences for hypoglycaemia management, and divers should create individual management plans in conjunction with their healthcare providers.

When developing management plans, divers and doctors alike can tap into the vast collective knowledge of thousands of active people living with diabetes by joining the thriving, knowledgeable online diabetes community. Online discussion boards such as those hosted by the American Diabetes Association (http://community.diabetes.org/), Diabetes.co.uk (http://www.diabetes.co.uk/forum/), and communities on Facebook such as the Type 1 Diabetic Athletes Group (https://www.facebook.com/groups/Type1DiabeticAthletes/) and Sporty Diabetic Type 1s (https://www.facebook.com/groups/SportyT1/) are rich sources of information acquired from years of lived experience. Divers and healthcare professionals can crowdsource problems and seek support from these powerful resources in order to attempt and achieve diving goals.

References

1 *The South Pacific Underwater Medicine Society Diving Medical*, 4th edition. Melbourne: South Pacific Underwater Medicine Society; 2010. [cited 2016 January 21]. Available from: http://www.spums.org.au.

2 Pollock NW, Uguccioni DM, Dear GdeL, editors. *Diabetes and recreational diving: guidelines for the future*. Proceedings of the UHMS/DAN 2005 June 19 Workshop. Durham, NC: Divers Alert Network; 2005.

3 Pollock NW, Uguccioni DM, Dear GdeL. Diabetes and recreational diving: guidelines for the future. *Diving Hyperb Med*. 2006;36:29-34.

4 Poon, K and King, AB: Glargine and detemir: safety and efficacy profiles of the long-acting basal insulin analogs. *Drug Healthc Patient Saf*. 2010;2:213-23.

Submitted: 21 January 2016; revised 10 February and 27 June 2016
Accepted: 28 June 2016

Rebecca Johnson, Telethon Type 1 Diabetes Family Centre and Curtin University, Perth, Western Australia

Address for correspondence:
Rebecca Johnson, MPH, LLB/BA
Chief Executive Officer
Telethon Type 1 Diabetes Family Centre
11 Limosa Close
Stirling, WA 6021
Australia
rebecca@telethontype1.org.au

Opinion

Insulin-dependent diabetes mellitus and recreational scuba diving in Australia

Rebecca Johnson

Abstract

(Johnson R. Insulin-dependent diabetes mellitus and recreational scuba diving. *Diving and Hyperbaric Medicine*. 2016 September;46(3):186-188.)
Dive medicine bodies worldwide recognise that, with comprehensive screening and careful management, people with insulin-dependent diabetes (IDDM) can dive safely. Despite this, people with IDDM in Australia are generally denied access to dive training, an out-dated status quo that is not acceptable to the Australian diabetes community. This paper reflects upon the important advocacy work that has been done to progress this issue, and what is still required to open up access and bring Australia into line with more flexible and supportive international standards.

Key words
Medical conditions and problems; fitness to dive; disability; health status; DAN – Divers Alert Network; instruction – diving

Introduction

Dive medicine bodies worldwide recognise that with comprehensive screening and careful management, people with insulin-dependent diabetes mellitus (IDDM) can dive safely. Despite this, it remains extremely difficult for people with IDDM to access dive training in Australia. People with IDDM are denied information, support and access to training courses, which drives some to choose not to declare their condition or to travel overseas in order to certify as divers, which is both unsafe and unfair.

Using advocacy processes and tools, such as creating awareness, education, and using legal levers, can open up access to dive training for people with IDDM in Australia. This article reflects upon the important advocacy work on this issue until now, and what must be done to change the current situation and bring Australia into line with the rest of the world.

Stakeholders

"*Alone we can do so little. Together we can do so much.*"[1]

Breaking down barriers to dive training access needs a group of stakeholders invested in changing the status quo. Active people with IDDM can help drive change, and we are both connected and committed. Thousands of people with diabetes participate in thriving online communities, and can be connected to a cause with the touch of a button through prolific social media groups, forums, and other online platforms. Indeed, between 2006 and 2012, the Australian online type 1 diabetes forum 'Reality Check' played a vital role in connecting people with diabetes from across Australia who were interested in breaking down barriers to accessing dive training. The diabetes online community has evolved and gathered momentum through social media, which is now the most effective way to disseminate information and drive change.

Both diving medicine and diabetes clinicians are also critical stakeholders, as they are the gatekeepers for patients seeking medical clearance to dive. The South Pacific Underwater Medicine Society (SPUMS) has taken the progressive step of adopting, in slightly modified form,[2] the Undersea and Hyperbaric Medical Society/Divers Alert Network (UHMS/DAN) guidelines for divers with diabetes, and showed a commitment to developing support for the diabetic diver with a strong focus upon diabetes at the 2015 SPUMS Annual Scientific Meeting. Dive medicine clinicians judge a patient's fitness to dive according to the UHMS/DAN criteria; however, they generally require support from the patient's diabetes clinician to find them fit to dive. Diabetes doctors, who are represented by the Australian Diabetes Society (ADS), are thus stakeholders in the process of screening and advising a patient with IDDM.

Dive training agencies and operators are also invested in this issue, as they train and certify divers. Their role is essential in not only providing dive certifications but in supporting divers to train safely without discriminating on the basis of disability.

Barriers

A variety of barriers to accessing dive training in Australia emerged from a robust roundtable discussion with stakeholders at the OzTek diving show in Sydney in 2015,

facilitated by Dr Catherine Meehan of SPUMS. The barriers identified at OzTek were threefold: people with IDDM have difficulty obtaining medical clearance to dive, are denied access to training courses by dive schools, and do not have the information, advice and support they need to confidently manage diabetes whilst learning to dive. Breaking the problem down like this was an interesting and necessary exercise that helped stakeholders understand the issues, and allowed specific targets to emerge.

Targets

The Australian diabetes community has a simple goal: to open up access to dive training for suitable diabetic candidates. However, important objectives sit within this: doctors must feel confident that their screening and advice will keep their patients safe, and training agencies and operators need to be aware of their role in supporting the diabetic diver.

Action

MEDICAL CLEARANCE

Attaining medical clearance to dive has emerged as the most pressing and significant barrier for people with IDDM who wish to learn to dive in Australia. Currently, the professional medical organisations that represent diving doctors and diabetes doctors, SPUMS and the ADS, promote conflicting messages. Doctors belonging to the ADS have historically been directed by the 1994 ADS Diving and Diabetes Position Statement, which states that diving and IDDM are contraindicated. By contrast, SPUMS is supportive of the diabetic diver and states that "*some individuals with insulin-required diabetes may be able to dive with an acceptable level of risk*"[3] and includes comprehensive screening advice and practical how-to information for divers with IDDM in the Society's dive medical.[2] Therefore, although a diving doctor may be willing to give the patient medical clearance to dive, the doctor is unlikely to have necessary support from the patient's diabetes clinician who will be informed by the 22-year-old ADS position statement.

The ADS position statement has therefore emerged as a key target for advocacy action. Between 2014 and 2016, people from the diabetes community repeatedly raised the statement with the ADS President, showing that a significant body of evidence to support a new position now exists and arguing that Australia should be brought up to date with international standards. The ADS statement was also criticized in the media in Western Australia.

In April 2015, the ADS archived its statement and announced it was under review. At the time of writing (20 August 2016), a new statement has yet to be released. A change in the ADS position is crucial to overcoming the barrier to attaining medical clearance to dive. Despite the disability rights maxim "*nothing about us without us*", people with diabetes are not participants in the development of the revised ADS position statement. However, we continue to maintain pressure, and expect the ADS to issue soon a new position statement that acknowledges the evidence base and international standards.

SPUMS demonstrated a commitment to the diabetic diver with the adoption of the DAN/UHMS guideline; however, discussions at the 2015 SPUMS ASM revealed a need to build the knowledge and confidence of both SPUMS members and training agencies around managing the needs of the diver with diabetes. Adapting the DAN online module about diving with diabetes into a brief online education tool was discussed at the 2015 SPUMS Annual Scientific Meeting, where it was agreed that this initiative should be pursued. This has yet to eventuate.

TRAINING ACCESS

A second barrier to learning to dive as a diabetic in Australia is being accepted to participate in an open water course. There are reports of divers with diabetes in Australia who have managed to overcome the hurdles and obtain medical clearance, only to be refused access to courses by dive schools. In the rare circumstance a person with IDDM is declared fit to dive in Australia, they may have special conditions placed upon their medical clearance recommending, for example, certain dive depth limits and surface interval lengths. However, dive schools in Australia do not generally accept conditional medical clearances. People with diabetes report that the two main reasons given to them by operators are that schools cannot manage the risks attached to training a diabetic diver, and that dive schools are unable to change the logistics of dive courses to suit special conditions. Neither reason stands up to scrutiny – in reality, the diabetic diver is simply put in the 'too hard' basket.

Major training agencies need to take the lead here, and assist dive schools to change their thinking about managing a diabetic diver. Indeed, in 2006, at a discussion about adopting the UHMS/DAN guidelines for diving with diabetes in Australia, the PADI representative present committed to supporting the guidelines if they were adopted: "[If] *SPUMS wishes to evolve guidelines and integrate these into the diving community … I can assure you that PADI would cooperate fully in getting the word out to divers and diving professionals.*"[3] Now that SPUMS has fully adopted the UHMS/DAN guidelines into the SPUMS medical, it falls to major training agencies to not only help 'get the word out' but meet their legal obligations in relation to offering training that does not discriminate on the basis of disability.

Dive schools internationally access the information they need to manage the needs of the diabetic diver, and Australian dive schools have access to that same information. Further, active people with IDDM are generally experts at blood glucose

management during physical activity and will know how to manage and articulate their needs; dive schools can learn how to support them by talking with a diabetic diver directly. Beyond that, resources about diving with diabetes are easily accessible online to educate and upskill dive schools: DAN offers an online training module about the guidelines and a series of informative papers on diving with diabetes,[4,5] and the SPUMS medical contains comprehensive information about dive-day management.[2] Indeed, in this issue an in-depth, stepwise account of how this author manages her IDDM on a dive day is presented.[6] The concept of a work slate (similar to those used in managing dive accidents) to assist dive instructors training people with IDDM was discussed in 2006,[3] and may well be a useful additional contribution from SPUMS.

Under disability discrimination legislation, operators are obliged to make reasonable adjustments for people with disabilities. The adjustments needed to support people with diabetes to undertake dive training are far from onerous; they may involve slightly altering dive times, depths or surface interval lengths. The issue of discrimination against divers with diabetes by failure to make reasonable adjustments is live – it emerged in 2015 in Queensland in an action brought to the Anti-Discrimination Commission, which was resolved by conciliation. As the diabetes community becomes more connected internationally, the discrepancy between international standards and Australian standards becomes more apparent; it is unlikely the action in Queensland will be the last.

Training agencies and dive schools must be aware of their legal obligations, and diabetes organisations have an important advocacy role to play in raising awareness of patient rights. On the ground, people with diabetes should not accept discriminatory practices; if they are cleared for diving but refused training they are likely to have grounds to lodge an action against the provider with their state anti-discrimination commission.

PATIENT CONFIDENCE

The final barrier to diving with IDDM is patient confidence. Unlike sports such as cycling or triathlon, which have built up large communities of participants with diabetes in clubs and online groups, as yet there is not a culture or community for the diabetic diver in Australia. However, this will change quickly as medical clearance and training barriers are broken down and people with diabetes are given access to this exciting sport. The diabetes community is agile and quick to embrace change; it is simply a matter of time before a local community of divers with diabetes arises in Australia.

One of the primary roles of SPUMS is to provide information about underwater medicine, and now is the time to deliver information in a targeted way to advocate for change. The diabetes community is relying on SPUMS to actively raise awareness of its position and the evidence that supports it with the ADS during the ADS position statement review. Beyond this, SPUMS' early commitment to the diabetic diver needs some follow through: adaption and simplification of the online training materials from DAN and developing a work slate or tool to inform diving instructors will build confidence amongst dive schools and divers and are certainly worth pursuing. Australian dive training agencies need to develop a more inclusive and progressive approach to divers with disability in order to avoid discrimination claims. Finally, people with diabetes need to keep this issue on the agenda – the medical community and training agencies need to see the demand from the diabetes community in order to be motivated to change.

References

1 Lash JP. *Helen and teacher: the story of Helen Keller and Anne Sullivan Macy*. New York: Merloyd Lawrence Book, Delacorte Press/Seymour Lawrence; 1980. p. 489. [cited 2016 April 10]. Available at: http://quoteinvestigator.com/tag/helen-keller/.

2 *The South Pacific Underwater Medicine Society Diving Medical*, 4th edition. Melbourne: South Pacific Underwater Medicine Society; 2010. [cited 2016 January 21]. Available at: http://www.spums.org.au.

3 Bennett, MH. Diabetes and diving: where to now for SPUMS? *Diving Hyperb Med*. 2006;36:220-5.

4 DAN Online Seminars. *Diabetes and recreational diving: history and new guidelines*. Durham, NC: Divers Alert Network. [cited 2016 June 27]. Available at: http://www.diversalertnetwork.org/training/seminars/diabetes/index.asp.

5 Pollock NW, Uguccioni DM, Dear GdeL, editors. *Diabetes and recreational diving: guidelines for the future*. Proceedings of the Undersea and Hyperbaric Medical Society/Divers Alert Network 2005 June Workshop. Durham, NC: Divers Alert Network; 2005.

6 Johnson R. A day in the life of a diabetic diver: the Undersea and Hyperbaric Medical Society/Divers Alert Network protocol for diving with diabetes in action. *Diving Hyperb Med*. 2016;46:181-5.

Conflict of interest

The author is the CEO, Telethon Type 1 Diabetes Family Centre, Perth, Western Australia and is a qualified Divemaster.

Submitted: 10 April 2016; revised 27 June 2016
Accepted: 02 July 2016

Rebecca Johnson, Telethon Type 1 Diabetes Family Centre and Curtin University, Perth, Western Australia

Address for correspondence:
Rebecca Johnson, MPH, LLB/BA
Chief Executive Officer
Telethon Type 1 Diabetes Family Centre
11 Limosa Close
Stirling, Western Australia 6021
Australia
rebecca@telethontype1.org.au

Critical appraisal

No evidence of benefit with hyperbaric oxygen therapy for sudden hearing loss

Clinical bottom line:

Statistically non-significant small benefit for those treated with HBOT

Citation:

Çekin E, Cincik H, Ulubil SA, Gungor A. Effectiveness of hyperbaric oxygen therapy in management of sudden hearing loss. *J Laryngol Otol*. 2009;123:609-12.

Three-part clinical question:

For patients with sudden hearing loss within three days of onset, does the application of hyperbaric oxygen combined with systemic corticosteroid therapy, compared to corticosteroid therapy alone, improve hearing recovery?

Search terms:

Sudden hearing loss; inner ear

The study:

Non-blinded, randomised controlled trial; intention to treat not stated

The study patients:

Males and females aged 18-82 with sudden onset hearing loss in either or both ears, within three days; hearing loss defined as loss of at least 30 dB in three frequencies within three days of enrolment.

Control group:
(n = 21) prednisolone 1 mg·kg^{-1} starting dose reducing over three weeks plus famotidine 40 mg daily; no HBOT

HBOT group:
(n = 36), 100% oxygen at 253 kPa for 90 minutes, 10 daily sessions over 10 days plus drugs as above

The evidence:
See Table 1

Comments:

1. Large difference in patient numbers between treatment and control arms is not explained;
2. Time period of outcome assessment not defined (assumed to be at the end of 10-day HBOT course);
3. Reducing dose of prednisolone regimen not stated;
4. Average mean audiometry quoted in dB, but how many frequencies affected not fully described;
5. Power calculation is inadequately described – no suggestion what effect they were aiming to confirm;
6. Twelve years to collect data at a single centre;
7. Two patients in study group recruited outside the protocol period;
8. Some discrepancy between text and their Table 2 results.

Appraised by:
David Smart; 01 August 2016
dsmart@iinet.net.au

Key words
ENT; inner ear; critical appraisal

Table 1
Outcome at 10 days (assumed) for patients with idiopathic sudden sensorineural hearing loss; NNT/H – number needed to treat/harm; * complete or 'moderate' improvement

	Control group rate	HBOT group rate	Relative risk reduction	Absolute risk reduction	NNT/H
Improved with treatment* (95% CIs)	0.71	0.83	14% (-13% to 42%)	0.12 (0.11 to -0.35)	8 NNT = 3 to INF NNH = 9 to INF

Letters to the Editor

Hypothesis: the influence of cavitation or vacuum phenomenon for decompression sickness

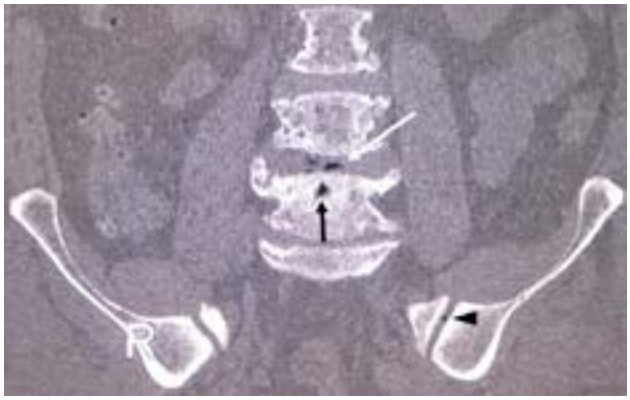
Attention has recently been focused on the vacuum phenomenon detected by computed tomography (CT), where gas in the human body is incidentally detected by CT. We introduce our hypothesis that the vacuum phenomenon increases the risk of decompression sickness (DCS) in subjects who engage in post-diving exercise.

When the screw propeller of a ship operates underwater, a swirling effect called cavitation occurs. This swirling effect is closely related to the ship's propulsive efficiency as well as propeller cracking and damage. Hydrodynamic cavitation describes the process of vaporization, bubble generation, and bubble implosion that occurs in a flowing liquid as a result of a decrease and subsequent increase in local pressure. The formation of cavitation depends on the pressure, speed, temperature, viscosity, turbulence, or existence of impurities in the fluid; the evaporation of inert gas; and the form and surface roughness of the screw. These factors also resemble risk factors of DCS.

In the human body, the cavitation effect has been recognized in radiological studies, where it is referred to as the 'vacuum phenomenon'.[1] The mechanism responsible for the formation of the vacuum phenomenon has been described recently.[2] If an enclosed tissue space is allowed to expand as a rebound phenomenon after an external impact, the volume within the enclosed space will increase. Under this condition of expanding volume, the pressure within the space will decrease. The solubility of the gas in the enclosed space will then subsequently decrease as the pressure inside the space decreases, allowing a gas such as nitrogen to leave solution. The combination of reduced nitrogen solubility and the minimal metabolism of nitrogen by the body mainly accounts for the formation of the vacuum phenomenon. The vacuum phenomenon has been observed in normal joints, degenerative intervertebral discs, the spine and spinal canal and traumatized tissues (Figure 1).[1]

Exercise induces the inflation and deflation of tissue or the extension and flexion of multiple joints. The pressure of the inflated tissue or extended joints decreases based on Henry's Law and Boyle's Law, resulting in cavitation. This phenomenon may be accelerated after diving, during the decompression phase. In an analysis of the effects of the ascent rate and post-dive exercise on the incidence of DCS in rats using ordinal logistic regression, higher rates of DCS and mortality were seen in rats which engaged in post-dive exercise than in control rats.[3] Accordingly, DCS following post-diving exercise may be induced by the vacuum phenomenon, particularly in cases with joint pains. The fact that the vacuum phenomenon is most frequently observed in the spine or spinal disc spaces may also influence the occurrence of spinal cord neurological DCS, which is rarely due to embolization from cardiac origin.

Figure 1
Computed tomography of a male with an open-book-type pelvic fracture due to a motorcycle accident shows the vacuum phenomenon in the lumbar disc space (white arrow), lumbar spine (black arrow), and left sacro-iliac joint (black triangle) (with permission)



References

1 Yanagawa Y, Ohsaka H, Jitsuiki K, Yoshizawa T, Takeuchi I, Omori K, et al. Vacuum phenomenon. *Emerg Radiol*. 2016;23:377-82. doi: 10.1007/s10140-016-1401-6. Epub 2016 May 4.

2 Gohil I, Vilensky JA, Weber EC. Vacuum phenomenon: clinical relevance. *Clin Anat*. 2014;27:455-62.

3 Pollard GW, Marsh PL, Fife CE, Smith LR, Vann RD. Ascent rate, post-dive exercise and decompression sickness in the rat. *Undersea Hyperb Med*. 1995;22:367-76.

Youichi Yanagawa, Kazuhiko Omori, Kouhei Ishikawa, Kei Jitsuiki, Toshihiko Yoshizawa, Ikuto Takeuchi, Hiromichi Ohsaka
Department of Acute Critical Care Medicine, Shizuoka Hospital, Juntendo University, Tokyo, Japan
yyanaga@juntendo.ac.jp

Key words
Bubbles; letters (to the Editor)

Commentary:

Dr Yanagawa and his colleagues present an interesting hypothesis, and our group has had some discussions around this vacuum phenomenon and decompression sickness (DCS). I am aware of at least one diver in whom

symptoms appeared after a 'self-manipulation' of his lower lumbar spine. The diver exited the water symptom-free and approximately 1.5 hours after the dive went to the hotel swimming pool. Before getting into the water, he self-manipulated his lumbar spine as he was in the habit of doing, provoking the familiar cracking sound. Some minutes after this, symptoms appeared and he went to the chamber for treatment. DCS was confirmed in the lumbar zone.

Several hypotheses can be raised: the 'habitual' manipulations may have changed the tissue properties in that zone and facilitated inadequate desaturation;[1] the symptoms would have appeared anyway despite any action; the low back pain was not DCS but another mechanical lesion that could be cured by the rapidly applied hyperbaric treatment, etc. We clearly understand that this episode can by no means confirm the hypothesis, it is just an observation, no objective link can be set nor, of course, eliminated.

Reference

1 Kawchuk GN, Fryer J, Jaremko JL, Zeng H, Rowe L, Thompson R. Real-time visualization of joint cavitation. *PLoS One*. 2015;10(4):e0119470. doi: 10.1371/journal.pone.0119470. eCollection 2015.

Costantino Balestra
Haute Ecole Paul Henri Spaak, Belgium
costantinobalestra@gmail.com

Key words
Decompression sickness; bubbles; letters (to the Editor)

Published errata

van der Bel R, Sliggers BC, van Houwelingen MJ, van Lieshout JJ, Halliwill JR, van Hulst RA, Krediet CTP. *Diving and Hyperbaric Medicine*. 2016 March;46(1):38-42.
In this technical report, the title of the article was omitted from the citation at the head of the Abstract. We apologise for this omission. The full citation does, however, appear in Medline.

Key word
Erratum

Sayer MDJ, Azzopardi E, Sieber A. User settings on dive computers: reliability in aiding conservative diving. *Diving and Hyperbaric Medicine*. 2016 June;46(2):98-110.)
The submission and acceptance dates for this paper were omitted from the end of the article. They were:
Submitted: 19 March 2015; revised 14 January, 16 March and 20 June 2016
Accepted: 20 June 2016

Key word
Erratum

Back articles from *Diving and Hyperbaric Medicine*

After a one-year embargo, articles from *Diving and Hyperbaric Medicine* (DHM) are placed on the Gesellschaft fuer Tauch- und Ueberdruckmedizin (GTUEM) database (GTUEMLIT) in Germany. This includes worldwide bibliographical information and articles from academic journals (all journals listed in MEDLINE), books, proceedings of the EUBS, UHMS and other congresses, and publication types like reports, projects, working papers, research and government papers etc. since 1907. All full text articles of *CAISSON*, the *SPUMS Journal* (since 1971) and DHM are included as attached pdf files. Articles from other sources are listed with abstracts and keywords. The GTUEMLIT is updated regularly and in 2016 it contained more than 41,000 articles.

The GTUEMLIT is accessible to GTUEM, EUBS and SPUMS members only via a link in the 'members' section of the society websites. This is a restricted-access database.

Articles are also placed (post one-year embargo) in the public domain on the **Rubicon Foundation** website: <http:// www.rubicon-foundation.org/>.

Rubicon is an open-access database, available free of charge and containing many thousands of other publications not available in the public domain elsewhere. Examples are *Undersea Biomedical Research*, back issues of *Undersea and Hyperbaric Medicine*, UHMS reports, research reports from the US and Royal Australian navies, DCIEM in Canada and the University of Pennsylvania and many other items. All *SPUMS Journal* and DHM articles to 2013 are currently searchable on the website (there are still a few gaps).

More recent articles or other enquiries about articles in DHM should be sent to: <editorialassist@dhmjournal.com>. Embargoed articles will be charged for; fee on application.

Complete back issues of DHM are available and may be purchased from the SPUMS Administrator at: <admin@spums.org.au>.
Price: AUD30.00 (incl P&P)

The
Diving and Hyperbaric Medicine Journal
website is at

<www.dhmjournal.com>

Articles for immediate release into the public domain, information about submitting to the Journal, profiles of the Editorial Board and contents of the most recent and previous issues are to be found on the site.

Notices and news

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

43rd EUBS Annual Scientific Meeting 2017

Preliminary Annoouncement
Dates: 06–09 September
Venue: Ravenna, Italy

Organising Committee: Paolo Pelaia (Ancona), Monica Rocco (Roma) and Pasquale Longobardi (Ravenna)

More details to come in the next issue
Save these dates in your diary!

International Congress on Hyperbaric Medicine (ICHM) 2017

Date: 11–14 May
Venue: The Sava Centre, Belgrade, Serbia

The ICHM President, Miodrag Zaric, and the organising committee invite you to participate in the 19th ICHM, hosted by the Centre for Hyperbaric Medicine and the University of Belgrade School of Medicine. The ICHM is the only world-wide association in this field, with meetings held every third year across the globe.

The scientific programme will include invited speakers, oral and poster presentations. Key topics include discussions on research pathways in hyperbaric medicine, controversial and new/promising indications, pathogenesis of DCI, cost effectiveness and basic research. A practical, problem-orientated pre-congress workshop, as well as post-congress courses are also planned for physicians, nurses and technicians.

Preliminary timetable:
10 October 2016 – 2nd announcement/registration opens
10 January 2017 – deadline for submission of abstracts
10 February 2017 – notification of accepted abstracts
15 February 2017 – Early-bird registration deadline

Website: <www.ichm2017.com>
E-mail: <office@ichm2017.com> or <chm@chm.rs>
Phone: (+381)-(0)11-3670-158
Fax: (+381)-(0)11-2650-823

The Science of Diving

Support EUBS by buying the PHYPODE book "*The science of diving*".

PHYPODE research fellows, <www.phypode.org>, have written a book for anyone with a keen interest in the latest research trends and results in diving physiology and pathology. Edited by Tino Balestra and Peter Germonpré, the royalties from this book are being donated to the EUBS. Need more reason to buy? TB and PG don't think so!

Available from: Morebooks <https://www.morebooks.de/store/gb/book/the-science-of-diving/isbn/978-3-659-66233-1>

German Society for Diving and Hyperbaric Medicine

An overview of basic and refresher courses in diving and hyperbaric medicine, accredited by the German Society for Diving and Hyperbaric Medicine (GTÜeM) according to EDTC/ECHM curricula, can be found on the website: <http://www.gtuem.org/212/Kurse_/_Termine/Kurse.html>

The EUBS website is at **<www.eubs.org>**

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

Notices and news

SPUMS notices and news and all other society information is now to be found mainly on the society website: <www.spums.org.au>

SPUMS Annual Scientific Meeting 2017

Main Theme: Medical Support of Commercial Diving

Dates: 22–26 May 2017
Venue: Exclusive use of Rama Candidasa Resort, Bali

Keynote speaker: Dr Debbie Pestell, Halifax, Canada
Additional speakers: Neal Pollock, Ian Gawthrope, David Smart, Sarah Lockley
Workshop: Hands-on diver-focused echocardiography with Neal Pollock and Ian Gawthrope

Conveners: Katherine Commons and Clinton Gibbs
Scientific Convener: Denise Blake
Call for abstracts opening soon: <scientific.convener@spums.org.au>

Facebook: facebook.com/spums2017
Save the dates; details to follow soon on the new SPUMS website

David 'Wilko' Wilkinson

Dr David Cameron Wilkinson, FANZCA, Cert DHM (ANZCA), Medical Director of the Hyperbaric Medicine Unit, Royal Adelaide Hospital and SPUMS Education Officer was elected to the Order of Australia (OAM) in the General Division in the Queen's Birthday 2016 Honours List for services to hyperbaric medicine. SPUMS extends its heartiest congratulations for a greatly deserved honour.

Terry Cummins

Terry Cummins, who retired recently from his role as Vice President of PADI Worldwide, was elected to the Order of Australia (OAM) in the General Division in the Queen's Birthday 2016 Honours List for services to recreational diving. Terry will be well known to longer-standing members of SPUMS. The Society extends its warmest congratulations on his award.

The Order of Australia is the pre-eminent way Australians recognise the achievements of their fellow citizens. The Order operates on the principles of independence and freedom from political patronage. Recipients of honours in the Order of Australia are from all walks of life with nominations in the General Division of the Order coming directly from the community.

Australian and New Zealand College of Anaesthetists Certificate in Diving and Hyperbaric Medicine

The ANZCA Certificate in Diving and Hyperbaric Medicine (DHM) is currently under review. ANZCA has not been accepting new trainee registrations since 01 August 2013 and this situation will continue until the Working Party recommendations have been finalised. The Diploma of DHM that is organised by the South Pacific Underwater Medicine Society (SPUMS) is not included in the review.

In accordance with a recommendation from a previous ANZCA Working Party, trainees who were registered for the ANZCA Certificate DHM prior to 01 August 2013 are able to complete and sit the examination. ANZCA has confirmed examination dates for 2016.

Periodic updates on the review of the DHM Certificate will be made available on the ANZCA website. All interested parties are advised to regularly visit the webpage <http://www.anzca.edu.au/training/diving-and-hyperbaric-medicine> to ensure you are kept up to date.

For further information contact: <dhm@anzca.edu.au>

Final 2016 dates for the ANZCA Certificate in Diving and Hyperbaric Medicine examination

SAQ examination	Friday 04 November
Oral viva examination	Friday 02 December

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:

1 (S)he must be medically qualified, and remain a current financial member of the Society at least until they have completed all requirements of the Diploma.
2 (S)he must 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 (S)he must 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 (S)he must 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 (S)he must 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 to authors' available on the SPUMS website <www.spums.org.au> or at <www.dhmjournal.com>.

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

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

Additional information – prospective approval of projects is required

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

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

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

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

Projects will be deemed to have lapsed if:

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

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

The Academic Board reserves the right to modify any of these requirements from time to time.

As of January 2016, the SPUMS Academic Board consists of:
Dr David Wilkinson, Education Officer, Adelaide;
Associate Professor Simon Mitchell, Auckand;
Dr Denise Blake, Townsville.

All enquiries and applications should be addressed to:
David Wilkinson
Fax: +61-(0)8-8232-4207
E-mail: <education@spums.org.au>

Key words
Qualifications; underwater medicine; hyperbaric oxygen; research; medical society

Capita Selecta Diving Medicine Academic Medical Centre, University of Amsterdam, The Netherlands

Course calendar 2016/2017

CSD offers advanced courses (content conforms to ECHM-EDTC Level 1, 2D).

26 November: *Exercise under water and working under pressure.* (6 cp); AMC, Amsterdam
18 March 2017: *Non-DCI-related diving disorders.* (6 cp), AMC, Amsterdam

For further information: <www.diveresearch.org> or e-mail: <n.a.schellart@amc.uva.nl>

British Hyperbaric Association ASM 2016

Dates: 05–09 December
Venue: Cayman Brac, Cayman Islands
Hosts: Cayman Hyperbaric Services

Invited speakers: Neal Pollock, John Freiberger and Ron Linden
Main diving theme: The disabled diver, encompassing optimal management for the diver acutely disabled by DCI, the diver who remains disabled after recompression and issues of fitness to dive for those disabled for other reasons.

This year's meeting acknowledges our determination to return to the Cayman Islands after our planned 2004 meeting there was cancelled because of Hurricane Ivan.

Full registration details can be found at:
<http://www.ukhyperbaric.com/meetings/2016-annual-scientific-meeting/asm.htm>

Ultrasound for decompression research Training workshop

Dates: 12–13 October 2016
Venue: Naval Research Centre, Karlskrona, Sweden

This course/workshop will train participants to use 2D ultrasound for diving research, exploring techniques used to monitor decompression bubbles (also touching on Doppler audio), bubble pathophysiology, the function of the machines and grading systems. It will follow closely the Consensus Guidelines drawn up at Ultrasound 2015. There will be three practical sessions monitoring divers following wet/dry dives and plenty of opportunities to learn the techniques involved. The course will be accredited by the European College of Baromedicine. Places are limited to 20 people.

Register at: <http://www.scotthaldane.nl/en/>

Scott Haldane Foundation

The Scott Haldane Foundation is celebrating its 40th anniversary in 2016. As an institute dedicated to education in diving medicine, organizing 230 courses over the past 20 years, in 2016 SHF is targeting a more and more international audience with courses world wide.

The courses Medical Examiner of Diver (part I and II) and SHF in-depth 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).

SHF courses for 2016
8 October: *NEW* Refresher course Diving Accidents; AMC, Amsterdam, NL
12–13 October: *NEW* Use of ultrasound for decompression research; Karlskrona, Sweden (see below)
5–12 November: Basic course Diving Medicine (level 1 part 1); Seychelles
12–19 November: *NEW* In-depth Course Diving in extreme conditions; Seychelles
19–26 November: *NEW* In-depth Course Diving in extreme conditions; Seychelles
Early 2017
21 January: Scott Haldane 40th Anniversary Diving Medicine Conference; The Netherlands
11 February: Refresher course Diving Accidents; The Netherlands
24-25 March: Basic course Diving Medicine (level 1 part I); Zeist, NL
1, 7, 8 April: Basic Course Diving Medicine (level 1 part II), AMC Amsterdam, NL

For further information: <www.scotthaldane.nl/en/>

Undersea and Hyperbaric Medical Society 50th Annual Scientific Meeting 2017

Dates: 29 June – 01 July

Venue: Naples Grande Beach Resort, Naples, Florida

For further information:
<https://www.uhms.org/index.php?option=com_civicrm&task=civicrm/event/info&reset=1&id=135>

ANZ Hyperbaric Medicine Group Introductory Course in Diving and Hyperbaric Medicine

Dates: 20 February–03 March 2017
Venue: The Prince of Wales Hospital, Randwick, Sydney
Cost: AUD2,400.00 (inclusive of GST)
Course Conveners: Associate Professor David Smart (Hobart), Dr John Orton (Townsville)

The Course content includes:

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

Approved as a CPD learning project by ANZCA: (knowledge and skills category): 56 hours for attendance at lectures and presentations for one credit per hour; 24 hours for workshops/PBLDs/small group discussions for two credits per hour

Contact for information:
Ms Gabrielle Janik, Course Administrator
Phone: +61-(0)2-9382-3880
Fax: +61-(0)2-9382-3882
E-mail: <gabrielle.janik@sesiahs.health.nsw.gov.au>

DAN Europe

DAN Europe has a fresh, multilingual selection of recent news, articles and events featuring DAN and its staff.

Go to the website: <http://www.daneurope.org/web/guest/>

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

P O Box 347, Dingley Village
Victoria, 3172, Australia
E-mail: <hdsaustraliapacific@hotmail.com.au>
Website:
<www.classicdiver.org>

Instructions to authors

A downloadable pdf of the 'Instructions to authors' (most recently revised June 2016) can be found on the *Diving and Hyperbaric Medicine* (DHM) website: <www.dhmjournal.com>. Authors must read and follow these instructions carefully.

All submissions to *DHM* should be made using the portal at <http://www.manuscriptmanager.com/dhm>. Before submitting, authors are advised to view video 5 on how to prepare a submission on the main Manuscript Manager website <http://www.manscriptmanager.com>.

In case of difficulty, please contact the Editorial Assistant by e-mail at <editorialassist@dhmjournal.com>.

Copyright

Advertising in *Diving and Hyperbaric Medicine*

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

Details of advertising rates and formatting requirements are available on request from:
E-mail: <editorialassist@dhmjournal.com>

Hyperbaric Oxygen, Karolinska

Welcome to: <http://www.hyperbaricoxygen.se/>
This site, supported by the Karolinska University Hospital, Stockholm, Sweden, offers publications and free, high-quality video lectures from leading authorities and principal investigators in the field of hyperbaric medicine. You need to register to obtain a password via e-mail. Once registered, watch the lectures online, or download them to your iPhone, iPad or computer for later viewing.

For further information contact:
E-mail: <folke.lind@karolinska.se>
Website: <www.hyperbaricoxygen.se>

DIVER EMERGENCY SERVICES PHONE NUMBERS

AUSTRALIA
1800-088200 (in Australia, toll-free)
+61-8-8212-9242 (International)

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

ASIA
+81-3-3812-4999 (Japan)

SOUTHERN AFRICA
0800-020111 (in South Africa, toll-free)
+27-10-209-8112 (International, call collect)

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

UNITED KINGDOM
+44-7740-251-635

USA
+1-919-684-9111

The DES numbers (except UK) are generously supported by DAN

DAN ASIA-PACIFIC DIVE ACCIDENT REPORTING PROJECT

This project is an ongoing investigation seeking to document all types and severities of diving-related accidents. All information is treated confidentially with regard to identifying details when utilised in reports on fatal and nonšfatal cases. Such reports may be used by interested parties to increase diving safety through better awareness of critical factors. Information may be sent (in confidence unless otherwise agreed) to:

DAN Research
Divers Alert Network Asia Pacific
PO Box 384, Ashburton VIC 3147, Australia
Enquiries to: <research@danasiapacific.org>

DAN Asia-Pacific NON-FATAL DIVING INCIDENTS REPORTING (NFDIR)

NFDIR is an ongoing study of diving incidents, formerly known as the Diving Incident Monitoring Study (DIMS). An incident is any error or occurrence which could, or did, reduce the safety margin for a diver on a particular dive. Please report anonymously any incident occurring in your dive party. Most incidents cause no harm but reporting them will give valuable information about which incidents are common and which tend to lead to diver injury. Using this information to alter diver behaviour will make diving safer.

The NFDIR reporting form can be accessed on line at the DAN AP website:
<www.danasiapacific.org/main/accident/nfdir.php>

CONTENTS

Diving and Hyperbaric Medicine Volume 46 No. 3 September 2016

Editorials

133 Poorly designed research does not help clarify the role of hyperbaric oxygen in the treatment of chronic diabetic foot ulcers
Mesut Mutluoglu, Gunalp Uzun, Michael Bennett, Peter Germonpré, David Smart and Daniel Mathieu

135 The Editor's offering

136 The Presidents' pages

Journal articles

138 Influence of the diving wetsuit on standard spirometry
Nico AM Schellart, Wouter Sterk

142 Danish diving-related fatalities 1999–2012
Julie Vinkel, Peter Bak, Ole Hyldegaard

150 Thirty years of American cave diving fatalities
Leah Potts, Peter Buzzacott and Petar Denoble

155 Safety of transport and hyperbaric oxygen treatment in critically-ill patients from Padua hospitals into a centrally-located, stand-alone hyperbaric facility
Gerardo Bosco, Giacomo Garetto, Alessandro Rubini, Antonio Paoli, Prachiti Dalvi, Devanand Mangar and Enrico M Camporesi

160 Hyperbaric oxygen therapy in the treatment of sudden sensorineural hearing loss: a retrospective analysis of outcomes
Susannah Sherlock, Kenneth Thistlethwaite, Mohsina Khatun , Christopher Perry and Alex Tabah

166 The effect of general anaesthesia and neuromuscular blockade on Eustachian tube compliance: a prospective study
Akeelesh Mungur, Guy Cochard, Yves Ozier and Pierre Lafère

170 Remote ischaemic conditioning in a rat model subjected to decompression stress
Nikolaj Hjort Schmidt, Kasper Hansen, Henrik Lauridsen, Annie Vesterby, Jens Randel Nyengaard, Alf Brubakk and Michael Pedersen

The World as it is

176 Requests for emergency hyperbaric oxygen treatment for carbon monoxide poisoning, in Ankara, Turkey
M Kübra Özgök-Kangal, Iclal Karatop-Cesur, Gökhan Akcalı, Senol Yildiz and Günalp Uzun

181 A day in the life of a diabetic diver: the Undersea and Hyperbaric Medical Society/Divers Alert Network protocol for diving with diabetes in action
Rebecca Johnson

Opinion

186 **Insulin-dependent diabetes mellitus and recreational scuba diving in Australia**
Rebecca Johnson

Critical appraisal

189 No evidence of benefit with hyperbaric oxygen therapy for sudden hearing loss
David Smart

Letters to the Editor

180 Carbon dioxide absorbents for rebreathers
John Pennefather

190 Hypothesis: The influence of cavitation or vacuum phenomenon for decompression sickness
Youichi Yanagawa, Kazuhiko Omori, Kouhei Ishikawa, Kei Jitsuiki, Toshihiko Yoshizawa, Ikuto Takeuchi and Hiromichi Ohsaka

190 Commentary:
Costantino Balestra

Published errata

191 van der Bel R, et al. *Diving and Hyperbaric Medicine*. 2016 March;46(1):38-42.

191 Sayer MDJ, et al. *Diving and Hyperbaric Medicine*. 2016 June;46(2):98-110.

EUBS notices and news

192 43rd EUBS Annual Scientific Meeting 2017

192 International Congress on Hyperbaric Medicine (ICHM) 2017

192 The Science of Diving

SPUMS notices and news

193 SPUMS Annual Scientific Meeting 2017

193 Australian and New Zealand College of Anaesthetists Certificate in Diving and Hyperbaric Medicine

194 SPUMS Diploma in Diving and Hyperbaric Medicine

195 Courses and meetings

Diving and Hyperbaric Medicine is indexed on MEDLINE, SciSearch® and Embase/Scopus

Printed by Snap Printing, 166 Burwood Road, Hawthorn, Victoria 3122, <hawthorn@snapprinting.com.au>