Diving and Hyperbaric Medicine

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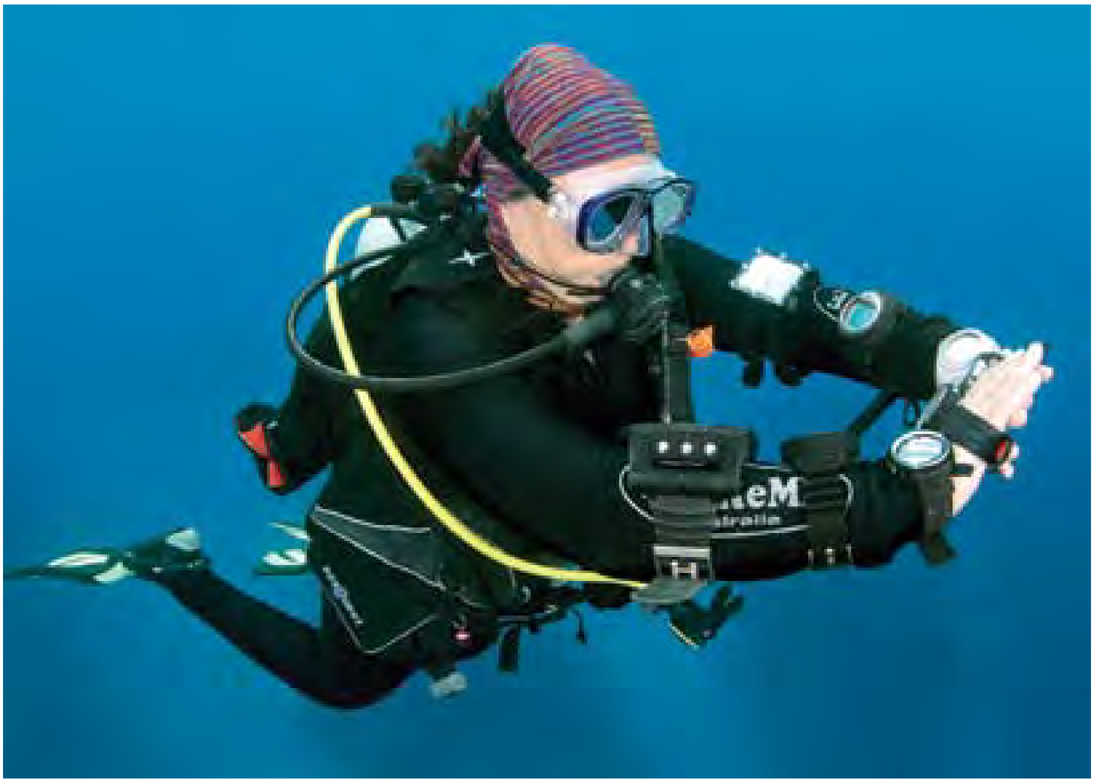

Conservatism settings in dive computers

Inner-ear barotrauma and Eustachian tube function

Perilymph fistula from inner-ear barotrauma

Inner-ear decompression sickness in trimix divers

Critical flicker fusion and diver performance

Different carbon dioxide absorbants are not equivalent

15 years of decompression sickness in Denmark

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PURPOSES OF THE SOCIETIES

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

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DIVING AND HYPERBARIC MEDICINE

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The Editor's offering

Carbon dioxide (CO_2) absorption in rebreathers

Translating new findings into everyday practice usually takes many months or even years. However, the grapevine in technical diving is such that the findings by the Auckland group, published in the March 2015 issue,[1] have already found their way into changes in the way divers are trained on some closed-circuit rebreathers (CCR). Their conclusions were that, whilst there are several reasons for a 'pre-breathe', identifying a carbon dioxide (CO_2) absorber problem is not one of them. In this issue, Harvey et al compare the duration of Sofnolime™ and Spherasorb™ CO_2 absorbants in a CCR under standard conditions and demonstrate a significant difference in performance between the two.[2] Thus, a diver cannot assume similar durations for the two products before CO_2 'breakthrough' occurs.

Of considerable importance for CCR diving safety is the fact that when CO_2 breakthrough does occur, the rise in PCO_2 in the rebreather circuit is rapid, leading to increased ventilation and work of breathing, which can be catastrophic at depth. Rebreather circuits, of which there are many varieties, mostly semi-closed, show this rapid change once a rate-limiting point resulting in CO_2 accumulation within the circuit is reached. For instance, in the Magill (Mapleson A) anaesthetic circuit this point is when the fresh gas flow into the circuit is reduced to less than alveolar minute volume, at which point expired alveolar gases reach the reservoir bag in the circuit.[3]

User settings on dive computers

The paper by Sayer et al arose from discussions at the SPUMS Annual Scientific Meeting 2014 in support of the SPUMS/UKSDMC joint statement on persistent (patent) foramen ovale (PFO) and the need for divers to add an element of conservatism to their diving.[4,5] It was originally devised with the aim of informing medical advisers about how dive computers may be used by divers with PFOs or who are returning to diving after PFO closure or having had a decompression illness incident. In these circumstances, there may be a wish to use dive computer personal settings and/or nitrox while decompressing for air as safety factors. Little information is provided by computer manufacturers about the underlying principles of 'conservatism' factors built into their products.

The authors had limited time and resources to do a comprehensive study and did not consider that one was necessary to bring most of the nuances of dive computer use to a readership that may have to provide guidance to a diver with a PFO. However, after peer assessment, it was decided that an element of review was necessary in order to cover all aspects of computer-controlled diving conservatism. In particular, some discussion of dual algorithm computers and gradient factors has been introduced. The reasons for doing this were that both these design elements will become more prevalent in recreational diving computers in the next few years, but were not available at the time of the original testing. It was considered that to not address both of these introductions in a paper that will most likely be the only one for some time that covers this overall subject would be an obvious omission.

Whilst accepting this technical review is somewhat limited, as only one example of each computer was tested, previous work by this group has shown that dive computers show minimal and insignificant variation at the single model level.[6] It is an important message that there is variation in conservatism methods even between models by the same manufacturer and that both consumers and medical advisors should be made aware of this.

Society meetings

With 103 full delegates, SPUMS's Annual Scientific Meeting in Fiji, just finished, was its largest gathering ever, and attendees heard a range of excellent talks from the Guest Speakers, Drs Chris Lawrence and Simon Mitchell and John Lippmann from DAN AsiaPacific. I wish EUBS the same success with their meeting in August in Switzerland.

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Michael Davis

Front page photo, by Dr Martin Sayer, shows Dr Cathy Meehan wearing the eight different makes/models of dive computer used by her diving group on a wreck dive in Truk Lagoon in June 2015.

The President's pages

David Smart, President SPUMS

At the time of writing this report, I am contemplating the 2016 year ahead. This report precedes our Annual Scientific Meeting being held in Fiji in May. Fortunately the hotel was not seriously affected by the cyclone. By the time this is published, the meeting will have been completed.

SPUMS' purposes and rules define our core business as follows:

- To take over and carry on the unincorporated association heretofore known as the South Pacific Underwater Medicine Society and the property and rights of that Association at the date of incorporation;
- To promote and facilitate the study of all aspects of underwater and hyperbaric medicine;
- To provide information on underwater and hyperbaric medicine;
- To promote communication between members of the Association and to publish a journal for the Association;
- To convene members annually at a scientific conference, to hold meetings and other functions or activities to inform and to develop fellowship and friendship amongst members of the Association;
- To undertake anything which an incorporated association is authorized to do under the Associations Incorporation Act 1981 or any later equivalent enactment.

The joint production and publication of our journal with EUBS is described in detail in a later section of the purposes and rules. The role of the SPUMS Executive is to manage our core business. I will summarise below some of our current activities so that members are better aware of the roles of individual executive members.

SPUMS President

The role of President is challenging and rewarding. Leadership of our executive, SPUMS governance, our meetings and strategic direction are key roles for the President, as is 'trouble shooting' of issues that arise. The President has oversight of and a supportive role for all executive committee members; sometimes this requires some 'stirring of the pot'.

International liaison is also a role for the President. With my EUBS counterpart(s), last year we facilitated the contract for reappointment of our Journal Editor, Associate Professor Mike Davis. A draft memorandum of understanding between SPUMS and EUBS is being prepared to cement our future relationship as joint publishers. As we strategically move to an electronic format for *Diving and Hyperbaric Medicine* (DHM), we are setting up a working group with EUBS colleagues to drive this process. I also have involvement in establishing broader parity internationally between Australian diving medicine courses and those that occur overseas. Educational responsibilities include the teaching faculty of the ANZHMG and RAN SUMU courses and setting up the Tasmanian Occupational and Offshore diving course. Along with the Royal Adelaide Hospital basic and advanced courses and the Western Australian short course, there are great opportunities to make diving medical training more consistent internationally.

One challenging area for the Executive in the past has been succession planning. It is an area that we have not done well. There can be a steep learning curve for members when they join the ExCom. We are preparing a SPUMS Executive Manual to assist with this and to provide clear role descriptions for all executive members. A great way to become familiar with the executive activities is to join as an elected general committee member, allowing a gradual introduction to the operations of SPUMS. General members undertake specific roles or targeted projects, and provide assistance to other executive members.

SPUMS Treasurer

The SPUMS Treasurer has a very important role in ensuring SPUMS' finances are kept in order and comply with our statutory financial obligations, including annual financial reports. (S)he also manages the journal finances, liaising with the Journal Governance Committee. Budgeting and forward predictions are provided for the Executive on the Society, DHM and the annual scientific meeting. The current Treasurer, Peter Smith is migrating the SPUMS accounts to another bank as our previous banking arrangements have proved unsuitable and frustrating in several ways. As a result, even simple processes like setting up new account signatories have proved challenging. Peter is also setting up systems to simplify the job for the next Treasurer. The existence of the Journal Governance Committee should also help to reduce the Treasurer's workload with regard to DHM.

SPUMS Secretary

The SPUMS Secretary is the official communication point for SPUMS' affairs, including as the nominated person for SPUMS' legal obligations with Consumer Affairs Victoria. The Secretary plans and circulates agendas for ExCom meetings, sets out the yearly plan for the ExCom and ensures that we undertake all scheduled administrative tasks in a timely manner. The Secretary circulates and finalises meeting agendas, records meeting minutes, receives correspondence and ensures general business, written processes and reporting are completed in a timely manner, consistent with SPUMS purposes and rules. Our present Secretary, Douglas Falconer is contributing more than his fair share to SPUMS as he has also assumed at relatively short notice the role of convener for this year's ASM.

Past President

The advantage of maintaining the Past President on the

ExCom is their wealth of knowledge and experience gained in their role as President. Mike Bennett has always been available to provide sensible advice, and his global perspectives and experience add great value to the ExCom. Mike is also Chairperson of the Journal Governance Committee and is facilitating the development of this very important committee. He also is working on many strategic projects such as the ANZCA Certificate working party and is the scientific convener of the 2016 ASM.

Education Officer

The role of the Education Officer is to manage and administer the SPUMS Diploma process. This process is well defined but has multiple components to ensure guidelines are followed. The SPUMS Diploma is assuming more prominence because the ANZ College of Anaesthetists Certificate DHM is on hold at present pending major review. With increasing numbers of active Diploma projects, David Wilkinson administers an important portfolio. The Education Officer maintains an overview of the courses in diving and hyperbaric medicine, and their approval by SPUMS.

Webmaster

Our website is currently in the process of being rebuilt and updated. There are many new features on the website which will significantly improve the way SPUMS operates. Joel Hissink is the SPUMS Webmaster and his role is to ensure that two-way communication occurs in a timely manner to support our web assistant, Nicky Telles, and to maintain close links between her and the SPUMS executive. Nicky Telles' expertise and support as a web developer are highly valued by SPUMS.

Chairman ANZHMG

John Orton is the chairman of The Australian and New Zealand Hyperbaric Medicine Group (ANZHMG) which is a SPUMS subcommittee. The main role of the ANZHMG is to represent the hyperbaric facilities of Australia and New Zealand politically, and in relation to standards. The ANZHMG also handles funding and economic issues that relate to diving and hyperbaric medicine and has a major role in ensuring hyperbaric medicine is represented at a national level. The recent Grattan Institute report is requiring input from the ANZHMG.[1] John Orton, as the current chairperson of the ANZHMG, has also taken on a major role as co-convener (with me) of the ANZHMG Course in Diving and Hyperbaric Medicine that is run annually at the Prince of Wales Hospital, NSW.

General Committee members
(also known as "Ordinary members", but far from ordinary!)

Janine Gregson was convener of the 2016 SPUMS ASM before she went on Defence deployment and is working with a sub-committee to plan future ASMs.

Denise Blake has spent much time rationalising the SPUMS membership list, which had major problems. She is also on the Academic Board for the SPUMS Diploma and is the Scientific Convener for the 2017 ASM.

Simon Mitchell provides input to a number of projects including the ANZCA Certificate in Diving and Hyperbaric Medicine and as a member of the Academic Board for the SPUMS Diploma. His advice and perspectives from across the 'ditch' are invaluable.

***Diving and Hyperbaric Medicine* Editor**

The Editor's perspectives are also valuable for SPUMS, because the Journal is part of our core business. Mike Davis, the current Editor, also has an encyclopaedic knowledge of SPUMS' history and processes from his many years' involvement. The DHM product speaks for itself.

Future committee issues and succession planning

The SPUMS ExCom needs new blood and a greater involvement from younger members of the Society. General practitioners, who make up over half of our members, need greater representation. To this end, at the 2016 AGM, I have proposed some changes to the SPUMS constitution, including adding two more general committee members to the executive and creating a position of President Elect, appointed one year in advance of when the current President completes their term of office. This would permit a smoother transition to the role of President. There is a need for a general committee member to take on the role of Assistant Treasurer, both to support the Treasurer but also potentially taking on the Treasurer's role in the future. This process would ensure that SPUMS' financial corporate memory is better maintained. There will be opportunities at the next AGM for SPUMS members to join the ExCom and make your mark. Please volunteer and contribute.

Reference

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Key words
Medical society, general interest

Journal articles

Perilymphatic fistula after underwater diving: a series of 11 cases

Jean-Baptiste Morvan, Emmanuel Gempp, Damien Rivière, Pierre Louge, Nicolas Vallee and Pierre Verdalle

Abstract

(Morvan J-B, Gempp E, Rivière D, Louge P, Vallee P, Verdalle P. Perilymphatic fistula after underwater diving: a series of 11 cases. *Diving and Hyperbaric Medicine*. 2016 June;46(2):72-75.)

Introduction: Onset of cochleovestibular symptoms (hearing loss, dizziness or instability, tinnitus) after a dive (scuba or breath-hold diving) warrants emergency transfer to an otology department. One priority is to investigate the possibility of the development of decompression sickness with a view to hyperbaric oxygen treatment of bubble-induced inner-ear damage. If this injury is ruled out, inner-ear barotrauma should be considered together with its underlying specific injury pattern, perilymphatic fistula.

Methods: We report on a series of 11 cases of perilymphatic fistula following ear barotrauma between 2003 and 2015, eight after scuba diving and three after free diving. All patients underwent a series of laboratory investigations and first-line medical treatment.

Results: Seven patients had a perilymphatic fistula in the left ear and four in the right. Eight cases underwent endaural surgical exploration. A fistula of the cochlear fenestra was visualised in seven cases with active perilymph leakage seen in six cases. After temporal fascia grafting, prompt resolution of dizziness occurred, with early, stable, subtotal recovery of hearing in seven. Of six patients in whom tinnitus occurred, this disappeared in two and improved in a further two. Two patients were not operated on because medical treatment had been successful, and one patient refused surgery despite the failure of medical treatment. Median follow-up time was 7.4 years (range 0.3 to 12).

Conclusion: The diagnosis of perilymphatic fistula is based on clinical assessments and various laboratory findings. When there was strong evidence of this condition, surgery yielded excellent functional outcomes in all patients treated early.

Key words

Inner ear; ear barotrauma; scuba diving; breath-hold diving; ENT; surgery; outcome

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Introduction

Cochleovestibular symptoms (dizziness, hearing impairment and tinnitus) after scuba or breath-hold diving should steer the diagnosis towards inner-ear barotrauma (IEBt) or inner-ear decompression sickness (DCS), requiring emergency otological assessment or transfer to a hyperbaric facility in case of inner-ear DCS.[1,2] The first priority is to detect the possibility of DCS development with a view to hyperbaric oxygen treatment (HBOT) to prevent functional sequelae from the formation of tissue and intravascular bubbles in the cochlear or vestibular organs. Treating IEBt essentially relies on conservative interventions (e.g., resting prone, vestibular suppressants) in association with other medications such as corticosteroids;[1] however, it is important to be aware that there may be an underlying perilymphatic fistula, i.e., an abnormal communication between the inner ear and the middle ear due to rupture of the cochlear or vestibular fenestra, especially if medical treatment has failed. This study reports on our experience managing post-dive perilymphatic fistulae and summarises our approach to diagnosis and treatment.

MATERIAL AND METHODS

We retrospectively reviewed all the patients treated in our department for a perilymphatic fistula as a result of pressure-induced injury following an underwater dive (scuba or breath-hold) between 2003 and 2015. The local ethics committee (Sainte Anne's military hospital; approval number 40 /HIA.S.A/SMC) approved the study design.

Each injured diver was given a clinical assessment including:

- An interview to establish details of the dive and the circumstances of onset, including scuba dive, breath-hold dive, depth, duration, compliance with decompression stops, rate of ascent, yo-yo diving, difficulties with ear-clearing manoeuvres, concomitant functional symptoms (otalgia, vomiting), time to onset of symptoms after the dive and how they manifested (with or without fluctuations);
- A full physical, neurological and ENT examination;
- Laboratory examinations:
    - air and bone pure-tone liminal audiometry with, in patients with hearing loss, Fraser positional audiometry (looking for an improvement of at least 10 dB at two frequencies comparing audiometry results with the pathological ear pointed down at an angle of 90^{O} and then in the normal position). To calculate the severity of hearing loss, the average audiometric tone threshold was taken as the mean of

the air conduction thresholds at frequencies of 500, 1,000, 2,000 and 4,000 hertz;

- Videonystagmoscopy: pressure fistula test (induction of nystagmus or vertigo when pressure is exerted in the external meatus using Siegle's speculum);
- Videonystagmography: caloric and pendular tests (ipsilateral vestibular reflex inhibited or absent);
- From 2008, Tullio's sign was added to the protocol: induction of vertigo and/or nystagmus on sonic stimulation (80 dB at 250 and 500 Hz);
- CT scanning without contrast medium to rule out fracture of the petrous bone, ossicle abnormality, dehiscence of the superior canal or congenital malformation of the inner ear, as well as to investigate pathognomonic pneumolabyrinth;
- Investigation of a right-to-left shunt by transcranial Doppler ultrasonography for patients whose initial diagnosis was consistent with inner-ear DCI.

All patients were given first-line medical treatment with intravenous methylprednisolone (1 $mg \cdot kg^{-1}$ daily) for seven days. If this failed and the clinical investigations pointed to a perilymphatic fistula, the patient was offered exploratory endaural surgery on the middle ear. The surgery aimed to confirm the diagnosis of perilymphatic fistula, targeting the fenestra responsible, if possible, and then blocking the fistula if necessary. The effectiveness of the surgery was determined by follow-up clinical and audiometric evaluation.

Some patients whose initial diagnosis was one of an inner-ear DCI were first given one or more HBOT sessions (US Navy Treatment Table 5 or 6). In parallel to the findings of laboratory investigations, failure of hyperbaric treatment or worsening of the symptoms during the sessions pointed towards a diagnosis of perilymphatic fistula.

Results

Eleven patients were admitted over the study period. All of them were male with an average age of 37 (range: 22–66) years. Seven had a perilymphatic fistula in the left and four in the right ear. In eight cases, symptoms developed after scuba diving and in three after a breath-hold dive. None of the scuba divers had omitted decompression stops. Yo-yo diving with rapid descents and ascents was reported by four of the scuba divers and all of the breath-hold divers. Difficulties in pressure equalization of the ears were reported by five of the scuba divers and two of the breath-hold divers.

On average, patients had sought medical advice three days after the dive (range: within hours to 12 days). All presented with deafness, fluctuating in nature in six cases, isolated in one. Mean audiometric loss was mild (20–40 dB) in one case, severe (70–90 dB) in five and profound (> 90 dB) in the remaining five patients. Six patients complained of dizziness or gait instability with five of these reporting severe instability after a period of mild-to-moderate rotatory vertigo. In most cases, symptoms were permanent but fluctuating. One patient was asymptomatic when seen, despite a vestibular syndrome with nystagmus at initial diagnosis. Nine patients had tinnitus and five reported a feeling of fullness in their ear. The full triad – deafness/dizziness/tinnitus – was seen in five patients: deafness/tinnitus in four, deafness/dizziness in one and dizziness/tinnitus was not seen.

Positional audiometry was informative for all patients apart from one patient with profound deafness. A fistula sign was detected in one patient. Using videonystagmography, there were three cases of inhibited vestibular reflexes on the side of the affected ear. Two cases had pronounced vestibular hyperreflectivity to hot water on the side of the affected ear. Pneumolabyrinth was not seen on petrous CT scanning (without contrast). The Tullio effect (added to the protocol in 2008 for four patients) was non-contributory in all cases. Persistent foramen ovale (PFO) was investigated in three patients with negative results.

After the failure of medical treatment and strong evidence pointing to a perilymphatic fistula, eight patients were referred for endaural surgical exploration of the middle ear. A fistula of the cochlear fenestra was observed in seven cases with active perilymph leakage in six. Exploration of the vestibular fenestra was negative in all cases. The cochlear fenestra was blocked in all cases by a temporal fascia graft kept in place with biological glue. A blood patch was also preventively placed on the vestibular fenestra in six cases because we were unsure whether a small fistula could not be seen.

The eight operated patients soon recovered their hearing, within one or two days of surgery in bone conduction, with stable improvement in the long term in seven cases. Hearing loss persisted at 8,000 Hz in three patients at -80 dB, -75 dB and -35 dB respectively. One patient improved by about 50% with a mean residual deficit of -60 dB. Dizziness and instability regressed quickly after surgery in all four patients with these symptoms. Tinnitus disappeared in two cases, improved in another two but persisted in two others.

Three patients were not operated on; one refused surgery whilst two responded well to medical treatment. The first of these patients completely recovered hearing in 11 days but with persistent tinnitus as well as instability (improved by vestibular rehabilitation). The second recovered 50% of his hearing with a mean deficit of -40 dB and persistent tinnitus and instability (partly improved by vestibular rehabilitation). The third patient recovered his hearing with a residual loss at 8,000 Hz of -40 dB, without tinnitus. Median follow-up time was seven years five months, range three months to 12 years.

Discussion

There are only a limited number of studies investigating series of perilymphatic fistulae secondary to barotrauma from diving because of the low incidence of this condition.[1]

One estimate was that an ENT department detects two perilymphatic fistulae per year but this is probably underestimated.[3] In our department, we have dealt with 19 cases of perilymphatic fistulae from all causes over the 12 years covered by this report, a rare similarity to this estimate.

In a diver with persistent cochleovestibular symptoms after surfacing, two main pathological events should be considered. The differential diagnosis of inner-ear DCI or IEBt needs to be resolved urgently on presentation because DCI requires emergency recompression using one of the standard DCI treatment tables. IEBt may present with or without an underlying perilymphatic fistula. At our clinic, of 117 divers presenting between 2010 and 2015 with cochleovestibular symptoms and signs, 95 (81%) were diagnosed with inner-ear DCI and 22 (19%) with IEBt, in seven of whom a perilymphatic fistula was documented.

In the literature, perilymphatic fistula is most commonly seen in young men with an average age of 40 years. Our patients were slightly younger (average 37 years) because many of them were military divers. In seven cases, the left ear was affected and in four it was the right ear. Our series is too small to test any hypothesis, but certain anatomical features may underlie this predominance, e.g., a wider cochlear aqueduct on the left than on the right.[4] In contrast, among the inner-ear DCI seen at our hospital, a large right-to-left shunt was detected in 77% of cases, with a significantly higher incidence on the right-hand side (80% of cases, $P < 0.001$), probably owing to a paradoxical arterial gas embolism selectively going through the right common brachiocephalic artery.[2]

In our series, no fistula was visualised in one case but, because of the clinical picture coupled with strong laboratory evidence, the cochlear fenestra was occluded leading to a good functional outcome. Taking all causes together, 90% of fistulae involve the cochlear fenestra, which is more likely to be affected because it is weaker than the vestibular fenestra, which is protected by the stapes and its annular ligament.

A perilymphatic fistula has no pathognomonic sign and the final diagnosis depends on an array of signs.[5] Analysing details of the dive can rule out a DCS after a non-provocative dive.[6] Arterial gas embolism with patent foramen ovale can be investigated by identifying a right-to-left shunt. Yo-yo diving with repetitive profiles of ascent and descent is often the cause (seven cases in our series). Difficulty in equalising middle-ear pressures (e.g., Valsalva manoeuvres) is often seen (seven cases in our series). The lack of clinical improvement or exacerbation of symptoms (vomiting, dizziness) during HBOT to manage a suspected DCI case should trigger a review of the diagnosis and the consideration of IEBt and possibly a perilymphatic fistula.[7,8] The dynamics of onset (delayed onset, progressive deterioration) and how the deafness evolves (later exacerbation, fluctuation) also constitute further evidence for this diagnosis.[9]

It is important to repeat Fraser positional audiometry because, after an initially negative result, the test can turn positive later on.[10] Videonystagmoscopy can identify a fistula sign, although we only detected this in one of our patients, a similar rate to that of another series (20%).[11] Videonystagmography can detect inhibition or abolition of the vestibular reflex.[12] CT scanning without contrast medium is necessary for the detection of pneumolabyrinth, which is highly consistent with a breach through the windows.[13] CT scanning of the middle ear can also detect ossicle damage, dehiscence of the superior semicircular canal and malformation of the inner ear (abnormalities of the cochlear and vestibular aqueducts).

When inner-ear DCS is suspected, recompression should only be considered after an ENT investigation and the possibility of a perilymphatic fistula has been ruled out in a patient with ears cleared. Although experimentation has not shown that recompression is deleterious in the presence of a fistula,[14] it is important to avoid exacerbating the pressure damage by carrying out the compression phase with caution. Any exacerbation of the symptoms during HBOT points to the presence of a fistula; the sessions should be stopped and surgical investigation should be considered.

If a perilymphatic fistula is suspected, it is important to attempt medical treatment, which can afford cure in some cases.[9] The diagnosis of perilymphatic fistula should not be overestimated under the pretext of risk-free surgery without any risk of exacerbating the symptoms. The diagnosis should be backed up by the various special investigations mentioned earlier. Portmann's diagnostic scale can also be of help.[11] When this rule was followed, surgery gave an excellent outcome in every case.

In our series, hearing was improved after surgery in all eight cases and recovered fully in seven. Four patients had residual high-frequency loss. Other series have shown variable improvement with surgery, ranging from 26% to over 90%.[5,8,11,12,15] Deguine documented improvement in 63%. Pullen[8] observed a 55% cure rate, 39% improvement and a failure rate of 6% in 31 patients; Delvaux de Feffen 33% improvement,[15] 53% stable state and 15% exacerbation; Portmann 26% improvement;[11] and Black 43% improvement.[12] Disparate results are seen in the literature because the various series are not homogeneous, bringing together fistulae from different causes and, in some cases, long delays to surgery – up to years. Among the six patients with dizziness and instability, all four operated patients had excellent outcomes and improvement was obtained in both patients who received medical treatment alone. Improvement in other series has ranged from 45% to nearly 90%.[3,5,7,11,12,15] Portmann reports 33% disappearance and 12% improvement;[11] Black 89% improvement;[12] House 49% improvement;[3] Sheridan and Deguine 84% improvement;[5,7] and Delvaux de Feffen 84% improvement.[15] For tinnitus, in our series, the improvement rate was four out of six patients, compared to about half in other reported series: Black 54% improvement;[12] Deguine 53% improvement;[5] Delvaux de Feffen 49% improvement.[15]

In a retrospective series of 50 cases of inner-ear barotrauma after scuba diving, two-thirds of divers were treated medically with improved symptoms in two-thirds of these and a cure obtained in only five.[16] Thirteen divers were operated on with improvement in hearing loss in nine cases, full recovery in two and deterioration in one. Both the tinnitus and vestibular symptoms often improved soon after the procedure.

The middle-ear compartment was investigated via an endaural approach. Examination of the two fenestrae can be facilitated by creating a Rosen bone notch[9] or using an otoendoscope. Once the fistula has been visualised – be it active or not, i.e., whether or not there is visible perilymph leakage – this fenestra has to be occluded to stop the leakage. In our series, the cochlear fenestra was occluded with a temporal fascia graft held in place with biological glue. Most experts recommend that, if no perilymphatic fistula is seen, both fenestrae ought to be occluded.[7] However, occluding the vestibular fenestra is a more delicate procedure with a mobile stapes in place. Therefore, in cases in which no fistula is seen it seems reasonable to occlude only the cochlear fenestra and to place a blood patch on the stapes footplate.

Time to treatment is important, with less likelihood of success beyond 15 days.[7,8] Some surgeons propose surgery from the outset for a broad range of different indications.[1] In our series, the timing of surgery was not a major parameter. However, rapid, ongoing hearing loss represents a relatively urgent situation. We discourage carrying on diving after surgical repair of a perilymphatic fistula.[3,7] Military divers ought to be reassigned.

Whatever the underlying mechanism suspected, a diver with persistent cochleovestibular symptoms after exiting the water ought to be put on first-aid oxygen, rehydrated and evacuated as soon as possible to a therapeutic hyperbaric facility. Once the possibility of an inner-ear DCS has been ruled out – especially if medical treatment for inner-ear barotrauma has failed – a diagnosis of perilymphatic fistula should be considered.

Conclusions

Fluctuating symptoms and sensitivity to position (positional audiometry) or pressure (fistula sign or Tullio phenomenon) are highly suggestive of a diagnosis of perilymphatic fistula. Medical treatment is always indicated. Surgical exploration of the middle ear may confirm a perilymphatic fistula, which can then be repaired. If exploration is indicated, it should be undertaken as soon as possible to ensure a good outcome. In this series, eight out of 11 divers with perilymph fistula underwent endaural surgery and had considerable sustained improvement in their symptoms and signs.

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Quantitative analysis of inner-ear barotrauma using a Eustachian tube function analyzer

Naoharu Kitajima, Akemi Sugita-Kitajima and Seiji Kitajima

Abstract

(Kitajima N, Sugita-Kitajima A, Kitajima S. Quantitative analysis of inner ear barotrauma using a Eustachian tube function analyzer. *Diving and Hyperbaric Medicine*. 2016 June;46(2):76-81.)

Objectives: We investigated the relationship between Eustachian tube function and incidence of inner-ear barotrauma (IEBt) in recreational divers.

Methods: Sixteen patients who experienced a scuba diving injury affecting the inner ear and 20 healthy volunteers who had not experienced a diving injury participated. Healthy volunteers and divers with IEBt received impedance tests regularly to assess Eustachian tube function. Test results from these groups were compared.

Results: There were no significant differences between test results of IEBt divers and healthy volunteers. However, seven IEBt divers were judged to have irregular compliance curves on impedance testing. Seven of the 16 IEBt divers experienced vertigo. In nearly all of the IEBt divers with vertigo, hearing loss type was manifested as high-tone deafness, and IEBt symptoms appeared during diving. These symptoms were more serious especially when the diving depth was deeper.

Conclusions: To prevent IEBt in scuba divers, we recommend a thorough Eustachian tube function evaluation. Any dysfunction should be treated before engaging in scuba diving. We need to assess more divers who have experienced IEBt and thoroughly examine how their injury happened.

Key words

ENT; scuba diving; injuries; vertigo; patient monitoring; equipment

Introduction

The most common injuries in diving are middle ear and nasal sinus barotrauma.[1] Inner ear barotrauma (IEBt), which is related to pressure changes in the middle and inner ear, is less common after diving incidents, but can produce permanent and disabling injury to the vestibulocochlear system.[2] For example, IEBt during descent is directly related to impaired ability to equalize middle ear pressure on the affected side. Subsequently, sudden large pressure changes in the middle ear can be transmitted to the inner ear, resulting in damage to the vestibulocochlear system. The affected diver reports deafness and vertigo, singly or in combination.

In the present study, we investigated the relationship between Eustachian tube function and the incidence of IEBt in recreational scuba divers. We evaluated IEBt using impedance testing. Impedance testing mainly evaluates changes in air content within the middle ear during the Valsalva manoeuvre and swallowing. Thus, we reasoned that impedance testing would be an ideal method for examining ‘ear clearing’ in divers. In Japan, impedance testing is the most commonly used test for evaluating Eustachian tube function; sonotubometry,[3] tubotympanoaero-dynamography,[4] and nine-step inflation/deflation testing[5] are also used. To our knowledge, this is the first study to use impedance testing to evaluate IEBt in scuba divers.

Materials and methods

Sixteen patients who had experienced a scuba diving injury affecting the inner ear (eight men and eight women; mean age ± SD: 43.5 ± 12.4 years) and 20 healthy volunteers who had not experienced a diving injury (six men and 14 women; mean age ± SD: 33.5 ± 13.9 years) participated. This study was conducted in accordance with the Declaration of Helsinki for the ethical treatment of human subjects. All procedures were approved by the review board of Tokyo Medical University (No. 3032) and carried out with the adequate understanding of the subjects and their written consent. We used the diagnostic criteria of Edmonds et al.[6] to diagnose IEBt; that is, the presence of otological barotrauma, sensorineural or combined hearing loss, or tinnitus or demonstrable vestibular damage implying IEBt. In a previous study, we classified patients with scuba diving-related aural barotrauma into unilateral and bilateral groups.[7] In the present study, we examined the unilateral group with IEBt.

During the patients’ first visit to our clinic, the divers underwent nystagmic examinations at their bed side and audiometric measurements, including pure tone audiometry (PTA), tympanometry, Eustachian tube function testing and a fistula test. Based on the criteria for evaluating hearing, as determined by the Research Committee on Acute Profound Deafness, Ministry of Health and Welfare, Japan,[8] we calculated the average hearing level at five frequencies (0.25, 0.5, 1.0, 2.0, and 4.0 kHz), representing the worst PTA results. To evaluate hearing level, we tested air conduction. However, if there was a difference between air conduction and bone conduction (i.e., an air-bone gap), we used bone conduction testing instead.

A JK-05 Eustachian tube function analyzer (RION, Japan)

Figure 1
Examples of normal impedance test curves constructed from a healthy volunteer; opening pressures less than 200 daPa are consistent with a diagnosis of patulous Eustachian tube type, whereas opening pressures greater than 650 daPa are consistent with a diagnosis of stenotic Eustachian tube type

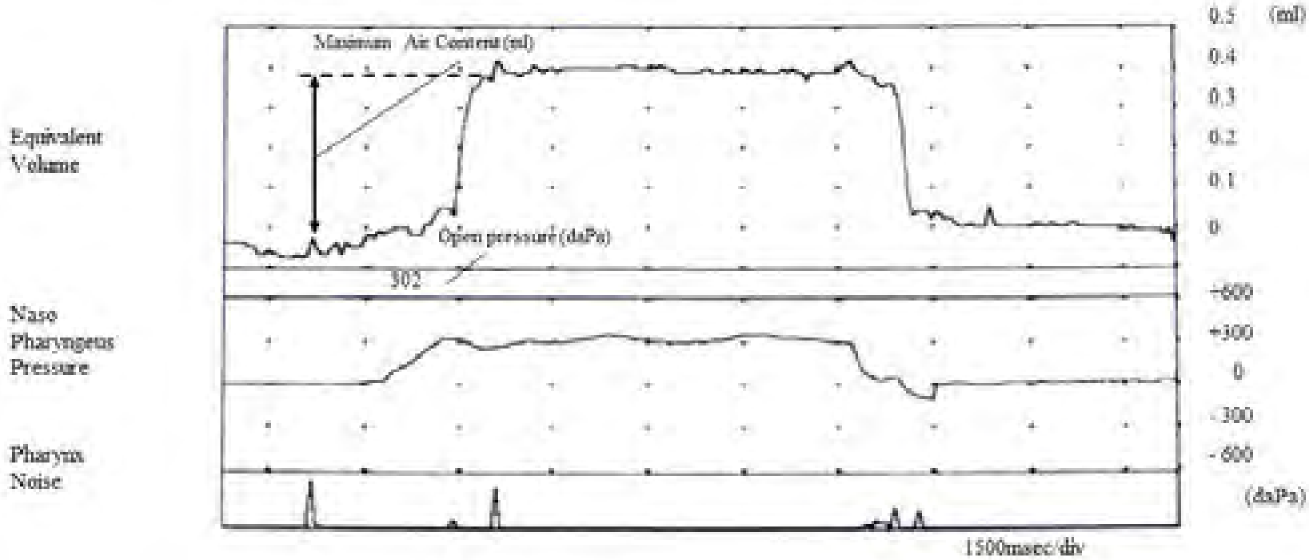
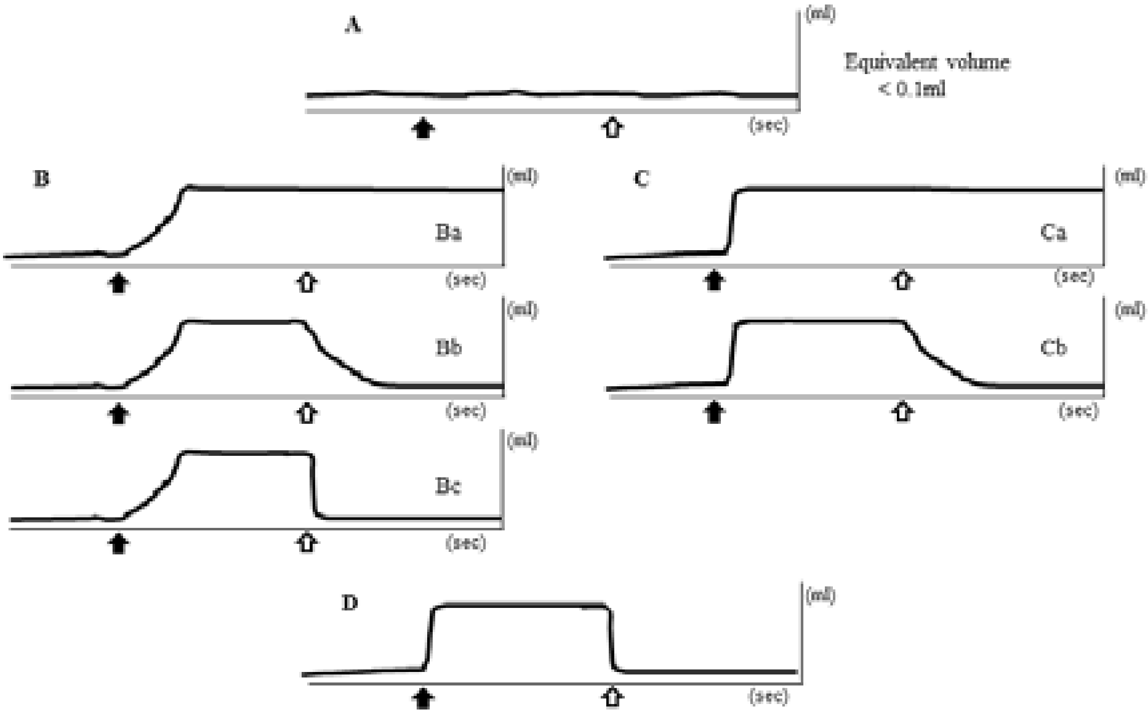


Figure 2
Classification of Eustachian tube function based on compliance curves; in each graph, the filled arrow at the lower left represents the start of the Valsalva manoeuvre, and the open arrow at the lower right represents swallowing after the Valsalva



was used to perform impedance testing. Examples of impedance test curves measured from a normal subject are shown in Figure 1. Impedance tests were performed by simultaneously recording tympanic membrane impedance and nasopharyngeal pressure. The passive opening capacity of the Eustachian tube during the Valsalva manoeuvre can be determined from the curve pattern of impedance changes recorded from the external ear canal.[9] The presence of respiratory fluctuations and opening pressures of less than 200 daPa are consistent with a diagnosis of patulous Eustachian tube, whereas opening pressures greater than 650 daPa are consistent with a diagnosis of stenotic

Table 1
Eustachian tube function results of healthy divers; * data not obtainable

Subject	**Impedance Test**				**Eustachian tube function**
	Opening pressure (daPa)	Maximum air content (ml)	Compliance curve	Respiratory fluctuation	
1	496	0.35	D	No	Normal
2	330	0.2	D	No	Normal
3	*	0.2	D	No	Normal
4	796	0.2	Cb	No	Stenotic
5	330	0.4	Cb	No	Stenotic
6	*	0.9	D	No	Normal
7	*	0.9	Cb	No	Stenotic
8	185	0.3	D	No	Normal
9	145	0.8	D	No	Normal
10	*	0.45	Cb	No	Stenotic
11	242	0.2	D	No	Normal
12	335	0.6	Cb	No	Stenotic
13	*	0.2	D	No	Normal
14	420	0.4	Cb	No	Stenotic
15	597	0.3	D	No	Normal
16	338	0.5	D	No	Normal
17	169	0.8	D	No	Normal
18	582	0.7	D	No	Normal
19	407	0.4	D	No	Normal
20	*	0.3	Cb	No	Stenotic

Eustachian tube type.[7] We defined the maximum value of equivalent volume as maximum air content in the middle ear. If we could not accurately determine the opening pressure because of a technical error, we diagnosed the patient with either stenotic or patulous Eustachian tube type from the shape of his or her compliance curve.

Classification of Eustachian tube function based on compliance curves is shown in Figure 2.[10] In each curve, the black arrow at the lower left represents the start of the Valsalva manoeuvre and the white arrow at the lower right represents swallowing after the Valsalva. When the Eustachian tube did not open or close for more than 10 seconds, we designated the compliance curve as type A or a, respectively. If the Eustachian tube opened or closed immediately, we designated the curve as type C or c, respectively. If Eustachian tube opening or closing was delayed, we designated the curve as type B or b, respectively. Compliance curves showing normal patterns were designated as type D, whereas those showing abnormal patterns were designated as 'other types' (A; Ba, Bb, Bc; and Ca, Cb; see Figure 2). If compliance curves had abnormal patterns, we designated the curves as 'stenotic' Eustachian tube type and diagnosed the patient with tubal stenosis. However, if respiratory fluctuations were evident from inspections of the compliance curves, we designated the curves as 'patulous' and diagnosed the patient with patulous Eustachian tube. If the Eustachian tube slightly opened (maximum air content < 0.1 ml), we designated the curve as type A for convenience and assigned the data point for maximum air content to 0.1 ml.

We compared Eustachian tube function in healthy volunteers with that in divers who experienced IEBt. Calculations were performed with Stat Mate 3 software (Atoms, Japan). Data are presented as means ± standard deviation. The Mann-Whitney U test was used for statistical analysis; $P < 0.05$ was considered significant.

Results

DIVERS WITHOUT IEBt

Seven of the 20 healthy volunteers were diagnosed with Eustachian tube dysfunction of the stenotic type (Table 1). With the impedance test, the mean ± SD opening pressure was 384 ± 184 daPa, and the maximum air content was 0.5 ± 0.2 ml. Seven of 20 healthy volunteers had irregular, type Cb compliance curves.

DIVERS WITH IEBt

There were no significant differences between the IEBt divers and healthy volunteers in terms of age. Twelve of the divers with otological symptoms were diagnosed with Eustachian tube dysfunction of the stenotic type (Table 2). For the impedance test, the opening pressure was 579 ± 341 daPa, and the maximum air content was

Table 2
Clinical findings of divers with inner-ear barotrauma; † parameters were technically difficult to measure; * maximum equivalent volume in A type was set to 0.1 ml for convenience

No.	Onset	Pure tone audiometry		Tympanometry	Impedance test				Eustachian tube function	Vertigo	Fistula sign
		dB (mean)	hearing loss type		Open pressure (daPa)	Maximum air content (ml)	Compliance curve	Respiratory fluctuation			
1	after ascent	16	dip (4,000Hz)	A	286	0.7	D	No	normal	No	No
2	not clear	19	flat or horizontal	A	1200	0.2	D	No	Stenotic	No	No
3	after ascent	19	dip (4,000Hz)	A	530	0.7	D	No	Stenotic	No	No
4	during descent	21	flat or horizontal	A	577	0.3	Bb	No	Stenotic	No	No
5	during ascent	22	high tone (gradual)	A	311	0.5	D	No	Stenotic	No	No
6	after ascent	25	middle tone	A	1200	0.2	Bb	No	Stenotic	No	No
7	after ascent	26	flat or horizontal	A	139	0.5	D	No	normal	No	No
8	during descent	26	middle tone	C1	611	0.4	D	No	normal	No	No
9	after ascent	33	high tone (gradual)	A	†	0.4	Ca	No	Stenotic	No	No
10	during diving (>10m)	9	high tone (abrupt)	A	503	0.4	Cb	No	Stenotic	Yes	No
11	during diving (>10m)	25	high tone (gradual)	A	614	0.6	D	No	normal	Yes	No
12	after ascent	25	low tone deafness	A	310	2.0	Bc	No	Stenotic	Yes	No
13	after ascent	26	high tone (abrupt)	A	370	0.7	Ca	No	Stenotic	Yes	No
14	during diving (>10m)	30	high tone (gradual)	A		0.1*	A	No	Stenotic	Yes	No
15	during diving (>20m)	41	high tone (gradual)	A	†	0.6	Ba	No	Stenotic	Yes	No
16	during diving (>20m)	106	flat or horizontal	C1		0.1*	A	No	Stenotic	Yes	Yes

0.5 ± 0.5 ml. There were no significant differences between IEBt divers and healthy volunteers on these variables. Seven divers were judged to have irregular compliance curves. Seven divers experienced vertigo and of these, six had irregular compliance curves (Table 2).

The clinical findings of IEBt divers are also summarized in Table 2. Except in the case of two IEBt divers (nos. 8 and 16; Table 2), tympanometry results of the IEBt divers were normal (Jerger A type). Five of the seven IEBt divers with vertigo experienced a high-tone hearing loss and IEBt symptoms during diving. The deeper the diving depth, the more serious were the symptoms. Of the IEBt divers who underwent fistula testing, only one diver (No. 16) tested positively. This diver was subsequently diagnosed with perilymphatic fistula after exploratory tympanotomy, during which both the oval and round windows were patched with fascia.

Discussion

Generally, IEBt among scuba divers is believed to be caused by any one of three conditions: a haemorrhage in the inner ear, a tear of the labyrinthine membrane, or a perilymphatic fistula,[11] moreover it is thought to be caused by a pressure difference between the inner ear and the middle ear cavity. The general characteristics described for IEBt are:

- the same symptoms are experienced repeatedly with pressure load;
- hearing loss, tinnitus, or both;
- unilateral hearing loss;
- primarily high-tone deafness (gradual/abrupt form and flat or horizontal form);
- hearing ability is moderately impaired;
- satisfactory convalescence.[12]

For the most part, our present findings are comparable to these criteria.

In the present study, most of the IEBt divers had Eustachian tube dysfunction (Table 2). The IEBt divers with irregular compliance curves on impedance testing tended to experience vertigo (Table 2). We previously reported that to avoid a diving injury, it is particularly important to have an improved compliance curve.[10] These results are in line with our hypothesis.

In the present study, five of the seven IEBt divers with vertigo displayed type a/b (including type A) compliance curves when subjected to impedance testing (Table 2). This means that divers with type a/b compliance curves are prone to vertigo during diving, probably because expanding air in the middle ear is not released promptly via the Eustachian tube. However, seven of the healthy volunteers had irregular compliance curves of the Cb type (Table 1), indicating that IEBt does not always occur in divers displaying type Cb compliance curves. The Eustachian tubes of divers with type Cb compliance curves opened easily only if the divers ascended from a dive slowly. In this case, the diver could release expanding air volume from their Eustachian tubes without difficulty. In general then, type Cb compliance curves might be considered to be a normal type of curve, as can type D curves. Needless to say, whether a diver with a type Cb curve is able to clear his Eustachian tubes successfully depends on his diving skills and experience.

IEBt onset does not always depend on diving depth.[13,14] However, in our study, when the dive was deeper, IEBt divers were more likely to experience vertigo. Excessive pressure caused by forceful Valsalva manoeuvres could be one contributory factor. The opening pressures of the IEBt divers were not always higher than those of the healthy volunteers. However, divers who had difficulty clearing their ears may have become impatient due to discomfort, leading them to Valsalva more forcefully.

In the diver with a perilymphatic fistula (No. 16), both inner-ear dysfunction and Eustachian tube dysfunction were more serious than those in other divers with IEBt. Therefore, we need to be particularly aware about perilymphatic fistula being the most serious cause of IEBt. In certain cases, it is difficult to diagnose whether divers with IEBt will develop perilymphatic fistula. Thus, in these cases, fistula testing and high-resolution CT scanning of the temporal bone[15] need to be performed. If possible, levels of cochlin tomo-protein (CTP), a perilymph-specific protein,[16] should also be measured.

Conclusions

This study supports the idea that divers who experience IEBt should undergo thorough evaluation of their Eustachian tube function and of their vestibulocochlear system if they are to receive proper treatment. To ensure safe diving that avoids inner-ear-associated injury, divers first need to determine whether they are prone to IEBt. To dive safely, they would need to display normal (type D or Cb) compliance curves. To lessen the likelihood of injury, divers should also be instructed on how to solve diving-related problems. Since various other factors make it difficult to evaluate divers thoroughly, we need to assess more divers who have experienced IEBt and thoroughly examine how their injuries happened.

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A comparison of simple reaction time, visual discrimination and critical flicker fusion frequency in professional divers at elevated pressure

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Abstract

(Tikkinen J, Wuorimaa T, Siimes MA. A comparison of simple reaction time, visual discrimination and critical flicker fusion frequency in professional divers at elevated pressure. *Diving and Hyperbaric Medicine*. 2016 June;46(2):82-86.)

Introduction: Inert gas narcosis (IGN) impairs cognitive performance and some divers are more susceptible to IGN than others. We compared the sensitivity of two reaction time tests to detect changes in performance at pressure and compared these results with critical flicker fusion frequency (CFF) changes at the same ambient pressures.

Methods: The study assessed simple reaction time (RT), mean time correct of the discrimination reaction time (MTC) and CFF in 30 professional divers breathing air at 101 kPa and 608 kPa in a hyperbaric chamber.

Results: RT and MTC increased at 608 kPa by 5.1 ± 9.4% ($P = 0.04$) and 7.3 ± 12.3% ($P = 0.01$) respectively. RT decreased to pre-compression level after decompression and MTC decreased to a level lower than pre-compression ($P < 0.001$) values. CFF increased by 2.5 ± 2.8% ($P < 0.001$) at 608 kPa. CFF decreased to pre-compression level after decompression. An increase in CFF was inversely correlated with a decrease in RT (r = 0.38, $P = 0.04$) and in MTC (r = 0.43, $P = 0.02$) at 608 kPa.

Conclusions: Response speeds of the same subjects were impaired in both reaction time tasks at 608 kPa, whereas CFF increased at depth. An association between changes in response times and changes in CFF suggests that divers susceptible to IGN may also be susceptible to the effects of elevated oxygen partial pressure. If this holds true, the future selection of professional divers could be improved by the use of simple cognitive tests.

Key words

Narcosis; nitrogen; performance; psychology

Introduction

The impairment in human cognitive performance while breathing compressed gases at increased ambient pressure has been explained on the basis of the raised partial pressure of inert gases such as nitrogen, termed inert gas narcosis (IGN).[1] Measurable changes in diver performance have been shown from pressures as low as 203 kPa (2.0 atmospheres absolute).[2] Some divers seem to be more susceptible to IGN than others, and its onset pressure varies among individuals.[3]

The finding that human performance deteriorates due to elevation of ambient pressure and increased partial pressure of nitrogen is explained by the slowed processing model.[4] According to this model slowing is primarily a result of decreased arousal and is manifested by an increase in simple reaction time (RT), slowing in other tasks such as abstract reasoning tests and sorting cards.[5–7] However, the strategy used to perform a task also changes under IGN and it is considered to be a response to slowing. For example, speed can be increased by shifting speed-accuracy trade-off setting, allowing more mistakes. It has been demonstrated that rehearsal strategies also may be modified by IGN but can be manipulated experimentally.[8] Controlling for the strategies during experiments is important in revealing the slowing of psychomotor performance by IGN. Reaction time is a commonly used parameter in experiments attempting to quantitate IGN. It measures total decision-making time that constitutes total information processing. Total information processing also involves higher-order cognitive functions, such as learning. Skill and procedural learning become confounders when the complexity of the task increases.[9] Repeating the same task improves the results and comparing the results obtained at different ambient pressures becomes challenging.

There is a long-standing experience with the critical flicker fusion frequency (CFF) in the evaluation of the effect of psychoactive drugs,[10] and as a measure of the ability to discriminate sensory data.[11] CFF appears to be a simple and reliable way of assessing changes in cortical arousal,[12] and has been demonstrated to be stable to repeated tests.[13]

The results of studies investigating the relation between ambient pressure, composition of inhaled gases and CFF have been somewhat ambiguous. Breathing normobaric oxygen (O_2) increased CFF in one study,[14] whilst in another CFF was unchanged during 71 kPa O_2 exposure, decreased at 141 kPa O_2 but increased at 283 kPa O_2.[15] In a study of divers performing wet air dives at a depth of 33 metres' fresh water (mfw), CFF was reported to initially increase and then decrease, this decrease being sustained after decompression.[16] Similar results were reported in another study of wet air dives.[17]

The aims of the present study were to compare the sensitivity of two reaction time tests to detect changes in performance at pressure and to compare these results with CFF changes at the same ambient pressures in order to evaluate the potential of the CFF test to detect IGN. We also assessed whether there were any correlations within individuals between the changes in the cognitive performance tests and CFF.

Methods

SUBJECTS

The study protocol was approved by the Ethical Committee of the University Hospital of Helsinki and the Headquarters of the Finnish Defence Forces. We studied 30 professional male divers from the Finnish Navy and the Coast Guard aged from 23 to 50 (mean 35 ± 8) years. The divers gave their written informed consent to participate following a detailed explanation in writing of the study procedures. Divers abstained from strenuous exercise, diving, alcohol, nicotine products,[18] medicines and caffeine[19] for at least 24 h before the experimental trial.

Divers were exposed to a pressure of 608 kPa (50 metres' sea water, msw) in a dry hyperbaric chamber as part of their annual medical examination. Compression was at a rate of 9 ± 1 msw·min^{-1} and the target pressure was reached in 6 ± 1 min. Decompression was based on a 51 msw/15 min bottom time table (Finnish Navy, DCAP-FINN). Decompression stops were made at 9, 6 and 3 msw for 7, 2 and 8 min, respectively. Temperature, oxygen (PO_2) and carbon dioxide (PCO_2) partial pressures were measured during the simulated dives, with the PO_2 between 21.0 and 21.5% and the PCO_2 under 1000 ppm by ventilation and Haux absorbers. The temperature varied from 18 to 32^{O}C during the compression and decompression of the chamber.

Subjects, in pairs, did three 'dives' at the same time of day during which, whilst seated at rest, they performed either one of two reaction time tests or were tested for their CFF. This was in order to minimize the exposure time and to avoid fatigue influencing the results. The interval between the tests varied from two to four weeks. Simple RT was performed on the first test day, a discrimination reaction time test on the second day and CFF on the final test day.

SIMPLE REACTION TIME

We utilized the reaction time test form S1 from the Schuhfried Vienna Test System RT (reaction test).[20] A simple visual signal was shown on an LCD monitor; the subjects were required to react to the signal by pressing the correct trigger button. The reaction time is the time interval that elapses between a signal and the start of the mechanical response movement, i.e., when the subject lifts his finger from the rest button. The visual signal was shown 28 times at each pressure condition, the test taking 3 to 5 min to complete.

The divers practiced the test once at ambient pressure, in the hyperbaric chamber once and went through short training sequences before commencing the actual tests. We then measured the RT in the chamber before compression, at 608 kPa and immediately after decompression. The mean reaction time values were used only from those reactions that were correct and complete. In order to normalize the distribution of the raw reaction time scores the Box-Cox transformation was carried out.[21] The results were presented as milliseconds (ms). An increase of 16% or more in the values was considered as important.[5]

DISCRIMINATION REACTION TIME

We utilized the Cognitrone trial form S7 from the Schuhfried Vienna Test System.[22] A pair of figures was shown on an LCD monitor; the subjects, after comparing the figures, decided whether they were identical or not by pressing the green button for identical or the red one for not identical. The subjects performed the trial seven times. The divers were expected to achieve their maximum response speed by the fifth trial.[23] During a trial, 50 pairs of figures, 25 pairs of identical and 25 pairs of different figures, are presented twice in immediate succession in a random order. It took 3 to 7 min to complete a test. The divers were instructed to work as accurately and quickly as possible.

A minimum criterion of 85% correct answers for both identical and different figures was used. Short training sequences were performed before each of the actual trials at ambient pressure, 608 kPa and immediately after decompression. The variable 'mean time correct' (MTC) of the discrimination reaction time was calculated. This value represents the time spent recognizing that the figures are different. The trials were performed in the chamber four times before compression, once at 608 kPa pressure and once immediately after decompression. The MTC were used only from those reactions that were both correct and complete. Results are presented in seconds (s). An increase of 19% or more in the values was considered as important.[22]

CRITICAL FLICKER FUSION FREQUENCY

Critical flicker fusion frequency (CFF) thresholds were measured by the FLIM test from the Schuhfried Vienna Test System.[24] Visual stimulation with a luminous diode was achieved through the flicker fusion unit (model 64031, Schuhfried Vienna Test System). The frequency of flickering light was increased in steps of 0.1 Hz from 10 Hz until the subject pressed a button as an indication of fused light. Similarly, the frequency was decreased stepwise from 80 Hz until the subject perceived the light to flicker. CFF was calculated as the average of eight fusion and flicker frequencies. It took 5 to 12 min to complete a test.

STATISTICS

The IBM SPSS 20 computer package was used for statistical analyses. The results are presented as mean ± standard deviation (SD). The Shapiro-Wilk test was used to assess the

Table 1

The mean ± SD of transformed reaction time (1/RT), transformed mean time correct of the discrimination reaction time (1/MTC) and actual critical flicker fusion frequency (CFF) for 30 professional divers measured in a hyperbaric chamber before compression, at 608 kPa and after decompression; * $P = 0.04$; † $P = 0.01$; ‡ $P < 0.001$

Test	**Ambient pressure** (kPa)		
	101.3 (pre-compression)	608	101.3 (post-compression)
1/RT	0.0037 ± 0.0006	0.0035 ± 0.0006*	0.0038 ± 0.0007‡
1/MTC	1.04 ± 0.16	0.98 ± 0.18†	1.13 ± 0.18‡
CFF	38.1 ± 1.7	39.0 ± 2.2‡	37.9 ± 2.1‡

Figure 1

Individual changes in simple reaction times (RT) and in mean time correct of the discrimination reaction time (MTC) of 30 professional divers after compression to pressure of 608 kPa in a hyperbaric chamber compared to baseline; lines of identity drawn to mark an increase of 16% or more in RT and of 19% or more in MTC

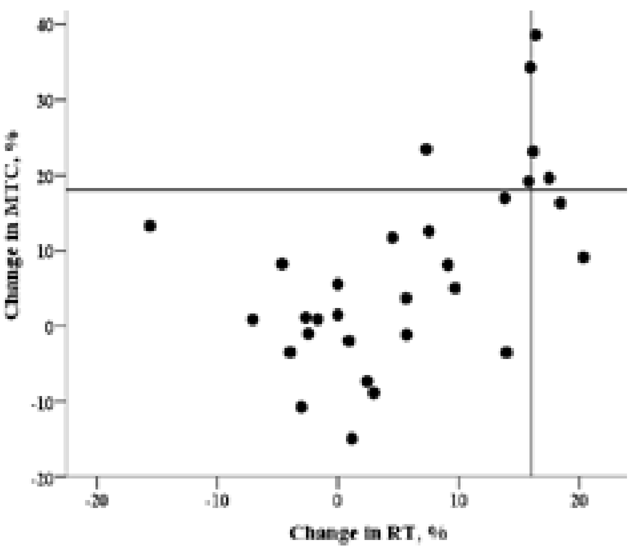
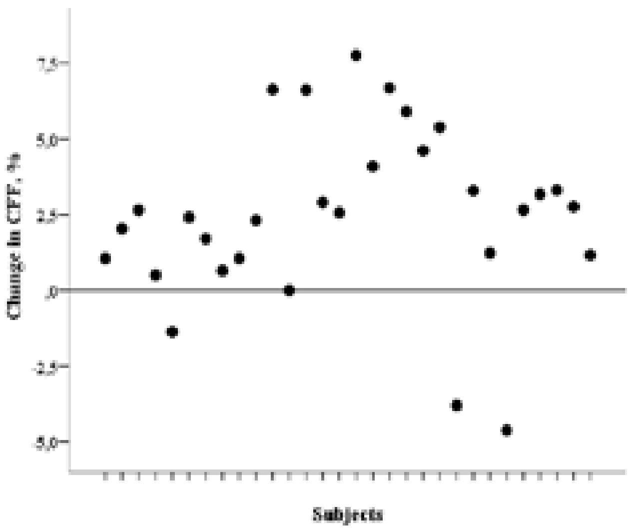


Figure 2

Individual changes in critical flicker fusion frequencies (CFF) of 30 professional divers after compression to pressure of 608 kPa in a hyperbaric chamber compared to baseline



normality of the distribution of RT, MTC and CFF. Skewed values (RT, MTC) were transformed by 1/x transformation to allow parametric statistical analyses. The association of the ambient pressure and time values from the three separate trials was assessed by repeated measures analysis of variance (ANOVA) and the post hoc analysis by Bonferroni test. Associations between transformed RT, transformed MTC and CFF were calculated by using Pearson's correlations coefficient. A pre-study power analysis was not performed. A P-value less than 0.05 was considered as significant.

Results

REACTION TIME AND DISCRIMINATION REACTION TIME

The means ± SD of the transformed RT and MTC data and the actual CFF values are shown in Table 1. RT, MTC and CFF all increased significantly at 608 kPa by 5.1 ± 9.4%, 7.3 ± 12.3% and 2.5 ± 2.8% respectively. There was a significant effect of experimental conditions on the RT values ($F(2, 58) = 9.89$, $P < 0.001$). Mauchly's test indicated that the assumption of sphericity had not been violated ($\chi^2(2) = 1.89$, n.s.). Post hoc comparisons revealed that the RT values were elevated at 608 kPa compared to the pre-compression values ($P = 0.04$) and the values measured after decompression ($P < 0.001$). The pre-compression and after-decompression values did not differ from each other.

The experimental conditions also had an effect on MTC ($F(2, 58) = 27.36$, $P < 0.001$); sphericity was not violated ($\chi^2(2) = 2.82$, n.s.). Post hoc tests showed that MTC values were elevated at 608 kPa compared to both pre-compression and post-compression values ($P = 0.01$ and $P < 0.001$ respectively). After decompression MTC was lower than pre-compression MTC ($P < 0.001$).

The changes in RT and MTC are shown in Figure 1. There were seven divers with an increase of 16% or more in RT at 608 kPa.[5] Similarly, there were six divers with an increase of 19% or more in MTC[22] at 608 kPa. Five of the divers had an increase of 16% or more in RT and an increase of

19% or more in MTC. Maximal increase was 20% in RT and 38% in MTC.

CRITICAL FLICKER FUSION FREQUENCY

There was a statistically significant effect of the experimental condition on CFF of the divers ($F(2, 58) = 16.30$, $P < 0.001$). CFF increased at 608 kPa compared to pre- or post-compression values ($P < 0.001$ for both). The pre-compression and post-decompression values did not differ from each other. The individual changes in CFF compared with pre-compression CFF at 608 kPa and post-compression are plotted in Figure 2.

Actual RT values were not associated with MTC values (r = 0.11, ns), whilst CFF values were not associated with RT, or MTC values (r = -0.33 and r = 0.22 respectively; both n.s.). A significant association between the changes in RT and the changes in MTC between the pre-compression values and those at 608 kPa was found ($r = 0.56$, $P = 0.001$). The change in CFF was associated with both the change in MTC and with the change in RT ($r = 0.43$, $P = 0.02$ and $r = 0.38$, $P = 0.04$ respectively).

Discussion

We observed a reduction in psychomotor performance similar to that found in our previous study using similar tasks at the same (608 kPa) pressure condition.[5,22] The complexity of the responses to be performed influenced the results in that MTC changed more under pressure than simple reaction time, again, in keeping with previous studies. The return of MTC to less than pre-dive values is possibly due to a learning effect. The deterioration in performance was of short duration, having recovered immediately post compression. We hypothesise that the increase in reaction times is caused by IGN. This obviously has importance when performing complex tasks during a dive or in a hyperbaric chamber.

The pressure-related changes in CFF could be a result of modified neuronal activation due to selective and transient activation of the central nervous system resulting from a changed tissue oxygen partial pressure (PO_2). Unlike a previous study, in which the observed decrement in CFF was sustained after decompression,[16] post-compression CFF in our study had returned to pre-compression levels. However, this difference post-compression could be because of different environmental conditions, including differing workloads, in the two studies; ours was with subjects seated in a dry chamber, whereas the previous study was of actual scuba dives to 33 msw.[16] Other factors, such as CO_2 retention, may also have a role and could explain the initial increase in CFF observed in the scuba divers.[25] Also physical activity of a diver is likely to be lower in a hyperbaric chamber than during a wet dive. Fatigue has been demonstrated to have an effect on CFF.[26]

A previous study has demonstrated that there is an association between CFF and discrimination reaction time.[27] We also observed an association between changes in CFF and changes in the simple and discrimination reaction times at 608 kPa, but not in the absolute values of these parameters. Our study supports the concept of individual susceptibility to IGN. If a subject is more susceptible to the impairment of performance due to increase in ambient pressure, could he also be more susceptible to increased arousal caused by an increased PO_2 or some other variable? Identifying those individuals might improve selection of divers for training and for deeper and more demanding diving tasks.

Some limitation of the study should be pointed out. CFF appears to be sensitive to a variety of extrinsic and intrinsic factors, e.g., ambient temperature, systolic blood pressure and personality have been shown to affect CFF.[28–30] Control for these factors is difficult in a hyperbaric chamber. Task practice may result in improved performance, and many cognitive tasks involve stimulus-response pairings which can be learned. The discrimination reaction test is an example of such a task.[22]

Conclusion

Breathing air at 608 kPa increased the simple reaction time and discrimination reaction time. Response speeds in some of the subjects were impaired in both tasks. The simple reaction time decreased to pre-compression level after decompression and the discrimination time to a level lower than pre-compression values, possibly because of a learning effect. CFF increased at depth then decreased to pre-compression level after decompression. An association between changes in response times and changes in CFF was observed. This suggests that divers susceptible to IGN may also be susceptible to the effects of elevated PO_2. If this holds true, the future selection of professional divers could be improved by the use of simple cognitive tests. Further studies are needed to evaluate these findings.

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Decompression illness treated in Denmark 1999–2013

Christian Svendsen Juhl, Morten Hedetoft, Daniel Bidstrup, Erik Christian Jansen and Ole Hyldegaard

Abstract

(Svendsen Juhl C, Hedetoft M, Bidstrup D, Jansen EC, Hyldegaard O. Decompression illness treated in Denmark 1999–2013. *Diving and Hyperbaric Medicine*. 2016 June;46(2):87-91.)

Introduction: The incidence, diver characteristics and symptomatology of decompression illness (DCI) in Denmark has not been assessed since 1982, and the presence of long-term residual symptoms among divers receiving hyperbaric oxygen therapy in Denmark has never been estimated to our knowledge.

Methods: We undertook a retrospective study of the incidence and characteristics of DCI cases in Denmark for the period of 1999 to 2013. Medical records and voluntary questionnaires were reviewed, extracting data on age, gender, weight, height, diver certification level, diving experience, number of previous dives, type of diving, initial type of hyperbaric treatment and DCI symptoms. Trend in annual case numbers was evaluated using run chart analysis and Spearman's correlation. Age, height, weight, and BMI were evaluated using linear regression. The presence of long-term residual symptoms was investigated by phone interviewing the subgroup of divers treated in 2009 and 2010.

Results: Two-hundred-and-five DCI cases were identified. The average annual case load was 14 with no significant trend during the study period ($P = 0.081$). Nor did we find any trend in age, weight, height or BMI. The most frequent symptoms were paraesthesia (50%), pain (42%) and vertigo (40%). Thirteen out of the subgroup of 30 divers had residual symptoms at discharge from hospital, and six out of 24 of these divers had residual symptoms at the time of follow-up.

Conclusion: We observed a more than ten-fold increase in DCI-cases since the period 1966–1980. In the subgroup of divers treated in 2009/2010, a quarter had long-term residual symptoms as assessed by telephone interview, which is in keeping with the international literature, but still a reminder that DCI can have life-long consequences.

Key words

Decompression sickness; diving incidents; hyperbaric oxygen therapy; recompression; outcome

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Introduction

Decompression illness (DCI) is an acute condition that may follow a reduction in ambient pressure, typically when a submerged diver ascends back to the surface breathing hyperbaric air or oxygen-enriched breathing mixtures with either nitrogen and/or helium as inert diluent. DCI comprises two conditions: decompression sickness (DCS) and arterial gas embolism (AGE).

In DCS, gas bubbles form when the amount of dissolved gas in the diver's blood and tissue compartments decreases as ambient pressure is reduced. The gas bubbles exert a pressure on the surrounding tissue, leading to nerve injury, local necrosis and endothelial disruption.

AGE occurs when expanding gas causes pulmonary barotrauma, allowing alveolar gas to enter the circulation, or when venous gas bubbles migrate to the systemic circulation through arteriovenous shunts, e.g., a persistent foramen ovale (PFO), causing stroke-like symptoms.[1,2]

The incidence of diving-related injuries has previously been estimated to 5–152 per 100.000 person-dives.[3] In Denmark, divers suspected of having DCI are transported to the national treatment facility at the Rigshospitalet, Copenhagen, to receive hyperbaric oxygen treatment (HBOT).

To our knowledge, the incidence of DCI cases in Denmark has not been assessed since Madsen's study of the period 1966–1980,[4] and the long-term outcome of HBO-treated DCI has never been investigated. Since diving activity has changed in recent times owing to its increasing popularity as a recreational sport, we felt it was important to study the recent Danish DCI incidence and to characterise the acute and residual symptoms of the condition.

Methods

This is a retrospective, descriptive quality study of HBO-treated cases of DCI in Denmark. The study was approved by the Danish Data Protection Agency and written informed consent of data acquisition from the individual patients was obtained. The study complied with the Declaration of Helsinki. Following written consent, all divers are given a voluntary questionnaire regarding demographic data, diving experience, technical equipment and circumstances regarding the dive.

We undertook a retrospective audit of all cases treated at the Rigshospitalet, Copenhagen in the period from 01 January 1999 to 31 December 2013. The inclusion criterion was receiving HBOT because of suspected DCI. Medical records and questionnaires were reviewed, and the following data were extracted: age, gender, weight,

Table 1

Demographics, diving experience, certification level and initial type of hyperbaric oxygen treatment of 205 divers with decompression illness (DCI), treated with hyperbaric oxygen therapy in Denmark in 1999–2013. [a] PADI open water, CMAS*; [b] PADI advanced OW/Rescue diver/dive master/assistant instructor, CMAS**, CMAS***, CMAS nitrox basic; [c] PADI instructor/master diver, CMAS instructor*/instructor**/instructor***; USN T6 – US Navy Treatment Table 6; USN T6 ext – US Navy Treatment Table 6, extended; [d] US Navy Table 5 or RH14

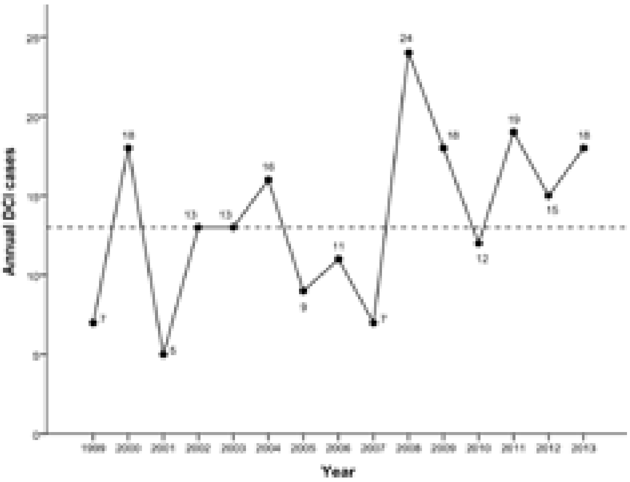
Demographics	**Number**	**%**
Sex (n = 205)		
Male/Female	161/44	79/21
	Mean (SD)	
Age (years)	35.5 (10.1)	
Weight (kg)	79.6 (15.7)	
Height (cm)	178.1 (9.0)	
BMI (male)	25.8 (3.4)	
BMI, female	21.8 (2.6)	
Type of diving (n = 164)		
Commercial	13	8
Recreational	151	92
Experience level (n = 90)		
Number of previous dives	1–5	8
	6–10	4
	11–50	28
	51–100	17
	> 100	39
Self-estimated level of experience (n = 112)		
Inexperienced	14	13
Some experience	40	36
Experienced	34	30
Very experienced	24	21
Certification level (n = 157)		
Basic open water[a]	31	20
Advanced[b]	95	60
Instructor[c]	29	19
Other	2	1
Initial HBO treatment (n = 205)		
USN T6	103	50
USN T6 ext	38	19
Other[d]	64	31

height, diver certification level, diving experience, number of previous dives, type of diving, type of HBOT and DCI symptoms. Both subjective and objective symptoms present at the time of hospital admittance were included.

Identification of any trend in annual number of DCI cases was our primary end-point. Secondary end-points were identification of trends over time in age, height, weight or BMI. We also wished to determine the prevalence of long-term residual symptoms after HBOT. To do this, we reviewed the medical records of the subgroup of divers treated during the period of 01 January 2009 to 31 December 2010 to identify symptoms at hospital discharge, and conducted telephone interviews during July/August 2012 to determine the presence of long-term residual symptoms. Long-term sequelae were defined as the persistence of subjectively experienced symptoms after a period of 1.5 to 3.5 years from the onset of DCI.

Figure 1

Annual decompression illness (DCI) cases in Denmark 1999–2013; the interrupted line marks the median



STATISTICAL ANALYSIS

The data were analysed using IBM SPSS version 20. Annual number of DCI cases were depicted in a run chart and subsequently checked for shifts, trends, or abnormal amounts of runs as signals for non-random variation.[5] A possible trend in annual caseload was analysed using Spearman's rho correlation coefficient. Trends in age, weight, height and BMI were analysed using linear regression. A P-value of 0.05 or less was considered statistically significant.

Results

A total of 205 HBO-treated DCI cases were identified in the period 1999 to 2013. Out of these 205 cases, the voluntary questionnaires regarding type of diving, number of previous dives, self-estimated level of experience, and certification level, were answered by 164 (80%), 90 (44%), 112 (55%), and 157 (77%) divers respectively. Demographics, diving characteristics, and initial type of HBOT are summarized in Table 1.

The mean annual incidence of treated DCI for the entire 15-year period was 14 (rounded, range 5–24; Figure 1). No shifts, trends or abnormal runs were detected, only random variation. There was a slight increase in annual DCI cases but this was not significant (ρ = 0.465; P = 0.081). Mean age was 35.5 (SD 10.1). No trend in diver age (P = 0.44) was found nor was there any trend in weight (P = 0.52), height (P = 0.22) or BMI (P = 0.82) over the 12-year period.

Figure 2

Symptom characteristics in 30 DCI cases from 2009–2010 on admission (white); 13 cases with symptoms at discharge from hospital (grey) and among the six divers with long-term residual symptoms at the time of the follow-up interview (black)

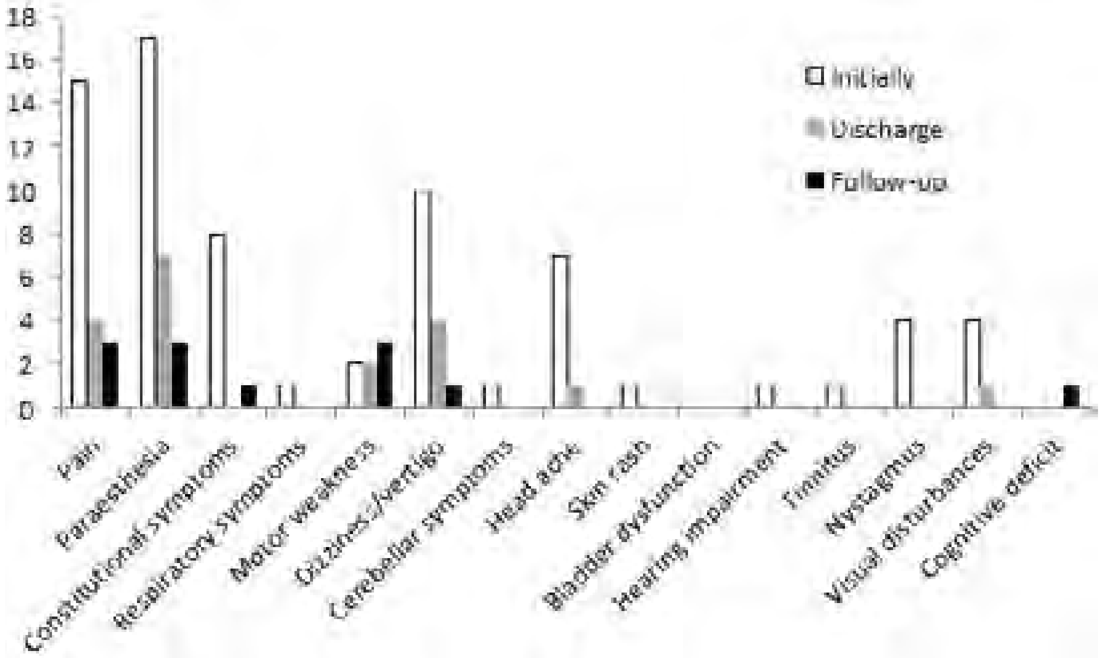


Table 2

Number of decompression illness (DCI) cases with a given symptom; constitutional symptoms comprise general symptoms such as nausea and malaise

Symptom	(n = 205)	%
Paraesthesia	103	50
Pain	87	42
Dizziness/vertigo	81	40
Headache	57	28
Constitutional symptoms	51	25
Motor weakness	48	23
Respiratory symptoms	28	14
Visual disturbances	25	12
Cerebellar symptoms	19	9
Bladder dysfunction	10	5
Skin rash	10	5
Nystagmus	8	4
Hearing impairment	7	3
Tinnitus	6	3

The most frequent DCI symptoms are listed in Table 2. Paraesthesia (50%), pain (42%) and vertigo (40%) were the three commonest symptoms. Few divers exhibited cerebellar symptoms, bladder dysfunction, skin rash, nystagmus, hearing impairment or tinnitus (Table 2).

Among the 30 subjects who were treated in 2009/2010, 13 had reduced but lingering symptoms at discharge from hospital. At the time of the follow-up interview, one subject had died from a subsequent diving accident. It was possible to successfully contact 24 of the remaining 29 subjects in 2012, of whom six had residual symptoms. As five divers were lost in the follow-up interview, the true prevalence of residual symptoms is between 20% and 37% depending on the prevalence of residual symptoms in the lost group.

Out of the six divers with subjective, residual symptoms, three had no symptoms at discharge from hospital. One of the six divers had suffered a concussion during the period between treatment for DCI and the follow-up interview. It was not possible to determine whether his reported symptoms derived from DCI or the later concussion. However, this diver had symptoms from the time of hospital discharge in 2010 until the concussion in December 2011. Figure 2 illustrates symptoms present at the time of hospital admittance in all DCI cases (n = 30) in 2009/2010, compared to the symptoms present among 13 divers at discharge and among the six divers with residual symptoms at the time of the follow-up interview.

The average duration of hospital stay was 2.5 (range 0–8) days among the six divers with residual symptoms compared to 2.0 (range 0–12) days for the entire subgroup. All six divers with residual symptoms were employed at the time of the interview in 2012, one having reduced to part-time work because of their residual symptoms. Three of the six divers were still active divers, one as an occupational diver.

Discussion

The present study is, to our knowledge, the first to describe the incidence of DCI cases in Denmark since Madsen's study of DCI cases in Denmark in the period 1966 to 1980.[4] The incidence found in this study represents a more than ten-fold increase in DCI cases compared to then, when only three out of 21 DCI cases were the result of recreational diving. In the present study, 92% of the DCI cases were the result of recreational diving. We speculate that this shift is because of the increase in recreational scuba diving since the 1960/70s. A major strength in our study compared to other international studies is that treatment for DCI is centralized to one centre in Denmark. Hence, all patients were examined by doctors from the same department and received HBOT in the same recompression chamber.

Others have studied the connection between annual number of DCI cases and the number of diving certificates issued. In New Zealand (NZ), a decline in annual DCI cases was found over the period 1995 to 2012, and this was linked to a similar decline in the number of newly issued diving certificates in NZ over the same period.[6] Likewise, a decline in the incidence of DCI in Australia in the period 1995 to 2007 was found.[7] There are no official statistics on numbers of new diving certificates issued in Denmark. As many Danish recreational divers take their certificates abroad, and consequently many diving incidents that lead to DCI happen abroad, it would be misleading to compare the DCI caseload with certificates issued in Denmark. We attempted to obtain data regarding the annual number of new diving certificates issued in Denmark by three major diver training agencies but were unsuccessful.

The lack of any significant trend in annual DCI caseload in the present study could be owing to the low number of cases, with an average of only 14 DCI cases per year in 1999–2013, compared to 31 cases per year in New Zealand in 1996–2012 and 274 per year in Australia in 1995–2007.[6,7]

We found paraesthesia to be the most common DCI symptom followed by pain. In the NZ series, musculoskeletal pain was the most frequent symptom (65% of cases) followed by cutaneous tingling (45%) among 520 DCI cases.[6] Similarly pain (68.0)% and numbness/paraesthesia (63%) were the commonest symptoms in another study of 2,346 divers.[8]

We did not investigate the use of mixed gases such as trimix or heliox, nor did we estimate the use of rebreathing systems. These advanced types of diving were previously reserved to commercial and military diving activities. We speculate that in the future they will become more widespread among recreational divers and potentially affect the incidence of DCI, as they permit deeper and longer dives.

DCI is associated with long-term neurological and psychiatric symptoms, along with reduced health-related quality of life.[9,10] To our knowledge, the long-term outcome of HBO-treated DCI has not been investigated previously in Denmark. Other studies have found residual symptoms among 22 to 55% of divers at hospital discharge, and 26 to 33% of divers after one month.[11–14] The outcome in the small cadre of divers followed up for 1.5 to 3.5 years in the present study is in agreement with these studies. There were no significant differences between the number of HBOT given to each of the patients in this subgroup, but the group is too small to determine whether length of hospital stay could be used as a measure of DCI severity and the risk of developing long-term symptoms.

There is evidence from several studies, such as that from Scotland of 536 cases, that divers presenting with more severe symptoms are likely to have a poorer outcome.[15] The prevalence of long-term residual symptoms is merely a snapshot at the time of the follow-up interview. Ideally each patient should be interviewed at a fixed time after the initial treatment e.g., after one year, and even if this was done, exclusion bias would still be present.

As this was a retrospective study, the assumption that all patients were equally and thoroughly examined, and all findings, both subjective and objective, fully documented in the medical records is a potential weakness. Furthermore, some selection and recall bias can be expected regarding the voluntary questionnaires.

Conclusions

Annual DCI cases in Denmark during the period 1999 to 2013 have increased ten-fold since the period 1966–1980. We found an annual DCI caseload of 14, predominantly from recreational diving, with no significant trend in annual caseload or secondary endpoints during the period. In a subgroup of 30 divers treated in 2009/2010, nearly half had residual symptoms at discharge from hospital and a quarter developed subjective long-term symptoms, a rate similar to the published literature. This is a reminder that DCI is a serious condition with possible devastating consequences for the individual.

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The duration of two carbon dioxide absorbents in a closed-circuit rebreather diving system

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Abstract

(Harvey D, Pollock NW, Gant N, Hart J, Mesley P, Mitchell SJ. The duration of two carbon dioxide absorbents in a closed-circuit rebreather diving system. *Diving and Hyperbaric Medicine*. 2016 June;46(2):92-97.)

Introduction: Diving rebreathers use canisters containing sodalime preparations to remove carbon dioxide (CO_2) from the expired gas. These preparations have a limited absorptive capacity and therefore may limit dive duration. The Inspiration™ rebreather is designed for use with Sofnolime 797™ but some divers use Spherasorb™ as an alternative. There are no published data comparing the CO_2-absorbing efficacy of these sodalime preparations in an Inspiration rebreather.

Methods: An Inspiration rebreather was operated in a benchtop circuit under conditions simulating work at 6 metabolic equivalents (MET). Ventilation was maintained at 45 $L{\cdot}min^{-1}$ (tidal volume 1.5 L; respiratory rate 30 min^{-1}) with CO_2 introduced to the expiratory limb at 2 $L{\cdot}min^{-1}$. The P_ICO_2 was continuously monitored in the inspiratory limb. The rebreather canister was packed to full volume with either Sofnolime or Spherasorb and 10 trials were conducted (five using each absorbent), in which the circuit was continuously run until the P_ICO_2 reached 1 kPa ('breakthrough'). Peak inspiratory and expiratory pressures during tidal ventilation of the circuit were also recorded.

Results: The mean operating duration to CO_2 breakthrough was 138 ± 4 (SD) minutes for 2.38 kg Spherasorb and 202 ± minutes for 2.64 kg Sofnolime ($P < 0.0001$). The difference between peak inspiratory and expiratory pressures was 10% less during use of Spherasorb, suggesting lower work of breathing.

Conclusions: Under conditions simulating work at 6 MET during use of an Inspiration rebreather a canister packed with Spherasorb reached CO_2 breakthrough 32% earlier with 10% less mass than Sofnolime packed to similar volume. Divers cannot alternate between these two preparations and expect the same endurance.

Key words

Technical diving; equipment; rebreathing; exercise; risk management; safety

Introduction

Effective removal of carbon dioxide (CO_2) is fundamental to the function of rebreathing systems, such as those widely used in anaesthesia and in semi- or fully closed-circuit rebreathers (CCRs) used in technical diving. This is most commonly achieved by passing exhaled gas through granular 'sodalime'; a mix of sodium hydroxide and calcium hydroxide which reacts with CO_2 to produce calcium carbonate ($CaCO_3$) and water (H_2O). This is a consumptive reaction and a given mass of sodalime therefore has a finite absorptive capacity. If this capacity is exceeded during a dive, exhaled CO_2 will 'break through' the scrubber canister and be rebreathed by the diver.[1] CO_2 rebreathing is hazardous because it may result in hypercapnia which, in turn, can cause debilitating symptoms and increase the risk of cerebral oxygen toxicity.[1]

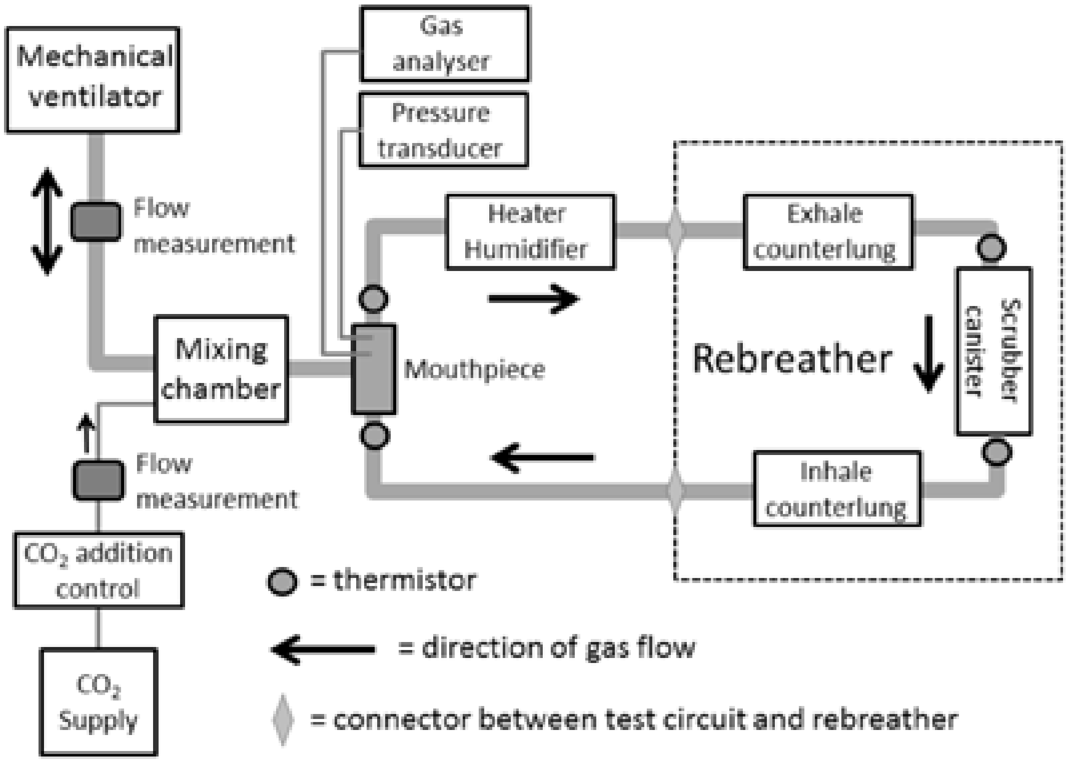
CCRs are usually tested for use with specific sodalime preparations. However, divers may use alternative preparations for reasons that include cost, availability, and/or for perceived advantages in endurance or work of breathing. For example, the Inspiration Rebreather™ (AP Diving, Helston, Cornwall, UK) is designed and tested to use Sofnolime 797™ (Molecular Products, Essex, UK), but divers often report using Spherasorb™ (Intersurgical, Berkshire, UK), a product commonly used in anaesthetic circle circuits in operating rooms.[2] There is controversy regarding the performance of these different sodalime preparations. For instance, an unpublished clinical study (which is nevertheless used in promotion of Spherasorb) concluded that Spherasorb has a 30% longer useful duration than Sofnolime 797,[3] and yet a recent diving fatality during use of an Inspiration rebreather was speculatively attributed to breakthrough with the use of Spherasorb.[2]

There is a conspicuous absence of available data from independent sources describing the relative CO_2 absorbing performance of these two sodalime preparations, particularly in the context of their use in CCRs. We undertook a laboratory study in which the primary outcome was comparison of their respective durations to significant CO_2 breakthrough when used in a CCR under conditions simulating moderate but sustainable underwater work. The null hypothesis was that there would be no difference in duration of use to reach a breakthrough PCO_2 of 1 kPa (7.5 mmHg). A secondary outcome was comparison of the difference between peak inspiratory and expiratory pressures generated when moving a tidal volume of 1.5 L around the rebreather loop during use of the two absorbents.

Methods

Although primarily a bench test study, development of the protocol required human participation and the study was approved by the University of Auckland Human Participation Ethics Committee (Reference 015280).

Figure 1
Schematic layout of the test circuit and monitoring equipment. See text for explanations



CHOICE OF EXPERIMENTAL PARAMETERS

For the purpose of our bench tests we aimed to reproduce conditions of moderate sustainable exertion in respect of ventilation (V_E), tidal volume (T_V), respiratory rate (RR), oxygen consumption ($\dot{V}O_2$) and CO_2 production ($\dot{V}CO_2$). It has previously been agreed that a sustained exercise intensity of 6 metabolic equivalents (MET; one MET equals an assumed resting metabolic rate oxygen consumption of 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$) is a plausible functional capacity standard for divers.[4] Therefore, a well-trained male diver (57 years, height 186 cm, weight 89 kg) exercised on an electronically-braked bicycle ergometer (Velotron, Racermate, Seattle, WA) at 6 MET whilst breathing on an Inspiration Evolution+ CCR (AP Diving, Helston, Cornwall) with a CO_2 scrubber canister packed with Sofnolime 797. The rebreather diluent gas was air, and the PO_2 set-point was 71 kPa (representing an inspired oxygen fraction of 70% at atmospheric pressure).

The inspiratory and expiratory hoses of the rebreather were modified to incorporate a low resistance one-way respiratory valve (5710, Hans Rudolf, Shawnee, KS, USA), which was ported to allow for continuous measurement of mouthpiece dead space gas composition, temperature, and pressure. A heated respiratory flow head (GAK-801 Hans Rudolph, Shawnee, KS, USA) was interposed in the exhale hose to measure ventilation. Gas composition was analysed using an infrared CO_2 sensor and optical O_2 detector (ML206 Gas Analyser, AD Instruments, Dunedin, New Zealand). All data were captured at 1 kHz using a Powerlab 16/35 and the LabChart 7 data acquisition and analysis system (AD Instruments, Dunedin, New Zealand), which was configured to provide real-time breath-by-breath analysis of all physiological variables. Exercise was performed for several hours ensuring stability of the data, with the diver resting for three minutes after every 30 minutes of exercise. During each rest period a gas flow calibration (3-L Calibration Syringe, Hans Rudolph, Shawnee, KS, USA) and gas concentration calibrations were performed, using a three-point calibration for O_2 and CO_2 with reference gases spanning the measurement range.

Using this method with the diver exercising at 6 MET we recorded a mean steady-state ventilation rate of 44 $L \cdot min^{-1}$ (T_V = 2.0 L, RR = 22 $breaths \cdot min^{-1}$) and CO_2 production of 2.0 $L \cdot min^{-1}$. The experimental parameters above, including rest periods every 30 minutes, were replicated for all subsequent bench test trials.

BENCH TEST CIRCUIT DESIGN

The inspiratory and expiratory hoses of an Inspiration Evo+™ rebreather were attached to a test circuit (Figure 1) using tubing adaptors (MLA304, AD Instruments, Dunedin, New Zealand) modified to include Tuohy-Borst instrument seals which provided ports for the introduction of respiratory temperature probes (MLT415/DL, AD Instruments, Dunedin, New Zealand) routed to lie in the gas flow path just proximal and distal to the CO_2 scrubber canister. The scrubber canister was packed as described below with either Spherasorb or Sofnolime 797. As in the preliminary human study (above) the rebreather diluent gas was air, and the PO_2 set-point was 71 kPa (representing a circuit oxygen fraction of 70% at atmospheric pressure).

The test circuit conduit was composed of 35 mm (internal diameter) smooth bore respiratory tubing (MLA1015, AD Instruments, Dunedin, New Zealand) connected to a one-way respiratory valve (5710, Hans Rudolf, Shawnee, KS, USA). The valve assembly included ports within the mouthpiece dead space for sampling gas concentration and pressure. Sealed instrument adaptors were positioned proximal and distal to the inhale and exhale one-way valves, to measure inspired and expired gas temperatures. A clinical heater-humidifier (Fisher and Paykel Medical, Auckland, New Zealand) was incorporated into the exhale limb of the circuit to reproduce the heating and humidification of expired gas that would occur with a human breathing on the loop. The heating function was set to 34°C in all experiments.

Breathing (inspiratory/expiratory ratio 1:1) was simulated using a sinusoidal mechanical ventilator (17050-2 Lung Simulator, VacuMed, Ventura, CA, USA) with the T_V set at 1.5 L and the RR at 30 breaths·min^{-1} for all unmanned experiments. Ventilation was monitored via a pneumotachograph (800 L, Hans Rudolf, Shawnee, KS, USA) and these apparatuses were connected to a 4-L chamber where the inspired and expired gas mixed with instrument grade CO_2 introduced at 2 L·min^{-1} from a Douglas bag reservoir using a precision flow pump (R-2 Flow Controller, AEI Technologies, Pittsburgh, PA, USA). CO_2 flow was monitored and recorded using an independent flow transducer (MLT10L, AD Instruments, Dunedin, New Zealand). Operated in this mode with a functional CO_2 scrubber, the circuit consistently produced a physiologically authentic end-tidal CO_2 of 5–6 kPa at the mouthpiece dead space. Gas analysis and data acquisition for all parameters were performed as described for the human trial. Barometric pressure, environmental temperature and humidity were measured continuously via instruments (EE10 series monitor, E+E Elektronik, Engerwitzdorf, Austria) positioned adjacent to the test circuit.

CO_2 SCRUBBER CANISTER PACKING

All sodalime material was newly purchased, in date, and stored before use within the supplied sealed containers. The initial packing of the scrubber canister with both types of sodalime was supervised by an experienced instructor on the Inspiration rebreather. Usual practices designed to ensure proper distribution of material within the canister were employed. Emphasis was placed on ensuring an evenly distributed tight pack to eliminate the possibility of settling of material and channelling of gas flow which might cause inaccurate results. After the first supervised pack with each type, the sodalime was precisely weighed (before exposure to CO_2) using a laboratory balance (GM-11, Wedderburn Scales, Auckland, New Zealand) and precisely the same weight of the two materials was used for all subsequent experimental repetitions. The respective weights of the material after this standardised approach to packing were 2.64 kg for Sofnolime and 2.38 kg for Spherasorb. The presence of a greater mass of sodalime in a properly packed canister of Sofnolime resulted from the smaller granule size and implied an advantage in capacity for CO_2 removal (see later). However, since the aim of the study was to predict relative performance of the two materials in the 'real world' of rebreather diving and, since our packing weights reflected canisters packed appropriately for volume as would be done in normal use, it would have been inappropriate to balance the masses of the two materials in the study.

EXPERIMENTAL PROTOCOL

All trials were conducted in the Exercise Physiology Laboratory at the University of Auckland in air temperature and relative humidity of 19.4 ± 0.4°C, 54 ± 6.2%, respectively. The laboratory is effectively at sea level and mean ambient pressure was 101.9 ± 0.5 kPa. The rebreather was not immersed in water.

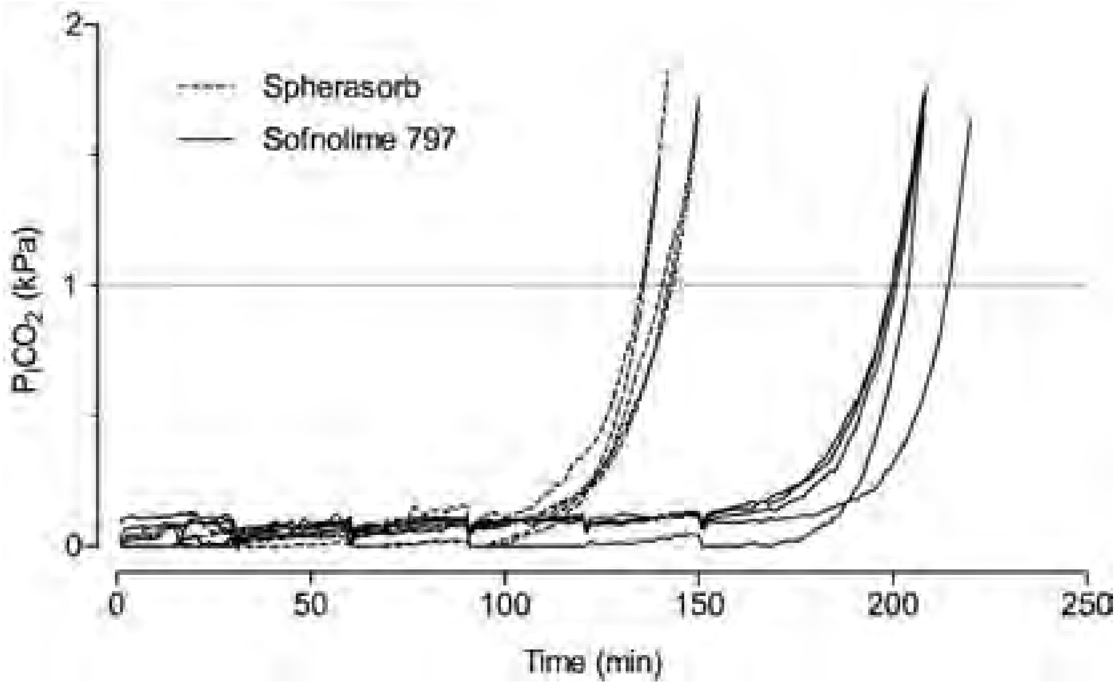
Packing of the scrubber was always conducted within 15 minutes of the start of the experiment. After assembly and positive pressure testing of the circuit, the rebreather was switched on and configured as described above. The heater-humidifier was switched on and the circuit was ventilated as previous described. After verification that circuit ventilation was taking place normally and that monitoring systems were working, the CO_2 flow (2 L·min^{-1}) was opened to the circuit at Time zero. Every 30 minutes thereafter the CO_2 flow and circuit ventilation were suspended as for the human trial (with elapsed time paused). During these rest periods any pooling condensate was removed from the circuit whilst gas flow and gas concentration sensors were recalibrated to external standards. The recalibration was considered necessary because of the potential for even a small error in inward CO_2 flow to confound the results.

The primary endpoint was the elapsed time for the PCO_2 in the inspired gas to reach 1 kPa (7.5 mmHg). To generate more complete CO_2 breakthrough curves the experiment was maintained until 10 minutes after the inspired CO_2 first reached 1 kPa. Ten trials were conducted in total; five using Spherasorb and five using Sofnolime, performed in no specific order.

STATISTICAL ANALYSIS

Times are shown as mean ± standard deviation (SD). A two-tailed Student's *t*-test was used to compare the mean

Figure 2
Breakthrough curves (P_ICO_2 versus time) for 10 trials in which scrubber canisters containing Spherasorb (5 trials) or Sofnolime (5 trials) were ventilated at 45 L·min^{-1} with introduction of CO_2 at 2 L·min^{-1}



elapsed time for the PCO_2 in the inspired gas to reach 1 kPa (7.5 mmHg) for the two sodalime preparations. An alpha value < 0.05 was taken to represent statistical significance.

Results

The elapsed times to reach an inspired PCO_2 of 1 kPa in each of the five trials for Spherasorb and Sofnolime are given in Table 1. The mean duration for Spherasorb was 68% that of a similar packed volume of Sofnolime, and the difference was both statistically significant ($P < 0.0001$) and practically important (being approximately one hour). Therefore, the null hypothesis was rejected. There was a 10% greater mass of Sofnolime in the volume, but the time to breakthrough was 46% longer. 'Breakthrough' curves for these trials are shown in Figure 2. It is clear that at this level of ventilation and CO_2 exposure the deterioration in scrubber canister function was precipitous once breakthrough began, irrespective of the sodalime preparation used.

The peak-to-peak inspiratory/expiratory pressure difference measured at the mouthpiece and averaged across all trials was 8.94 ± 0.29 mmHg for Spherasorb and 10.07 ± 0.63 mmHg for Sofnolime. Thus, in our experimental equipment configuration just over 10% more pressure was required to drive the same tidal volume around the loop when Sofnolime was used. This difference was statistically significant ($P < 0.003$). The temperature of gas entering the CO_2 canister typically was 30.5 ± 2.2°C. The temperature of gas immediately downstream of the CO_2 canister was considerably hotter (47.6 ± 10.7°C) due to the exothermic reaction between sodalime and CO_2.

Table 1
Elapsed time in minutes to reach a P_ICO_2 of 1 kPa in 10 trials in which scrubber canisters containing Spherasorb (5 trials) or Sofnolime (5 trials) were ventilated at 45 L·min^{-1} with introduction of CO_2 at 2 L·min^{-1}

Trial	Duration (min)	
	Spherasorb	Sofnolime
1	135	202
2	139	198
3	142	198
4	141	213
5	134	199
Mean ± SD (min)	138 ± 4	202 ± 6

Discussion

Our experiment exposed a commercially available diving rebreather to ventilation and incoming CO_2 at rates simulating moderate levels of physical exertion. It took, on average, just over an hour longer for CO_2 breakthrough to reach 1 kPa during use of Sofnolime 797 compared to Spherasorb. This outcome was a very consistent, reproducible finding with very small within-material variance.

This result contradicts that of the only other relevant comparison that we can find in the public domain.[3] That study compared the total anaesthetic time in adult patients undergoing general anaesthesia before 1 kg of Spherasorb or Sofnolime allowed CO_2 breakthrough to 0.2 kPa in the inspiratory limb of the anaesthetic circuit. The author reported that Spherasorb lasted 30% longer than Sofnolime; an opposite finding to our result. However, the exact exposure of the CO_2 scrubber canisters to CO_2 was unknown, and the canisters were stored for unreported periods between cases. This makes the results difficult to interpret. The study was internally published in a Russian institution and has not appeared in the mainstream peer-reviewed medical literature.

One important difference between our methods and the Russian study is that the latter used equal masses of absorbent material (1 kg) whereas we used the mass of each material that achieved an optimal pack in the Inspiration CCR scrubber canister (2.64 kg for Sofnolime and 2.38 kg for Spherasorb). The greater mass (0.26 kg; 11%) of absorbent present in the Sofnolime-filled canister would be expected to result in a greater absorptive capacity. However, it seems implausible that this difference in mass alone accounts for the disparity in duration we recorded. Based on the performance of the Spherasorb canisters in our study, this material was capable of absorbing approximately 12 L $CO_2 \cdot 100\ g^{-1}$ of sodalime (calculated from: mean duration to breakthrough of 138 minutes at 2 L $CO_2 \cdot min^{-1}$ = 276 L ÷ 2.38 kg = 11.6 $L \cdot 100 \cdot g^{-1}$). Thus, another 0.26 kg of Spherasorb could be expected to absorb 2.6 x 11.6 L = 30.2 L. This accounts for only 25.2% of the extra 120 L of CO_2 the Sofnolime canisters were exposed to over their extra hour of operation.

We have not attempted to elucidate the explanation for the discrepancy in absorptive capacity between the two materials but it is likely to be due to their respective physical presentations. The Spherasorb granules are roughly spherical in shape and larger (4–8 mesh, 2.5–5 mm diameter) than the Sofnolime 797 granules (8–12 mesh, 1.5–2.5 mm) which are irregular in shape. It follows that Sofnolime absorbent material not only allows packing of a greater mass into a scrubber canister, but also presents a greater surface area to the passing gas. It seems reasonably well appreciated within the industry (even if not among the wider group of end users) that this is likely to result in greater absorptive capacity. Almost certainly for this reason the company that manufactures Spherasorb also produces a 8–12 mesh non-spherical product which (according to in-house testing) has similar absorptive capacity to Sofnolime.[5]

It is also possible that differences in chemical composition of the two products could contribute to different absorptive performance. The amount of calcium hydroxide present is the primary determinant of the amount of CO_2 that can be incorporated into calcium carbonate. The material datasheets for Sofnolime 797 and Spherasorb specify ">75%"[6] and "93.5%"[7] respectively. The preparations also contain sodium hydroxide (a recycling intermediary in the multistage chemical reaction[1]) at "<4%" and "1.5%" respectively. The imprecision in the reported composition of Sofnolime makes direct comparison difficult and detailed analysis of the chemical engineering of these products is not essential to the practical interpretation of our results by divers.

Although its lower absorptive capacity may be a disadvantage, the use of Spherasorb is probably also associated with a lower work of breathing compared to the finer grain Sofnolime material. This may be an advantage in certain circumstances; particularly in Spherasorb's intended medical applications when CO_2 production and respiratory minute volumes are usually much lower. We recorded an approximate 10% reduction in the difference between peak inspiratory and expiratory pressures when using Spherasorb in comparison with Sofnolime. Given the artificial nature of our circuit (which was not immersed and included long hoses and a heater-humidifier) we can draw no quantitative conclusions about the effect of Spherasorb on work of breathing when diving on a rebreather.

It is pertinent to clarify several of the methodological choices we made in this study. Firstly, the studies were conducted with the rebreather not immersed. Testing protocols for establishing the duration of a rebreather scrubber canister typically include immersion of the rebreather in cold water because this is known to reduce scrubber efficiency. We chose not to do this because the goal of our study was to compare the absorptive capacity of two absorbents rather than to generate definitive guidelines on predicted duration. Since both absorbents were operated under identical conditions we believe the comparison of efficiency is valid. We acknowledge it is likely that both materials would have returned shorter durations if the experiment had been conducted in cold water and we cannot exclude the possibility that extreme cold might disproportionately affect performance of the preparations.

Secondly, we chose a P_ICO_2 of 1 kPa as a simple, easily understood, but admittedly arbitrary endpoint for the comparative experiment. We provide the breakthrough curves so that readers can satisfy themselves that changing the inspired CO_2 endpoint would not alter the conclusions. For experiments aiming to establish recommendations for safe duration of CO_2 scrubber canisters in diving we concur with other commentators who advocate conservative (low) limits,[8] and consider a breakthrough P_ICO_2 of 0.5 kPa to be an appropriate choice of endpoint in that setting.

Conclusions

In a simulation of sustained moderate exercise with an Inspiration rebreather, 2.38 kg of Spherasorb CO_2 absorbent allowed CO_2 breakthough (P_ICO_2 = 1 kPa) into the inhaled gas after a significantly shorter period (138 min) than 2.64 kg of Sofnolime 797 (202 min). Thus, the simple but important message for divers using rebreathers is that they cannot alternate between materials and expect the same CO_2-absorbing performance from both.

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User settings on dive computers: reliability in aiding conservative diving

Martin DJ Sayer, Elaine Azzopardi and Arne Sieber

Abstract

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Introduction: Divers can make adjustments to diving computers when they may need or want to dive more conservatively (e.g., diving with a persistent (patent) foramen ovale). Information describing the effects of these alterations or how they compare to other methods, such as using enriched air nitrox (EANx) with air dive planning tools, is lacking.

Methods: Seven models of dive computer from four manufacturers (*Mares*, *Suunto*, *Oceanic* and *UWATEC*) were subjected to single square-wave compression profiles (maximum depth: 20 or 40 metres' sea water, msw), single multi-level profiles (maximum depth: 30 msw; stops at 15 and 6 msw), and multi-dive series (two dives to 30 msw followed by one to 20 msw). Adjustable settings were employed for each dive profile; some modified profiles were compared against stand-alone use of EANx.

Results: Dives were shorter or indicated longer decompression obligations when conservative settings were applied. However, some computers in default settings produced more conservative dives than others that had been modified. Some computer-generated penalties were greater than when using EANx alone, particularly at partial pressures of oxygen (PO_2) below 1.40 bar. Some computers 'locked out' during the multi-dive series; others would continue to support decompression with, in some cases, automatically-reduced levels of conservatism. Changing reduced gradient bubble model values on *Suunto* computers produced few differences.

Discussion: The range of possible adjustments and the non-standard computer response to them complicates the ability to provide accurate guidance to divers wanting to dive more conservatively. The use of EANx alone may not always generate satisfactory levels of conservatism.

Key words

Computers – diving; decompression; safety; altitude; persistent (patent) foramen ovale (PFO); enriched air – nitrox; review article

Introduction

There are a number of physical or physiological conditions that may increase the risk of divers getting decompression sickness (DCS).[1] These include having a persistent (patent) foramen ovale (PFO),[1,2] congenital heart disease,[3] previous DCS events,[4,5] increasing age and/or higher body-mass indices.[1,6,7] Medical advice to some of these divers is usually to consider a more conservative approach to their diving.[3,8–11] For instance, the recent position statement on PFO and diving, published jointly by the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Sports Diving Medical Committee (UKSDMC),[12] provides examples of more conservative types of diving. These include: reducing dive times; restricting dive depths; eliminating multiple dives per day; diving using enriched air nitrox while managing decompression with air-based methods; and increasing the duration of safety or decompression stops.

Some dive computers have the capability to generate more conservative dive profiles by modifying decompression management based on a number of settings that can be altered by the user.[13] Forty out of 47 dive computers reviewed in one study possessed some form of adjustment that was capable of producing more conservative decompression management.[14] However, there are potential risks to applying these adjustments without knowing what the implications of those changes are. The case has been reported of a diver who, following the closure of a PFO, had set their computer to calculate decompression at an heightened altitude but also employed a less conservative version of the decompression software.[15] The diver was unaware of the impact the alterations made and, as a result of improper dive management, the computer locked up on surfacing. The diver continued diving with a new computer clear of any prior pressure/time exposure and, as a consequence, they experienced a relatively severe episode of DCS, with post-treatment relapse and significant sequellae.[15] It was suggested in that report that a better knowledge of the implications of employing some of the adjustable computer safety features may have prevented the DCS event.

The present study reviews the exact forms of adjustment that can be made on a representative sample of dive computers in current use by recreational scuba divers. A series of pressure/time exposures is used to compare the effects of employing one or more of the available changes. The scales of the possible computer adjustments are compared against default settings and also against the use of enriched air nitrox while managing the dive using air-based decompression procedures as if this had been used as the

Table 1
The seven models of dive computer employed in the study and the settings available for adjustment by the diver; MB – microbubble level; P – personal setting; PF – personal factor; A – altitude; RGBM – reduced gradient bubble model

Brand	Model	Personal settings	Altitude settings	Other adjustments
Mares	Icon HD	P0, P1, P2	A0, A1, A2, A3	
Mares	Nemo Excel	PF0, PF1, PF2	A0, A1, A2, A3	
Suunto	D9	PF0, PF1, PF2	A0, A1, A2	RGBM 100%, RGBM 50%
Suunto	Vyper Air	PF0, PF1, PF2	A0, A1, A2	RGBM 100%, RGBM 50%
Oceanic	Atom 2	On, Off		
UWATEC	Galileo Sol	MB0, MB1, MB2, MB3, MB4, MB5		
UWATEC	Tec 2G	MB0, MB1, MB2, MB3, MB4, MB5		

Figure 1
Nominal multi-level depth/time dive profile (see text for details) with five sampling points (A–E)

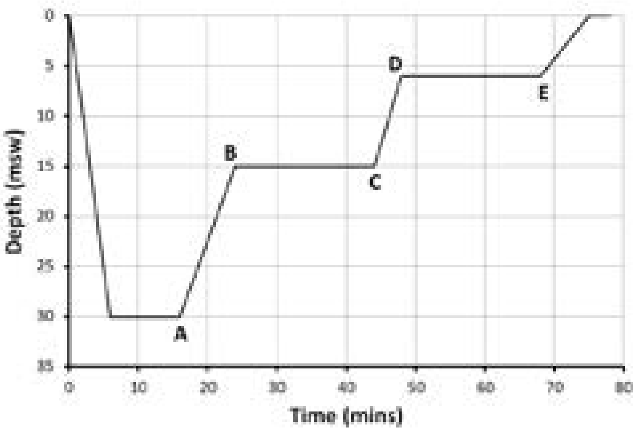
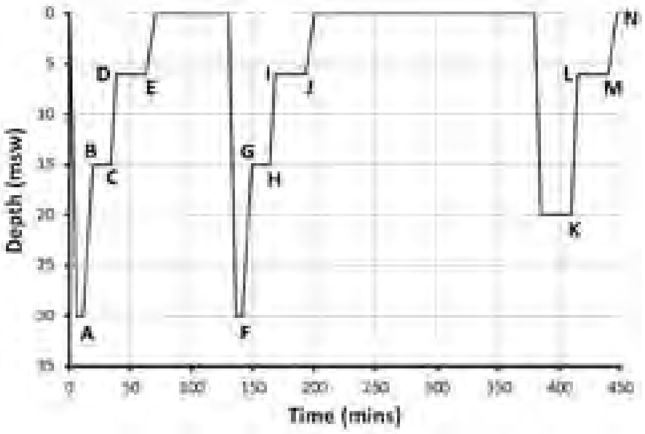


Figure 2
A series of three multi-level depth/time dive profiles (see text for details) with 14 sampling points (A–N)



only modification. Breathing nitrox gas mixtures while using air-based decompression management tools is a stand-alone conservative diving practice that could be recommended by medical practitioners for divers at risk.[9,11,12] We also review adjustments to computers which are untested in the present study but which advisors should be aware of when providing guidance to divers who wish to dive more conservatively.

Methods

Seven models of dive computer were studied, being representative of the current four main manufacturers (*Mares, Suunto, Oceanic* and *UWATEC*; Table 1). Personal settings were described as P values on the *Mares Icon HD*, personal factor (PF) settings on the *Mares Nemo Excel*, *Suunto D9* and *Suunto Vyper Air* and micro-bubble (MB) settings on the two *UWATEC* models; the *Oceanic Atom 2* has simply an On/Off setting for a 'conservatism factor' feature (Table 1). Both *Mares* and *Suunto* models had altitude settings: *Mares* computers had four altitude settings (A0-3; although sometimes given as P0-3) where A0 was for diving at altitudes of 0–700 m, A1 for 700–1,500 m, A2 for 1,500–2,400 m, and A3 for 2,400–3,700 m; *Suunto* computers had three altitude settings (A0–2) where A0 was for diving at 0–300 m, A1 for 300–1,500 m and A2 for 1,500–3,000 m; the *UWATEC* models and the *Oceanic Atom 2* reportedly measured altitude automatically and so they were unable to be tested for these settings in the present study. In all cases where there were multiple settings, it was assumed that the higher numbered settings corresponded with a more conservative approach to decompression management. In addition, the decompression modelling could be altered on the *Suunto* models between the default *Suunto* reduced gradient bubble model (RGBM) 100% and the purportedly less conservative RGBM 50% settings.

Testing took place in a compression chamber located at near sea level following the protocols outlined in a previous paper.[16] The pressure exposures were identical for all the dive computers as they were exposed to the test dive profiles at the same time. Units of pressure are nominally given in metres' sea water (msw); this followed the gauge depth of the chamber used but makes no allowances for the salinity of the water the computers were tested in. Single examples of all seven models were subjected to four independent dive profiles with one dive made per profile for each dive computer:

- square-wave excursion to a nominal depth of 40 msw

held until 30 min of staged decompression had been registered or exceeded;
- square-wave excursion to a nominal depth of 20 msw held until 30 min of staged decompression had been registered or exceeded;
- a multi-level dive to a maximum depth of 30 msw with ascents to 15 and 6 msw, with five sampling points (A–E; Figure 1);
- a series of three multi-level dives: two to maximum depths of 30 msw with ascents to 15 and 6 msw with an one hour surface interval, followed three hours later by a dive to a maximum depth of 20 msw with a single ascent to 6 msw, with 14 sampling points (A–N; Figure 2).

The square-wave profile tests examined the effects of personal settings and altitude settings; the multi-level tests only examined the effects of personal settings; the effects of applying RGBM 100 and 50% were compared on the *Suunto D9* during the multi-dive series. For the two square-wave profiles, downloaded data were used to collate the relative times taken to reach the maximum *no staged decompression limit* (NSDL) and to generate or exceed 3, 5, 8, 10, 12, 15, 20 or 30 min of staged decompression. For the single multi-level dives, downloaded data were sampled after 10 min at the maximum depth 30 msw (Point A), on reaching 15 msw (B), after 20 min at 15 msw (C), on reaching 6 msw (D) and after 20 min at 6 msw (E; Figure 1).

For the series of multi-level dives, downloaded data were sampled after 5 min at the maximum depth 30 msw (A and F; one hour surface interval between dives), on reaching 15 msw (B and G), after 15 min at 15 msw (C and H), on reaching 6 msw (D and I), after 25 min at 6 msw (E and J), after 25 min at 20 msw (K: three hour surface interval between dives two and three), on reaching 6 msw (L), after 25 min at 6 msw (M), and at the surface (N; Figure 2). No replicate tests were made for any of the experiments; data logging rates for the seven computers varied from 1 to 20 s.

Comparisons between computer personal settings and diving enriched air nitrox (EANx) using air-based decompression methods were made on the 20 and 40 msw square-wave profiles; EANx32 (32% oxygen: 68% nitrogen) and EANx36 on the 20 msw profile, and EANx28 was used on the 40 msw profile. EANx28 was chosen as the maximum oxygen content for a depth of 40 msw if the maximum allowable partial pressure of oxygen was set at 1.4 bar; EANx32 and 36 are commonly used recreational breathing gas mixtures. The two square-wave profiles were run for all the personal factor settings to give the dive-times at which the NSDL was reached; the EANx dives used the same dive-times as for the non-modified computers. Hempleman's Exposure Factor (EF)[17] was used to make comparisons:

$$EF = P_{abs}\sqrt{t} \qquad (1)$$

where P_{abs} is the absolute pressure (in bar using the nominal conversion of 1 bar = 10 msw) and t is time (min); the EANx dives used the same equation to generate EF values but these were based on pressure values equivalent to their respective equivalent air depths (EAD):

$$EAD = ((D + 10) \times (FN_2/0.79)) - 10 \qquad (2)$$

where D is gauge depth in msw, and FN_2 is the fraction of nitrogen in the mixture.

Results

20-msw SQUARE-WAVE PROFILE

For all the dive computers tested over the 20-msw square-wave dive profile, the time indicated to reach the nominal endpoints (the NSDL and all of the staged decompression values) was less when personal settings were applied (Table 2). The scale of some of these time variations occasionally varied with exposure; for example the MB3 and MB5 settings for the *UWATEC Galileo Sol* produced time values that were 50 and 21% respectively of those generated by the default (MB0) settings at the NSDL point at 20 msw, but were 80 and 68% respectively of the default value when 30 min of staged decompression was indicated by the computers (Table 2; Figure 3).

In other cases, the scale of variation was almost constant; P1 and P2 settings on the *Mares Icon HD* produced time reductions of 73–79% and 63–67% respectively of the P0 values for all dive durations tested (Table 2; Figure 4). Even when set to a personal setting, some of the less conservative computers produced similar decompression schedules at 20 msw to the more conservative units in default mode (e.g., the *Oceanic Atom 2* in "*On*" mode, compared with the *Mares Nemo Excel* on P0 setting; Table 2). The two *SuuntoD9* exposures that could compare the effect of altering the RGBM setting (A1/RGBM 100% versus A1/RGBM 50%; and A2/RGBM 100% vs A2/RGBM 50%) produced no major differences in NSDL or decompression times (Table 2).

40-msw SQUARE-WAVE PROFILE

A similar trend was observed in the 40-msw test where both *UWATEC* units showed time values converging with increased levels of decompression penalty. Both models when set to MB3 recorded 62% of the MB0 time at the NSDL but 84% when registering 30 min of decompression (Table 3); MB5 values for both units were 47% of the MB0 time values when 10 min of staged decompression was displayed but 72% when the computer displayed 30 min of staged decompression (Table 3). All the other units tested retained almost consistent differences across the nominal decompression penalty scale. For example, the PF1 and PF2 settings on the *Suunto Vyper Air* produced values that were 82–92% and 68–92% of the PF0 time values, respectively (Table 3; Figure 5). When the conservative factor feature was "*On*", the *Oceanic Atom 2* values were always between 86 and 90% of the time values when set to "*Off*" mode (Table 3; Figure 6). As above, the *Oceanic Atom 2* with the conservative factor feature "*On*" produced similar decompression schedules at 40 msw as the *Mares Nemo Excel* on P0 setting (Table 3). Setting the *Suunto D9* to either RGBM 50 or RGBM 100% produced identical NSDL or decompression times (Table 3).

ENRICHED AIR NITROX

The effects caused by employing a range of computer personal settings compared against the use of EANx during the 20 and 40 msw square-wave dive profiles are shown in Tables 4 and 5, respectively. At 20 msw, the computer default settings dived with air generated EF values of 18.2–20.6 at the NSDL (Table 4). At the same time limit, the most conservative settings produced EF values of 8.5–18.2 whereas values for EANx32 and 36 were 15.7–17.7 and 14.8–16.7, respectively. On the 40 msw dive, the default air NSDL EF values ranged 17.3–18.7, the most conservative settings were 14.1–17.3 and EANx28 produced 9.5–10.2 (Table 5).

MULTI-LEVEL DIVE PROFILE

The multi-level dive profile produced mixed responses (Table 6). The decompression management demonstrated by some computer units varied in appearance across the dive profile with both convergence and divergence of the time values being caused by the different settings during the dive (e.g., *Mares Icon HD*). Other units produced more constant differences between the settings (e.g., *Suunto Vyper Air*). Both *Mares* computers displayed missed decompression on surfacing after the multi-level dive when set to the PF1/PF2 and P1/P2 settings. The *Oceanic Atom 2* with the conservative factor feature "*On*" gave similar decompression schedules to the *Mares Icon HD* unit in P0 mode.

MULTI-DIVE SERIES

Results for the multi-dive series shown in Figure 2 are presented in Table 7. The majority of computer models set to default settings permitted decompression to be managed across all three dives. The exception was the *Mares Nemo Excel* which did not complete decompression after 25 min at 6 msw (point J). In this case, along with the *Mares Nemo Excel* set to PF1 and the *Mares Icon HD* set to P1 at J, and both *Mares* models set to P2 or PF2 at point E, the computers 'locked out' of decompression control and instead converted to 'gauge mode' only (referred to as 'bottom timer' in Table 7). The *Oceanic Atom 2* in both modes and both *UWATEC* models at MB0 and MB1 levels were largely free of decompression obligation across the three dives, with only small amounts of decompression obligation indicated at points H and I during the second dive.

When set to their maximum level of conservatism (MB5), both *UWATEC* models were still indicating the need for staged decompression at the end of the 6 msw stop on the second dive (point J). In both cases, the third dive was permitted and the decompression managed but the computers indicated that this was achieved through a reduction in the MB level.

When set at PF0, the two *Suunto* models managed the decompression for the three dive series even though staged decompression of 4 min was indicated in all cases at the end of the 6 msw stage of dive 2 (J). Irrespective of their RGBM adjustments, when set to PF1 or PF2, both *Suunto* models indicated significant amounts of decompression at point J on dive 2 (38–65 min); neither model locked out and both permitted and managed the decompression of the third dive.

There were no major differences between the results of the first dive for the *Suunto D9* between the RGBM 50 and 100% adjustments at any of the three PF settings. At the end of the 30 msw stage of the second dive (F), the RGBM 50% setting indicated longer bottom times at each PF setting. This relationship continued when the computer was set to PF0; for most of the second dive (G-I), the RGBM 50% adjustment either indicated longer bottom or shorter staged decompression times. A much shorter decompression time was indicated at PF1 for the RGBM 50% adjustment at the beginning of the 15 msw stage in dive 2 (G) but apart from that, there were no major differences indicated between the RGBM 50 and 100% adjustments for the remainder of the dive series.

Discussion

The main reason for undertaking the present study was to evaluate whether reasonable guidance could be provided to divers needing or wishing to dive more conservatively, or to the diving medical experts advising them, through modifying the decompression management provided by dive computers when adjusted by user-settings. This guidance could, for example, be used in support of the need to dive more conservatively following diagnosis of a PFO that may produce an increased DCI risk (Statement 5: joint position statement on PFO and diving of SPUMS and the UKSDMC).[12] Some guidance will be suggested at the end of this Discussion; however, the strength of that guidance will be compromised by the range in responses of the dive computers tested. This is in addition to the existing range in decompression strategies reported previously.[16,18–20] The present study was limited to single examples of seven dive computers and was based on single examples of the chosen range of diving exposures. Previous studies have shown relatively standard responses by dive computers tested over a series of replicated pressure/time exposures.[16]

In all the profiles tested, adjusting the user settings by increasing the personal factors and/or adding altitude levels,

Table 2
Dive times required to reach the no staged decompression limit (NSDL) or to generate 3−30 min of staged decompression* for a square-wave dive profile to 20 msw expressed as time (t) min or percentage change of default setting (Δ%); results are for seven models of dive computer set to varying settings; MB − microbubble level; P − personal setting; PF − personal factor; A − altitude; RGBM − reduced gradient bubble model; blank cells − missing data; *n* = 1 in each case

Brand & Model	Settings	NSDL		3 min		5 min		10 min		15 min		20 min		30 min	
		t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%
Mares															
Icon HD	P0	41	100	42	100.0	44	100	50	100	54	100	57	100	64	100
	P1	30	73			33	75	39	78	42	78	45	79	49	77
	P2	26	63			28	64	33	66	35	65	37	65	40	63
	P0/A1	24	59			26	59	31	62	34	63	36	63	39	61
	P0/A3	12	29			12	27			17	32			18	28
Nemo Excel	PF0	37	100			38	100	46	100	51	100	54	100	61	100
	PF1	31	84			32	84	40	87	44	86	46	85	51	84
	PF2	27	73			27	71	34	74	37	73	38	70	42	69
	P1/A1	27	73			28	74	35	76	37	73	40	74	43	71
	P3 /A3	15	41			15	40	19	41	21	41	21	39	22	36
Suunto															
D9	PF0/RGBM 100%	41	100	42	100	46	100	50	100	54	100	60	100	74	100
	PF1/RGBM 100%	32	78	33	79	37	80	42	84	45	83	49	82	62	84
	PF2/RGBM 100%	26	63	26	62	28	61	34	68	37	69	40	67	49	66
	A1/RGBM 100%	33	81	33	79	37	80	42	84	45	83	49	82	62	84
	A1/RGBM 50%	33	81	33	79	37	80	42	84	45	83	49	82	62	84
	A2/RGBM 100%	25	61	26	62	28	61	34	68	37	69	40	67	49	66
	A2/RGBM 50%	26	63	26	62	28	61	34	68	37	69	40	67	49	66
Vyper Air	PF0/RGBM 100%	40	100	41	100	45	100	49	100	54	100	59	100	73	100
	PF1/RGBM 100%	32	80	33	81	37	82	41	84	45	83	49	83	62	85
	PF2/RGBM 100%	25	63	26	63	28	62	34	69	36	67	39	66	49	67
	A1/RGBM 100%	33	83	33	81	37	82	41	84	45	83	49	83	62	85
	A2/RGBM 100%	25	63	26	63	28	62	34	69	36	67	40	68	49	67
Oceanic															
Atom 2	Off	47	100	47	100	51	100	55	100	59	100	64	100	76	100
	On	37	79	37	79	41	80	46	84	49	83	52	81	61	80
UWATEC															
Galileo Sol	MB 0	38	100	39	100	44	100	47	100	51	100	56	100	69	100
	MB 3	19	50	21	54	29	66	38	81	43	84	47	84	55	80
	MB 5	8	21	10	26	15	34	22	47	31	61	40	71	47	68
Tec 2G	MB 0	38	100	39	100	44	100	47	100	51	100	56	100	69	100
	MB 3	19	50	21	54	28	64	38	81	43	84	47	84	55	80
	MB 5	8	21	10	26	15	34	21	45	30	59	39	70	46	67

reduced the NSDL, reduced the dive time taken to generate nominal staged decompression values and/or increased the amount of staged decompression required. Only one user setting, RGBM 50% on the *Suunto* computers, was capable of reducing conservatism. This was a setting possibly used incorrectly in a case reported previously if the intention was to generate more conservative diving, although that in itself was not the reason for the eventual poor outcome.[15] The results from the present study suggest that adjusting the settings to RGBM 50% has limited effect within the context of the typical types of recreational diving.

An altitude setting was also used in the reported case to increase safety. It is probably prudent to advise divers to only employ altitude settings when diving at altitude as that is their design purpose. However, there are examples in the present study that indicate that some computer models apply the same penalties irrespective of the actual settings used. In the *Mares* and *Suunto* computers, which had manual altitude settings, the effect of the addition of an altitude penalty was nearly identical to a matching personal setting. In both the 20 and 40 msw tests, both *Mares* computers displayed near identical times to reach the nominal decompression times when set at either P2 or PF2, or at the matching P0/A1 or P1/

*** Footnote:**
The data for 8 min and 12 min decompression times are not shown in this table but are available from the author at <*mdjs@sams.ac.uk*>

Table 3
Dive times required to reach the no staged decompression limit (NSDL) or to generate 5–30 minutes of staged decompression for a square-wave dive profile to 40 msw expressed as time (t) min or percentage change of default setting (Δ%); results are for seven models of dive computer set to varying settings; MB − microbubble level; P − personal setting; PF − personal factor; A − altitude; RGBM − reduced gradient bubble model; blank cells − missing data; n = 1 in each case; † gave 62 minutes of decompression after a dive time of 11 min

Brand & Model	Settings	NSDL		5 min		10 min		15 min		20 min		30 min	
		t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%	t	Δ%
Mares													
Icon HD	P0	12	100	13	100	17	100	20	100	22	100	26	100
	P1	11	92			15	88	18	90	20	91	22	85
	P2	10	83			13	77	16	80	17	77	19	73
	P0/A1	10	83			14	82	15	75	17	77	19	73
	P0/A3					8	47			10	46	†	†
Nemo Excel	PF0	12	100			16	100	20	100	23	100	26	100
	PF1	11	92			15	94	18	90	20	87	23	89
	PF2	10	83			13	81	16	80	18	78	20	77
	P1/A1	10	83			13	81	15	75	18	78	20	77
	P3 /A3					8	50	10	50	11	48	11	42
Suunto													
D9	PF0/RGBM 100%	12	100	12	100	19	100	22	100	24	100	27	100
	PF1/RGBM 100%	11	92	11	92	16	84	19	86	20	83	23	85
	PF2/RGBM 100%	10	83	10	83	14	74	16	73	18	75	20	74
	A1/RGBM 100%	11	92	11	92	16	84	19	86	20	83	23	85
	A1/RGBM 50%	11	92	11	92	16	84	19	86	20	83	23	85
	A2/RGBM 100%	10	83	10	83	14	74	15	68	18	75	20	74
	A2/RGBM 50%	10	83	10	83	14	74	15	68	18	75	20	74
Vyper Air	PF0/RGBM 100%	12	100	12	100	18	100	22	100	23	100	27	100
	PF1/RGBM 100%	11	92	11	92	16	89	18	82	20	87	23	85
	PF2/RGBM 100%	10	83	11	92	14	78	15	68	17	74	20	74
	A1/RGBM 100%	10	83	10	83	16	89	18	82	20	87	23	85
	A2/RGBM 100%	10	83	11	92	14	78	15	68	17	74	20	74
Oceanic													
Atom 2	Off	14	100	16	100	20	100	22	100	25	100	28	100
	On	12	86	14	88	18	90	19	86	22	88	24	86
UWATEC													
Galileo Sol	MB 0	13	100	13	100	19	100	21	100	22	100	25	100
	MB 3	8	62	9	69	13	68	16	76	19	86	21	84
	MB 5					9	47	12	57	14	64	18	72
Tec 2G	MB 0	13	100	13	100	19	100	21	100	22	100	25	100
	MB 3	8	62	8	62	13	68	16	76	19	86	21	84
	MB 5					9	47	12	57	14	64	18	72

A1 levels (Tables 2 and 3). Similarly, there was no difference in performance of both *Suunto* computers if they were set to either PF1 or A1, or PF2 or A2 at RGBM 100% during either the 20 or 40 msw tests (Tables 2 and 3). However, this is not the case for all computers (see below).

Figures 3 to 6 illustrate the overall responses to differing levels of conservatism of some of the tested dive computers measured over dive series that had a range of NSDL and staged-decompression endpoints. A set of curves that were parallel would indicate that the penalties being applied were probably in the form of a relatively simple adjustment that was proportionate to the time taken to reach each nominal decompression value when unmodified. If the adjustments were achieved through a simple set-time penalty then the relationships would converge, while a set of curves that were diverging would suggest that progressively larger penalties were being applied with increasing decompression stress. Determining the exact relationships was complicated by the variable precision of the data that were retrievable from the download information plus some of the relatively large step changes in those data. Although it is possible that all three relationships (and thus all three methods of computer modification) were present in the recorded curve sets, the differences were slight. What was evident, however, was that there were no recorded instances where a markedly accelerated termination of the dive was indicated by a computer being subjected to what may be considered unwise diving practices (i.e., a considerable accumulation in the amount of staged decompression) for a diver who has employed some or many levels of conservatism.

Table 4

Hempleman's Exposure Factor (EF) values for seven models of dive computer calculated at the maximum no staged decompression limit (NSDL) at 20 msw; comparisons are between breathing air against breathing enriched air nitrox (EANx) with 32 or 36% oxygen (EANx32 or EANx36) when at the default computer settings; EF values are also given for other dive computer personal settings

Brand	Model	Settings	NSDL Air	NSDL EANx32	NSDL EANx36
Mares	Icon HD	P0	19.2	16.5	15.6
		P1	16.4		
		P2	15.3		
		P0/A1	14.7		
		P0/A3	10.4		
Mares	Nemo Excel	PF0	18.2	15.7	14.8
		PF1	16.7		
		PF2	15.6		
		P1/A1	15.6		
		P3 /A3	11.6		
Suunto	D9	PF0/RGBM 100%	19.2	16.5	15.6
		PF1/RGBM 100%	17.0		
		PF2/RGBM 100%	15.3		
		A1/RGBM 100%	17.2		
		A2/RGBM 100%	15.0		
Suunto	Vyper Air	PF0/RGBM 100%	19.0	16.3	15.4
		PF1/RGBM 100%	17.0		
		PF2/RGBM 100%	15.0		
		A1/RGBM 100%	17.2		
		A2/RGBM 100%	15.0		
Oceanic	Atom 2	Off	20.6	17.7	16.7
		On	18.2		
UWATEC	Galileo Sol	MB 0	18.5	15.9	15.0
		MB 3	13.1		
		MB 5	8.5		
UWATEC	Tec 2G	MB 0	18.5	15.9	15.0
		MB 3	13.1		
		MB 5	8.5		

Figure 3

Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *UWATEC Galileo Sol* dive computer subjected to a 20-msw profile and set to microbubble settings 0 (MB0, black), 3 (MB3, dark grey) and 5 (MB5, light grey); MB0: $y = 1.008x + 37.239$, $R^2 = 0.983$; MB3: $y = 1.227x + 22.287$, $R^2 = 0.920$; MB5: $y = 1.414x + 8.040$, $R^2 = 0.972$

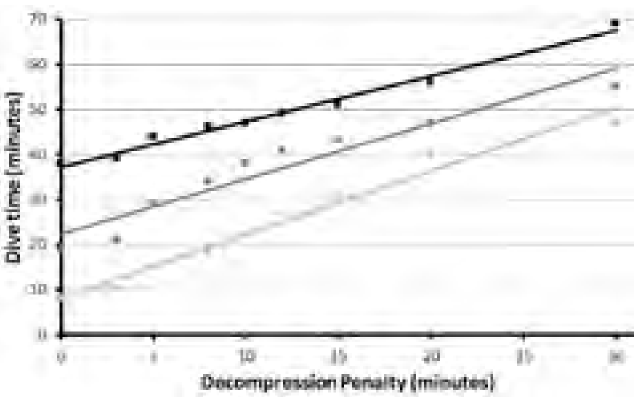


Figure 4

Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *MARES Icon HD* computer subjected to a 20-msw profile and set to personal settings 0 (P0, black), 1 (P1, dark grey) and 2 (P2, light grey); P0: $y = 0.8008x + 41.058$, $R^2 = 0.9817$; P1: $y = 0.6464x + 31.42$, $R^2 = 0.948$; P2: $y = 0.4712x + 27.235$, $R^2 = 0.932$

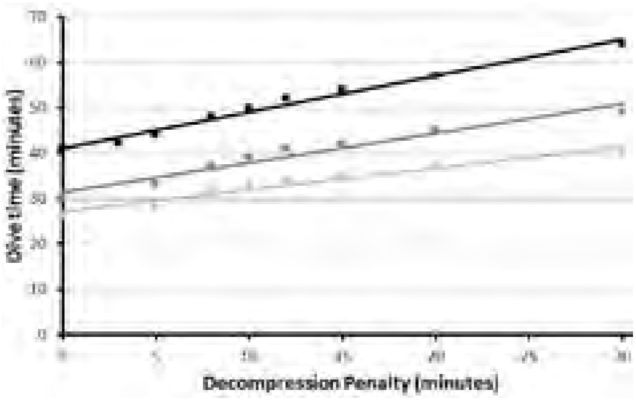


Table 5

Hempleman's Exposure Factor (EF) values for seven models of dive computer calculated at the maximum no staged decompression limit (NSDL) at 40 msw; comparisons are between breathing air against breathing enriched air nitrox (EANx) with 28% oxygen (EANx28) when at the default computer settings; EF values are also given for other dive computer personal settings

Brand	Model	Settings	NSDL	
			Air	EANx28
Mares	Icon HD	P0	17.3	9.5
		P1	16.6	
		P2	15.8	
		P0/A1	15.8	
Mares	Nemo Excel	PF0	17.3	9.5
		PF1	16.6	
		PF2	15.8	
		P1/A1	15.8	
Suunto	D9	PF0/RGBM 100%	17.3	9.5
		PF1/RGBM 100%	16.6	
		PF2/RGBM 100%	15.8	
		A1/RGBM 100%	16.6	
		A2/RGBM 100%	15.8	
Suunto	Vyper Air	PF0/RGBM 100%	17.3	9.5
		PF1/RGBM 100%	16.6	
		PF2/RGBM 100%	15.8	
		A1/RGBM 100%	15.8	
		A2/RGBM 100%	16.6	
Oceanic	Atom 2	Off	18.7	10.2
		On	17.3	
UWATEC	Galileo Sol	MB 0	18.0	9.9
		MB 3	14.1	
UWATEC	Tec 2G	MB 0	18.0	9.9
		MB 3	14.1	

The responses to the multi-level dive profile are even more complex to determine as the decompression stress does not increase linearly as would be expected in a square-wave pressure exposure. When registering a staged decompression obligation between points B and D (Figure 1), the trends for the computers set to a personal factor setting tended towards a form of parallel relationship between the conservative levels that, again, suggested either a consistent set value or proportional mathematical adjustment was being made.

The range of decompression strategies employed by dive computers means that there is the potential for overlap between computers that have some personal settings turned on and those that are still on default settings. This was repeatedly the case in this present study where the *Oceanic Atom 2* computer set to 'conservative factor ON' produced similar results to the *Mares* computers on default. The decompression algorithm in the *Oceanic Atom 2* is a modified version of the *DSAT* (Diving Science and Technology) tables that also employs some US Navy decompression theory to extrapolate outside of the *DSAT* tables for decompression dives and/or dives deeper than 27 msw.[14,21] Newer versions of *Oceanic* dive computers now employ dual decompression algorithms: the *DSAT* algorithm is now called the *Pelagic DSAT* and there is an added algorithm, the *Pelagic Z+*, based on the Bühlmann ZHL-16C decompression model.[22] Although amongst the least conservative of the dive computers tested here and in previous studies,[16] the *Oceanic* computers employing the *DSAT* algorithm are supposed to impose additional restrictions for repetitive decompression dives.[22] The *Pelagic Z+* algorithm, however, will produce NSDLs that are considerably more conservative, especially at shallower depths. The dual algorithm *Oceanic* computers default to the less conservative *DSAT* algorithm and require to be physically altered to *Pelagic Z+*.[22]

Figure 5

Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *Suunto D9* dive computer subjected to a 40-msw profile and set to personal settings PF0 (black), PF1 (dark grey) and PF2 (light grey); PF0: $y = 0.549x + 12.269$, $R^2 = 0.911$; PF1: $0.434x + 11.072$, $R^2 = 0.924$; PF2: $y = 0.3692x + 9.760$, $R^2 = 0.943$

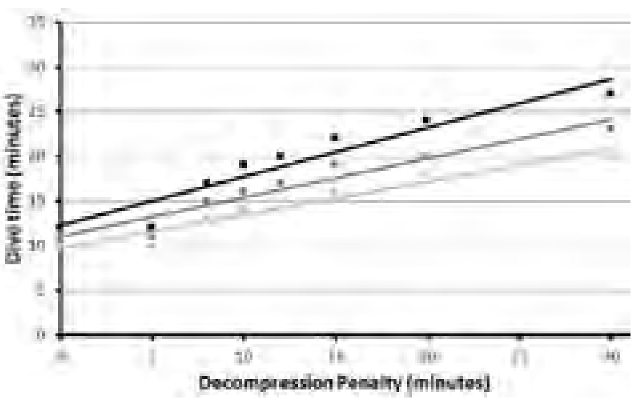


Figure 6

Scatter and linear regression relationships between decompression penalty and the dive time required to generate that penalty for the *Oceanic Atom 2* dive computer subjected to a 40-msw profile and set to 'conservatism factor Off' (black), and 'On' (grey); Off: $y = 0.549x + 12.269$, $R^2 = 0.911$; On: $0.410x + 11.631$, $R^2 = 0.967$

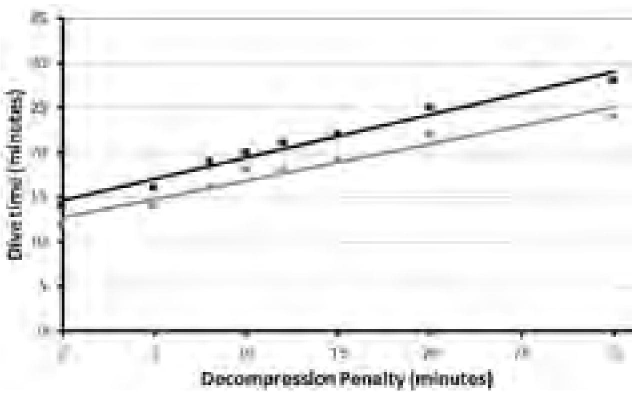


Table 6

Decompression times (min) given by seven models of dive computer with varying settings taken at five points (A–E) on a multi-level dive profile to a maximum depth of 30 msw (Figure 1 and text); positive values denote a staged decompression penalty; negative values are the times available before reaching the no staged decompression limit (NSDL); values of -99 and -199 denote that the computer had cleared of any decompression obligation; surface values are only given where there was missed decompression; all *Suunto* settings were at RGBM 100%; 'deepstop' is where a deep stop was indicated on the download but no other decompression information was given

Brand/Model	Settings	A	B	C	D	E	Surface
Mares							
Icon HD	P0	-2	-13	5	2	-99	
	P1	0	6	16	18	12	10
	P2	7	9	36	36	30	28
Nemo Excel	PF0	-3	deepstop	deepstop	-99	-99	
	PF1	5	4	12	15	9	3
	PF2	5	7	31	32	26	21
Suunto							
D9	PF0	-4	-27	-7	-99	-99	
	PF1	0	4	11	11	4	
	PF2	4	9	23	22	17	
Vyper Air	PF0	-5	-26	-7	-99	-99	
	PF1	0	4	12	11	0	
	PF2	4	10	23	23	15	
Oceanic							
Atom 2	Off	-6	-37	-18	-99	-99	
	On	-1	-9	4	3	0	
UWATEC							
Galileo Sol	MB 0	-2	-21	-1	-199	-199	
	MB 3	8	9	15	13	2	
	MB 5	15	17	22	20	10	
Tec 2G	MB 0	-2	-21	0	-99	-99	
	MB 3	8	9	15	13	3	
	MB 5	15	18	23	21	11	

There would remain the need, therefore, for a diver relying on setting more conservative personal settings in order to reduce potential decompression stress to still have a good understanding of the relative performance and working of specific dive computer models. To that end, there is relatively little information given by manufacturers in their supporting technical literature for a diver to base informed decisions as to how the computers operate in default or personal setting modes.

Of the computers used in the present study, *Oceanic* provides information on altitude[21] but only the literature supplied for the two *Suunto* models contained tables indicating the effects of personal settings on dive times.[23–25] However, it should be noted that the NSDLs (termed "*no decompression time limits*" in the *Suunto* manuals) quoted for similar computers marketed by *Suunto* do differ markedly.[23,25] For example, *Suunto* markets the *Vyper* dive computer plus the *Vyper Air*. When both models are set to default settings (P0/A0) and dived for the first dive of a series, there is little difference in the NSDL times (Table 8). However, when set to P2/A0, the *Suunto Vyper Air* permits much longer NSDL times than the *Suunto Vyper*; this relationship is reversed when set to P0/A2 (Table 8) and the differences continue at the other combinations of settings.[23,25] This suggests that in this case the manufacturer has, in a newer computer, moved from treating personal settings in the same way as ones used to compensate for diving at altitude. In particular, the penalty scale for altitude diving has increased compared to personal settings. While there will be added conservatism if a diver used altitude settings on a *Suunto Vyper Air* for sea-level diving, the reverse situation where a diver employs personal settings alone for altitude diving may produce dive times that are not as 'safe'. In providing guidance on this, it would reduce the likelihood for confusion if divers were advised only to use the altitude settings for when diving at altitude.

The *Galileo sol* computer gives the user the option of combining the wrist-mounted unit with a heart monitor and a tank pressure transmitter. The diver has the choice of either employing heart or breathing rate as an indicator of 'workload'.[26] A detection of rapid increases in workload will cause the *Galileo* to shorten the NSDLs and further modifications can occur if there is a temperature gradient detected in the water column.[26] Both aspects were not assessed in the present study but indicate that any published decompression data for this model of computer are liable to be modified in some circumstances. Even though many

Table 7

Decompression times (min) given by seven models of dive computer with varying settings taken at 14 points (A–N) on a series of multi-level dives (Figure 2 and text); positive values denote a staged decompression penalty, negative values are the times available before reaching the no staged decompression limit (NSDL); values of -99 and -199 denote that the computer had cleared of any decompression obligation; 'Bottom timer' indicates the computer has locked out of decompression management and now only operates in gauge mode

Brand/Model	**Settings**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
Mares															
Icon HD	P0	-7	-30	-16	-99	-99	-7	-12	4	6	-99	-9	-99	-99	-99
	P1	-4	-13	-2	-99	-99	-4	0	25	26	18	Bottom timer			
	P2	-3	-4	8	13	11	Bottom timer								
Nemo Excel	PF0	-7	-31	-17	-99	-99	-4	-1	15	16	5	Bottom timer			
	PF1	-5	-19	-4	-99	-99	0	19	35	37	27	Bottom timer			
	PF2	-2	-6	6	8	5	Bottom timer								
Suunto															
D9	PF0 RGBM 100%	-10	-38	-23	-99	-99	-3	-2	13	13	4	-10	-99	-99	-99
	PF0 RGBM 50%	-10	-38	-23	-99	-99	-6	-10	7	6	4	-12	-99	-99	-99
	PF1 RGBM 100%	-6	-23	-8	-192	-176	-1	13	33	39	38	-2		-194	
	PF1 RGBM 50%	-6	-23	-8	-199	-172	-4	7	33	39	38	-3		-188	
	PF2 RGBM 100%	-3	-3	7	8	-73	8	26	60	65	65	8	8	3	
	PF2 RGBM 50%	-3	-3	7	8	-76	-1	27	60	65	64	7	7	-93	
Vyper Air	PF0 RGBM 100%	-9	-37	-22	-99	-99	-3	-1	14	13	4	-10	-99	-99	-99
	PF1 RGBM 100%	-5	-22	-7	-192	-176	-1	14	33	40	39	-2		-194	
	PF2 RGBM 100%	-3	-3	7	8	-73	10	27	60	66	65	8	8	-89	
Oceanic															
Atom 2	Off	-11	-48	-34	-553	-528	-9	-31	-16	-379	-355	-17	-318	-294	-599
	On	-6	-30	-16	-375	-350	-6	-13	3	2	-195	-6	-157	-133	-599
UWATEC															
Galileo Sol	MB 0	-7	-32	-17	-199	-199	-7	-13	5	3	-199	-10	-199	-199	-199
	MB 1	-4	-27	-12	-199	-199	-4	-8	8	5	-199	-5	-199	-199	-199
	MB 5	10	11	13	8	-199	10	11	24	20	8	14	8	-199	
Tec 2G	MB 0	-7	-31	-16	-99	-99	-7	-11	6	3	-99	-10	-99	-99	-99
	MB 1	-4	-27	-12	-99	-99	-4	-8	8	6	-99	-5	-99	-99	-99
	MB 5	10	11	13	8	-99	11	11	24	21	9	14	9	-99	

dive computers sold in the EU are stamped with "CE" marks, there is a range in what European Normatives and/or Directives are used to justify this, none of which specifically refer in any detail to decompression management.[27]

The decompression algorithm used by the *Suunto* models examined in the present study employs a specific *Suunto* version of the RGBM but in two user-selectable versions: RGBM 100% and RGBM 50%.[23] The RGBM 100% is the default setting and is described by *Suunto* as giving the "*full RGBM effect*" and is the setting that *Suunto* strongly advises for use.[23] RGBM 50% is termed an "*attenuated RGBM*" that has smaller RGBM effects and which may carry higher risk.[23] This increased risk is shown by longer times to achieve NSDLs and reduced decompression obligations; these were only noticeable on the multi-dive series of this study as would be expected from a model that has a specific factor that accounts more for repetitive diving over periods of many days.[27] Although the effect of the RGBM 50% setting appears limited, it is obviously an adjustment that should not be used by divers seeking to increase their diving safety.

In the multi-dive series (Figure 2; Table 7), the *Oceanic Atom 2* in default mode permitted all three dives without any decompression and only some minor decompression penalties were incurred when the conservative setting was on. The *Mares Icon HD* also incurred minor decompression penalties in default mode but in all its other settings, and for all settings for the *Mares Nemo Excel*, either the third or both the second and third dives were not permitted. The response of the *Mares* models contrasts with those of the *Suunto* and *UWATEC* models which supported a third dive even when there appeared to be missed decompression after the second dive in the series (point J; both *UWATEC* models on the MB5 setting; both *Suunto* models on all settings). Both *UWATEC* models will automatically reduce the MB level set by one if the diver ascends more than 1.5 msw above the required level stop and the diving can continue at that modified MB level; in both cases, successive level stop violations will result in the MB levels dropping down towards or to MB0.[26,28]

The mechanism being employed by the *Suunto* models is

Table 8

NSDL times (min) for the first dive of a series for the *Suunto Vyper* and the *Suunto Vyper Air* for three different personal/altitude setting combinations; times are extracted from the user manuals;[22,24] Δ is the *Vyper* time subtracted for the corresponding *Vyper Air* value

Depth (m)	**P0/A0**			**P2/A0**			**P0/A2**		
	Vyper	**Vyper Air**	**Δ**	**Vyper**	**Vyper Air**	**Δ**	**Vyper**	**Vyper Air**	**Δ**
9	-	205		130	160	30	130	97	-33
12	124	124	0	67	93	26	67	54	-13
15	72	71	-1	43	59	16	43	34	-9
18	52	51	-1	30	43	13	30	24	-6
21	37	37	0	23	31	8	23	17	-6
24	29	29	0	19	25	6	19	11	-8
27	23	22	-1	15	19	4	15	8	-7
30	18	17	-1	12	14	2	12	6	-6
33	13	13	0	9	11	2	9	4	-5
36	11	10	-1	8	9	1	8	4	-4
39	9	8	-1	6	7	1	6	3	-3
42	7	6	-1	5	5	0	5	3	-2
45	6	5	-1	5	4	-1	5	2	-3

less clear. Manuals for both the tested *Suunto* models state that safety stops can be violated but the NSDL time will be reduced for the next dive.[23,24] However, the manuals also state that any violations of the decompression ceiling will result in the computer entering a locked out 'Error mode'. It would be anticipated that all the *Suunto* runs with PF1 or PF2 settings would have violated the decompression ceiling after leaving 6 msw on the second dive (J) because the required decompression was recorded as 38–65 min. The fact that the third dives were all allowed suggests some form of personal factor level cascade, similar to the *UWATEC* models, is also occurring in the *Suunto* computers. For the *UWATEC* and *Suunto* computer models, any advice that recommends the use of additional levels of conservatism must also highlight the cascading effect which could result in less conservative diving occurring part way through a multi-dive series, although only where staged decompression is required.

Using EANx as a breathing gas while employing air-based methods for managing decompression, has been advanced as one method for generating more conservative dive profiles, usually for divers with a PFO who want to avoid closure, or for those returning to diving following closure of a PFO.[9,11,12] The present study compared the use of three EANx mixtures against dive computer personal settings and whereas the use of EANx28 on the 40 msw square-wave profile dive produced a much lower level of decompression stress than the whole range of personal factor settings, using EANX 32 or 36 at 20 msw produced reductions in decompression stress that were no greater than one or two personal factor settings in many cases. There is, of course, a large difference in the PO_2 being breathed at all three combinations; breathing EANx28 at 40 msw has a PO_2 of 1.40 bar whereas EANx32 and 36 at 20 msw have PO_2 of 0.96 bar and 1.08 bar respectively.

The obvious advice, if using nitrox was the only method of delivering conservative dive profiles, would be for the diver to try and use EANx mixtures that deliver PO_2 closer to the maxima for the depths being dived. However, this is rarely possible for recreational divers; diving operators typically only supply a single standard EANx mix which tends to be relatively low in oxygen in order to minimise issues with the management of maximum operating depths, and to avoid the need for separate oxygen-clean diving equipment. Therefore, for dives at relatively shallow depths and with relatively lean EANx mixtures, using EANx alone may not produce the desired levels of conservatism and so the recommendations should include adding in at least one personal factor level on the dive computer in the knowledge that the vast majority of recreational divers use dive computers to manage their decompression.

The present study has focussed on personal and altitude settings on dive computers. Another method by which dive computers can be modified by the user to generate more conservative dive profiles is through the use of gradient factors.[17,29] Gradient factors are another way of modifying the background decompression algorithm in the computer to best suit the diver's own diving preferences; however, similarly to personal factors, gradient factors have yet to be validated in a scientific study. Whereas personal factors appear to be relatively simple proportional re-adjustments made at one to five set levels, gradient factors are used in pairs with, theoretically, dozens of combinations (although there are a much smaller number of typical settings).[29] Gradient factors were, until recently, mainly used by the technical diving sector but their use is increasing in recreational diving and the ability to apply gradient factors using more mainstream recreational dive computers may become more common.

Conclusions

For a diver with a physiological need or a personal wish to dive more conservatively, most dive computers do have user settings to make this possible. However, there is inter-model variability in how more conservative the modified profiles generated are and so, if a diver needs advice on continuing diving with a requirement to reduce DCS risk and intends using a dive computer to manage their decompression, the following recommendations should be considered in addition to other non-dive-computer-related advice.

- Where information exists, the diver should be aware of the baseline level of conservatism of their computer. Additional clues may come from comparing the operation of their computer against those of diving colleagues or by wearing two computers made by different manufacturers and decompressing as guided by the more conservative of the pair. The diver should make themselves aware of the operational implications of a dual-algorithm computer.
- Never use the RGBM 50% settings where available.
- Avoid any staged-decompression diving. In addition to possible increased risks, the computer may automatically cascade down the conservatism levels towards the default algorithm.
- Use higher-level personal factors if more conservatism is required.
- Employ altitude settings only when diving at altitude as that is their design purpose.
- When EANx is used below high PO_2 levels (i.e., in shallow waters with lean EANx mixtures) consideration should be made for adding at least one personal factor level to the dive computer but while still in air mode.
- If a computer 'locks up', or enters error or gauge-only mode, because of a violation then observe the period it becomes locked for (usually 24 h but may be longer when personal settings are applied) and do not dive during that period.

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Conflicts of interest

AS develops diving computers for commercial sale; however, no computer he has been involved in developing is included in the present study.

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Case reports

Inner-ear decompression sickness in nine trimix recreational divers

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Abstract

(Guenzani S, Mereu D, Messersmith M, Olivari D, Arena M, Spanò A. Inner-ear decompression sickness in nine trimix recreational divers. *Diving and Hyperbaric Medicine*. 2016 June;46(2):111-116.)

Introduction: Recreational technical diving, including the use of helium-based mixes (trimix) and the experimentation of new decompression algorithms, has become increasingly popular. Inner-ear decompression sickness (DCS) can occur as an isolated clinical entity or as part of a multi-organ presentation in this population. Physiological characteristics of the inner ear make it selectively vulnerable to DCS. The inner ear has a slower gas washout than the brain thus potentially making it more vulnerable to deleterious effects of any bubbles that cross a persistent foramen ovale (PFO) and enter the basilar artery, whilst the inner ear remains supersaturated but the brain does not.

Methods: A questionnaire was made widely available to divers to analyse the incidence of inner-ear DCS after technical dives. One-hundred-and-twenty-six divers submitted completed questionnaires, and we studied each incident in detail.

Results: Nine (7.1%) of the 126 responders reported to have had at least one episode of inner-ear DCS, of which seven occurred without having omitted planned decompression stops. Of these seven, four suffered from DCS affecting just the inner ear, while three also had skin, joint and bladder involvement. Five of the nine divers affected were found to have a PFO. All affected divers suffered from vestibular symptoms, while two also reported cochlear symptoms. Three divers reported to have balance problems long after the accident.

Conclusions: This small study is consistent with a high prevalence of PFO among divers suffering inner-ear DCS after trimix dives, and the pathophysiological characteristics of the inner ear could contribute to this pathology, as described previously. After an episode of DCS, vestibular and cochlear injury should always be examined for.

Key words

Decompression illness; helium; scuba/open circuit; rebreathers/semi-closed circuit; rebreathers/closed circuit; persistent (patent) foramen ovale (PFO); case reports

Introduction

During the last 20 years, recreational divers interested in exploring deep wrecks, caves and reefs have understood the importance of improving their diving techniques to avoid injury and to increase their enjoyment during these deeper dives. These objectives have been achieved using enhanced diving equipment and techniques and breathing gases different from air. These so-called recreational technical dives utilizing helium-based mixed gases (trimix) have become increasingly popular.[1] Compared to nitrogen, helium is non-narcotic and its lower density makes it easier to breath at high pressures. Gas-switches to hyperoxic nitrox/trimix mixes are often used during ascent to make decompression more efficient.[2,3]

Technical diving carries a greater risk of decompression sickness (DCS), mainly related to the greater depths and prolonged bottom times associated with this type of diving. The vestibulo-cochlear end organ of the inner ear can be damaged by inert gas bubble formation in DCS.[2] For a useful summary of the potential mechanisms of inner ear DCS, readers are referred to a recent review published in this journal,[4] based on previous theoretical and epidemiological studies.[5–8]

Reports describing inner-ear DCS in technical trimix divers are limited, so in this paper we present the case histories of nine divers who responded to a widely distributed, on-line questionnaire sent to technical divers in Europe to assess the occurrence of inner-ear DCS in this form of recreational diving.

Methods

The study was conducted between September 2014 and February 2015. An on-line questionnaire* in English and Italian was distributed to recreational trimix divers using mailing lists and social networks (GUE-mailing list, DIR-Germany mailing list, DIR-Italy mailing list, Facebook). Eligibility criteria for respondents were recreational technical divers having a trimix diving certification and at least five dives after their training course. Divers were asked to provide anthropometric data, number of dives in their career and any occurrence of inner-ear DCS after trimix dives. Divers who had suffered from inner-ear DCS were

*** Footnote:** Questionnaire available on request to the author <*silvia.guenzani@gmail.com*>.

Table 1
Summary of nine divers with inner-ear DCS injury and their symptoms; BMI – body mass index; CCR – closed-circuit rebreather; DCS – decompression sickness; OC – open-circuit scuba; PFO – persistent foramen ovale; SCR – semi-closed circuit rebreather;

Case	Age (y)	BMI (kg·m^{-2})	Total dives	Trimix dives	Equipment	Decompression model Gradient factors	Omitted stops	Isolated inner-ear DCS	Side	Vestibular symptoms	Cochlear symptoms	Long-term symptoms	PFO	Restart diving
1	41	23.3	2,500	350	OC	Buhlmann; 20/80	No	Yes	?	Yes	No	No	Yes	Yes
2	50	26.1	500	60	SCR	Buhlmann; 20/80	Yes	Yes	?	Yes	No	Imbalance	Yes	No
3	33	29.3	900	150	SCR	Buhlmann; 20/80	No	No	?	Yes	No	No	?	Yes
4	46	27.4	1,200	250	OC	Ratio method	No	No	?	Yes	No	No	Yes	Yes
5	55	31.5	405	68	OC	Buhlmann; 10/90	No	Yes	?	Yes	Yes	Imbalance	Yes	Yes
6	61	23.7	1,500	400	OC	Buhlmann; 20/80	No	Yes	Right	Yes	No	No	Yes	Yes
7	46	24.4	5,000	2,000	OC	Ratio method	No	Yes	Right	Yes	Yes	Imbalance	No	Yes
8	57	28.1	1,500	1,000	CCR	VPM 2	No	No	Right	Yes	No	No	No	Yes
9	37	21.8	2,000	350	SCR	VPM 2	Yes	No	Left	Yes	No	No	No	Yes

subsequently contacted directly by the authors to gather further information about their accidents. We analysed every case report and considered as inner-ear DCS only those episodes that were diagnosed and treated by hyperbaric physicians. Written permission was obtained from all the divers with diagnosed inner-ear DCS to publish their data and details of each case report.

Data analysis was performed using Prism 6 Graph Pad. Data is presented as mean (range) for continuous variables and as frequency for discrete variables.

Results

One-hundred-and-twenty-six divers completed the questionnaires (89.6% male, 10.4% female). Mean age was 44 (range 25–69) years and mean body mass index 24.7 (range 17.6–41) kg·m^{-2}. The median total number of dives in their career was 1,000 (range 153–6,500), and the median number of trimix dives 200 (range 5–4,000). Nine divers (7.1%), all male, reported having suffered from inner-ear DCS after a trimix dive (diagnosis confirmed by a hyperbaric physician). A summary of the cases appears in Table 1.

Seven divers suffered from inner-ear DCS without having omitted planned decompression stops. Of these seven subjects, four suffered from isolated inner-ear DCS, whilst three also had skin, joint and bladder involvement. Of the four divers with isolated inner-ear DCS, three were discovered to have a PFO after the accident, whilst the fourth diver's test was reported as negative but was performed without bubble contrast.

All nine divers suffered from vestibular symptoms, but only two reported tinnitus or hearing loss. The right ear was affected in three cases, the left in one whilst the other subjects' diagnosis did not specify the side of the injury. Considering long-term follow up, no subjects were examined subsequently for vestibular function,[8] despite three divers complaining of on-going balance problems. Hearing damage was not reported in the four divers who underwent a hearing test, this was normal post treatment. All but one subject has started diving again; the ninth diver is awaiting closure of his PFO.

CASE 1

This 41-year-old diver who had logged 350 mixed-gas dives suffered inner-ear DCS on two occasions using open-circuit (OC) trimix. The first dive was for a bottom time (BT) of 45 minutes (min) to a maximum depth of 84 metres of water (mw) using a bottom mix of 13% oxygen and 67% helium (13/67, residuum nitrogen) and, on ascent, nitrox 50 % (nitrox50) from 21 mw and oxygen (O_2) from 6 mw for decompression. The diver followed a Bühlmann algorithm with gradient factors of 20/80. The second dive, some months later, was for a 50 min BT to a maximum depth of

45 mw, using a bottom mix of 21/35 and nitrox50 from 21 mw on the ascent using the 'ratio deco' method. In neither dive were decompression obligations missed. No problems with equalisation occurred during either descent.

Symptoms included severe nausea and vomiting, vertigo, balance problems and nystagmus appearing within 10 min of the dive in the first incident and 90 min in the second. The victim was given high concentration O_2 and transferred to the nearest recompression chamber. On both occasions, he was recompressed on a US Navy Treatment Table 6 (USN T6) with a good response. After the second incident, he tested positive for a persistent foramen ovale (PFO) and decided to undergo surgery, following which he resumed diving. There does not appear to be any residual damage to cochlear or vestibular function, but he has not undergone any specific testing.

CASE 2

This 50-year-old diver, with 60 trimix dives, dived for a BT of 30 min to a max. depth of 60 mw, using a semi-closed rebreather (SCR); bottom mix was 21/35, 50/25 from 21 mw and O_2 from 6 mw. Decompression was planned according to a Bühlmann algorithm using gradient factors 20/80. The subject noticed something wrong during his gas switch at 21 mw, as indicated by his oxygen partial pressure (PO_2) monitor, which showed a PO_2 lower than expected, but he assumed the sensor was providing an erroneous output. At 15 mw, he switched momentarily to pure oxygen to test the sensors, noting a PO_2 of 2.1 bar (213 kPa) and concluding the sensor was reading correctly. The decompression stops were carried out as planned. On reaching the surface, he experienced vomiting and vertigo and was taken to the nearest recompression chamber where he underwent a USN T6 with a good response. Subsequent to the incident, the subject had an echocardiogram which showed a PFO and he is awaiting surgery. He reports on-going imbalance issues at times but has never undergone a specific medical exam to test vestibular function.

Comment: Following the incident, gas analysis showed that the 21-m cylinder had a 33/45 mix not nitrox50, so less O_2 than planned. The diver had not analysed the cylinder himself before the dive. Using Decompression Planner software and a Bühlmann algorithm with gradient factors 20/80, the same as used by the diver for his profile but with the actual gases used, 20 min of decompression had been omitted in the 21–9 mw range.

CASE 3

This 33-year-old diver, with 150 mixed gas dives was diving in a lake using a SCR. The diving profile was a V-shaped bounce dive with a BT of approximately 2 min to a max. depth of 140 mw using a bottom mix 12/60 and decompression mixes of 20/50 from 75 mw, 38/30 from 39 mw, 55/15 from 24 mw and oxygen from 6 m depth. At a depth of 30 mw, he had a strange feeling in the elbow which persisted during the ascent. At 9 mw, he started feeling nauseated but this went away after a short time on oxygen at the 6 mw stop. The subject followed the algorithm suggested by his dive computer (Bühlmann gradient factors 20/80) with an extension of the decompression time because of the pain he experienced at depth.

Approximately 10 min post dive, he developed vertigo and was unable to walk without holding on to fixed objects for stabilization. He was rapidly transferred to a hyperbaric chamber and recompressed following a COMEX 30 table. The following day, he underwent a second hyperbaric treatment at 253 kPa for a total treatment time of 150 min. At the end of this treatment he was asymptomatic. Some months later, he started to dive again. He claims to be asymptomatic concerning both hearing and balance but has not undergone any specific medical examination. Neither was echocardiography performed to examine for the presence of a PFO.

CASE 4

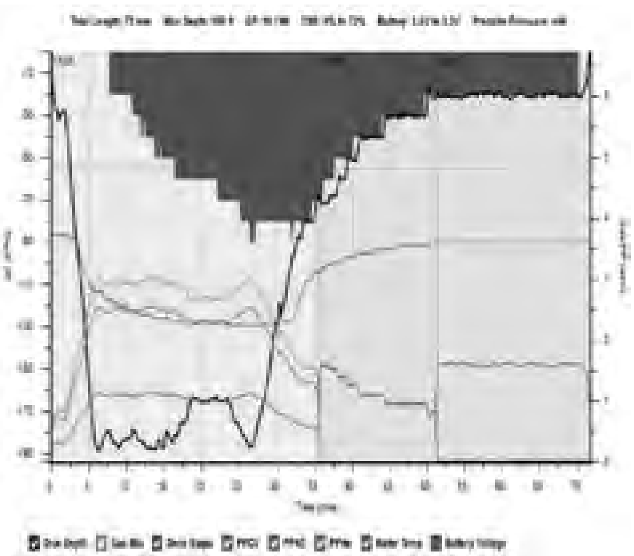
A 46-year-old diver, with 250 trimix dives, undertook a wreck dive using OC-scuba for a BT of 45 min to a max. depth of 57 mw. The bottom mix was 18/45 and decompression gases nitrox50 from 21 mw and O_2 from 6 mw. Following the 'ratio deco' method, no decompression stops were omitted and the other team members did not suffer any symptoms post dive. After 20 minutes on the surface the subject experienced vertigo, difficulty with balance, a skin rash and hypersensitivity to sunlight. He was treated with surface O_2 and subsequently taken to the nearest hyperbaric chamber. In the hospital, the diver had a chest X-ray, which was normal, and subsequently underwent a USN T6, resulting in complete resolution of his symptoms.

On two separate occasions after this incident, he reported DCI symptoms (skin rash) after trimix dives, so he decided to undergo an echocardiography which showed a PFO. This was repaired and he subsequently resumed diving. He also underwent a hearing test, which was normal, and has no balance problems.

CASE 5

This 55-year-old diver, with 68 trimix dives, undertook a wreck dive in a lake using OC-scuba. The dive profile was a BT of 25 min to a max. depth of 63 mw, with a total run time of 75 minutes. Bottom mix was 17/45, then nitrox50 from 21 mw and O_2 from 6 mw for decompression. No planned decompression was omitted according to the Bühlmann algorithm with gradient factors 10/90 (Figure 1). The subject claims to have started feeling sinus pressure during the 6 mw stop on O_2. Then 15 minutes after surfacing, severe vertigo, tinnitus and hypersensitivity to light and sound

Figure 1
Case 5 dive profile (downloaded from the diver's Shearwater™ computer)



developed. The Coast Guard happened to be on board for a routine inspection, so the diver was taken by their vessel to the nearest harbour where an ambulance was waiting to take him to the nearest hyperbaric chamber. He was recompressed with a USN T6. He received six more daily 2-h hyperbaric oxygen treatments, by which time he had improved considerably.

He resumed recreational diving, but decided to stop trimix technical diving activity. He also underwent echocardiography which showed the presence of a PFO. His vestibular or cochlear function were not tested, but he reports that, under certain circumstances, he still gets occasional episodes of imbalance, like riding a bike across a narrow bridge or going through a tunnel.

CASE 6

This 61-year-old diver, with 405 trimix dives, was on a wreck dive using OC-scuba with a BT of 20 min to a max. depth of 95 mw. Bottom mix was 15/65 and decompression gases 35/25 from 36 mw, nitrox50 from 21 mw and O_2 from 6 mw. During ascent, no decompression stops were omitted according to a Bühlmann algorithm with gradient factors 20/80. He experienced sudden onset of vertigo post dive while hauling up the boat's anchor. He was immediately administered surface O_2 until eventually arriving at the recompression chamber. He remined at the first hospital, which did not have an operational chamber, for about four hours whilst undergoing various tests including a brain CT scan before being transferred to a hyperbaric chamber. He was recompressed on a USN T6 with a two-hour extension, at the end of which he was asymptomatic. The diagnosis was right-sided inner-ear DCS.

Subsequent transthoracic echocardiography revealed the presence of a PFO. He chose not to have this closed and resumed diving as he was asymptomatic and a hearing test was normal. About one year later, he experienced sudden hearing loss in the right ear, which resolved spontaneously. Both a hyperbaric medicine physician and otolaryngologist excluded the possibility that this could have been related to the DCS incident.

Comment: This dive had the same decompression profile as another one a year before on the same wreck. The differences were that he had to haul up the anchor post dive on the incident dive and that he was colder because some water had entered his drysuit. It is not uncommon to see the onset of DCI symptoms at the time of or shortly after post-dive exertion.

CASE 7

This 46-year-old diver, with over 2,000 trimix dives using OC-scuba, dived to a max. depth of 45 mw for a 20 min BT using 21/35 as bottom mix and nitrox50 for decompression from 21 mw. No decompression stops had been omitted following the 'ratio deco' model. He did not "*feel right*" just after surfacing and developed tinnitus and heard crackling in the ear(s). After using a nasal spray to try to clear the ear, symptoms quickly deteriorated and as he was walking to obtain O_2 he collapsed from vertigo.

He was taken to a hospital and upon arriving was diagnosed with complete loss of hearing in the right ear. Despite this, he was sent home even though he had difficulty walking and maintaining a straight line without vomiting. The following day, he visited an ear specialist who confirmed there was no ear barotrauma. The diver then insisted on being referred to a hyperbaric chamber for treatment. A diagnosis of right-sided inner-ear DCS was made and, after receiving a USN T6, he felt much better. His tinnitus subsided completely over two weeks and a hearing test was normal. A transthoracic echocardiography, but without bubble contrast, did not demonstrate a PFO. He still experiences intermittent episodes of imbalance.

Comment: A past history that might be relevant included a bicycle crash a few months earlier, in which he fractured his right cheekbone. He also reported that he had slipped on a wet floor a few days before this dive, again striking the right side of his head.

CASE 8

This 57-year-old diver, with 1,000 trimix dives, undertook a wreck dive using a closed-circuit rebreather (CCR) with a BT of 30 min to a max. depth of 90 mw. Bottom mix was 8/60, with the PO_2 held at 1.2 bar (121 kPa) during the BT and 1.4 bar (143 kPa) during the ascent. Decompression stops were calculated using the VPM 2 algorithm, and no planned decompression was omitted. During the descent the diver did not have any trouble equalizing his ears. Soon after surfacing, he experienced vertigo, nausea and was unable to micturate. The diver was diagnosed with right-sided inner-ear DCS and neurological involvement of the bladder. He was promptly treated with a USN T6 in the nearest recompression chamber. He improved but at the end of the treatment balance problems remained. The day after he did a second treatment according to a US Navy Treatment Table 5 (USN T5) and was discharged home. He continued to have some balance problems for three days but is now asymptomatic, and audiometry is normal. Transthoracic echocardiography with bubble contrast did not demonstrate a PFO.

CASE 9

This 37-year-old diver, with 350 trimix dives, commented that prior to the day of the incident he was very tired following two weeks of hard work. He and his dive buddies were all diving with SCRs during the incident dive. The profile was a BT of 40 min to a max. depth of 88 mw, with a bottom mix of 10/70. At 43 min of run time, the subject and his team reached 57 mw and switched to a 21/35 mix. Some delay occurred during this gas switch and at 50 min run time they recommenced their ascent at a rate of 3 $m \cdot min^{-1}$ until reaching 42 mw. The subsequent deco stops were prolonged by 2 min every 3 mw until 27 mw, reaching 24 mw at 67 min run time. At 24 mw, the team did a 3-min gas break breathing the bottom mix, and then ascended to 21 mw, where the entire team switched to trimix 50/20. A few minutes after this gas switch, the diver experienced severe vertigo and loss of orientation. He decided to immediately switch to open circuit and signalled the team members of his situation. From 21 mw to the surface, no deco stops were omitted according to algorithm VPM 2. For the remaining two hours of the decompression, the subject needed constant assistance by his team in gas switches and position reference. Due to frequent vomiting the subject became dehydrated during the dive. Upon exiting the water, the subject reported pain in both knees and that he was unable to micturate. He was rapidly transferred to the nearest hyperbaric chamber and recompressed following a USN T6. During the next few days he was recompressed three times using a USN T5. The diagnosis was musculo-skeletal and inner-ear DCS, probably affecting the left ear. The difficulty with micturition was ascribed to severe dehydration. One month after the incident he had completely recovered and started diving again. Transoesophageal echocardiography with bubble contrast excluded the presence of a PFO. He declined vestibular or audiometric testing.

Comment: Some days after the incident, he and his dive buddies analysed the decompression profile and realised they had omitted about 20 minutes of deep deco stops according to the VPM-2 algorithm by not taking into account as bottom time the extra period spent at 57 mw to complete the gas switch.

Discussion

Among serious cases of DCI in recreational divers, the incidence of inner-ear symptoms is reported to be around 24 to 34%,[7,9,10] whilst in a reported case series from a single recompression centre, inner-ear DCS represented 11.7 % of all DCI occurring after trimix dives.[11] However, these data cannot be considered to reliably describe a true incidence, because the number of analysed cases was quite small. In our case series, about 7% of technical recreational divers completing the questionnaire had suffered from inner-ear DCS after a trimix dive during their career. It is likely the 'true' incidence would be lower because of a reporting bias to our questionnaire. Also, as it was specific for the incidence of inner-ear DCS, we cannot assign an incidence of inner-ear DCS among all DCI in trimix divers. In recreational diving, we can usually determine if a diver exceeds decompression limits. The evaluation of decompression exposure is more challenging with technical diving because of the array of algorithms and implementations that are used. None of the decompression techniques documented in these nine cases could be regarded as 'conservative' from a DCS-risk perspective.

Our data are in keeping with the reported association of inner-ear DCS with the presence of a PFO.[6,7,12] Venous gas emboli (VGE) are commonly detected after diving, often as 'silent' bubbles in asymptomatic divers. The presence of a PFO allows arterialization of venous bubbles, especially during particular manoeuvres such as a Valsalva or coughing. A high prevalence of arterial gas emboli has been reported after trimix diving, even without omission of decompression stops.[13] In that study, arterialisation of VGE was detected in five of seven divers who completed 21 trimix dives without protocol violations, although a PFO was detected in only one diver. The authors ascribed this to possible intrapulmonary shunts when a high venous bubble grade was detected in the right heart.

Another possible mechanism described for inner-ear DCS is the phenomenon of isobaric counter-diffusion.[14] This refers to the isobaric formation of bubbles as a result of supersaturation induced by the steady-state counter-diffusion of two gases with different solubilities and rates of diffusion. After a gas switch from a helium-rich mix to a poorer one, the vascular compartment of the inner-ear could be supersaturated because of the rapid transfer of helium from the perilymph into blood and the slower transfer of nitrogen into the perilymph from the vascular compartment. This mechanism could explain isolated inner-ear DCS occurring at depth.[4] Of our cases, only one diver suffering vertigo and nausea underwater and, in this case, this was more likely because of missed decompression earlier in the ascent, rather than to the gas switch per se.

In our series, all divers had vestibular symptoms, whereas only three suffered from cochlear symptoms. A greater prevalence of vestibular symptoms in inner-ear DCS has been reported in other studies.[11,12] This could be explained by the fact that cochlear blood flow is three times greater than vestibular flow,[15] so inert gas 'wash-out' is faster in the cochlea than in the vestibular organ.

Two studies have reported preponderance of inner-ear DCS to the right side.[9,10] We observed that of the four divers who were diagnosed with unilateral inner-ear DCS, three were on the right side. This has been ascribed to a narrower diameter of the right vertebral artery compared to the left.[10] However, bubbles are reported to reach the left ear 0.3 sec before the right, so time for their dissolution should be shorter and the left ear should be more susceptible than the right.[14] We believe this topic is worthy of more detailed analysis.

Three of the nine divers reported on-going balance problems. Unfortunately none of the divers underwent specific vestibular or audiometric testing. Residual vestibular damage after DCI has been reported to affect 62 to 78% of divers, even if less than 20% were symptomatic.[10,16,17] This emphasizes the need for thorough vestibular function evaluation after inner-ear DCS and before returning to diving activities. About 40% of divers have also been reported to have audiometric sequelae after inner-ear DCS.[10,16]

Conclusion

Nine of 126 (7.1%) trimix divers responding to a questionnaire reported suffering inner-ear DCS. The presence of a right-to-left shunt and poorly validated decompression profiles are important risk factors for inner-ear DCS, as are anatomical and physiological characteristics of the inner-ear. Inner-ear DCS may occur in isolation or be associated with other symptoms of DCS. Prompt recompression treatment should resolve symptoms. Subsequent to inner-ear DCS, residual vestibular and cochlear damage should be assessed even if the diver appears to be asymptomatic.

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Cerebral arterial gas embolism after pre-flight ingestion of hydrogen peroxide

Ben L Smedley, Alan Gault and Ian C Gawthrope

Abstract

(Smedley BL, Gault A, Gawthrope IC. Cerebral arterial gas embolism after pre-flight ingestion of hydrogen peroxide. *Diving and Hyperbaric Medicine*. 2016 June;46(2):117-119.)
Cerebral arterial gas embolism (CAGE) is a feared complication of ambient depressurisation and can also be a complication of hydrogen peroxide ingestion. We present an unusual case of CAGE in a 57-year-old woman exposed to both of these risk factors. We describe her subsequent successful treatment with hyperbaric oxygen, despite a 72-hour delay in initial presentation and diagnosis, and discuss the safety of aero-medical transfer following hydrogen peroxide ingestions.

Key words
Hyperbaric oxygen therapy; aviation; barotrauma; barometric pressure; case reports

Introduction

Cerebral arterial gas embolism (CAGE) is a documented but rare complication of hydrogen peroxide (H_2O_2) ingestion.[1–7] H_2O_2 is a readily available, clear, colourless, oxidizing agent found in different concentrations. Concentrations of approximately 35% are used for bleaching hair. There were 396 H_2O_2 exposures recorded by Australian National Poison Information Centres in 2013. Of these, 92% were recorded as accidental and only 9% where the concentration recorded was greater than 10% (unpublished data, with permission from the New South Wales, Queensland and Western Australia Poison Information Centres). Un-disassociated H_2O_2 undergoes rapid absorption across gastrointestinal mucosa and into the portal circulation. At standard temperature and pressure 1 ml of 35% H_2O_2 reacts with tissue catalases to liberate 100 ml of oxygen.[8] The volume of the gas emboli will be increased by a further reduction in ambient pressure, such as occurs with flying.

We report an unusual case of a patient who developed CAGE after accidental ingestion of H_2O_2 just prior to boarding an international flight. The patient gave written permission to report her case.

Case report

A 57-year-old retired hairdresser presented to an Australian Metropolitan Emergency Department with a two-day history of nausea and vomiting, abdominal pain, confusion and balance problems following a return flight from Malaysia. She was usually well, apart from well-controlled, late-onset insulin-dependent diabetes mellitus.

Two days prior to her presentation, the patient had been visiting her relatives in Malaysia. Whilst there, she had mixed up some hair perming solution in a plastic water bottle and placed it in her handbag to give to her sister. After celebrating Chinese New Year, she rushed to the airport to return to Australia. On passing through airport security an official reminded her that she could not take water onto the plane. Forgetting the bottle contained hair perming solution she took a "*big gulp*". The metallic taste immediately alerted her that she had ingested some of the perming solution; however, keen to get home she discarded the bottle and boarded the aircraft. Once on the plane she began to feel a burning sensation to her oropharynx and epigastrium. As the aircraft took off and gained altitude she began to vomit profusely and later described frothy "*bubbles*" in the vomit.

Whilst attempting to go to the aeroplane toilet she described feeling generally confused, had difficulty balancing and was unable to walk unaided. She was diagnosed with gastroenteritis and intravenous fluids and an antiemetic were administered during the flight. Interestingly, she described her confusion as improving on descent. On arrival to Australia, she refused a pre-arranged ambulance assuming that her symptoms would continue to improve.

Her symptoms persisted over the next 24 hours; she still felt generally confused and described poor balance. She was unable to eat or drink and developed diarrhoea and right-sided abdominal discomfort. She saw her general practitioner who arranged transfer to the local emergency department. There, she was treated for dehydration and corrosive oesophageal injury, with normal routine blood tests, and admitted under the medical team for blood sugar control and possible endoscopy. A CT scan of her abdomen was performed which did not show a clear cause for her pain but did show "*mild ascending colonic thickening of uncertain significance*". No portal or other gas emboli were demonstrated at that time. The following day, she had ongoing unexplained neurological symptoms and a toxicology review raised the possibility of CAGE in the setting of H_2O_2 ingestion and she was transferred for consideration of hyperbaric oxygen.

On arrival at the State Hyperbaric Unit, examination revealed a listless patient who had a flat affect, slow speech and was unable to stand unaided for more than a few seconds. She had some subjectively altered sensation of her right upper limb and weakened hip flexion bilaterally. She scored 29/30 on a mini mental state examination but slow answers and difficulty writing were noted. It was felt her symptoms and signs were consistent with a diagnosis of CAGE.

She was treated with hyperbaric oxygen (HBO) to a pressure of 284 kPa on a US Navy Treatment Table 5 (USN T5). At 284 kPa, her symptoms improved and within 15 minutes the patient stated that her vision had focussed, her mind had sharpened and her voice was clearer. At the conclusion of her initial treatment, she walked from the chamber unaided and was able to perform a sharpened Romberg test for 30 seconds. After her second treatment the following day, at 243 kPa for ninety minutes with a five-minute air break, her abdominal symptoms had resolved and she was bright, talkative and able to perform a sharpened Romberg for more than 60 seconds. She had one final session, again at 243 kPa and then was discharged feeling well and symptom free. The medical team chose not to perform any imaging of the brain as she had made a full recovery. On phone follow up one month later, she had no recurrence of her symptoms.

Discussion

CAGE resulting from pulmonary barotrauma is a well-recognised phenomenon and cause of mortality and morbidity after compressed gas diving. It is also seen post open cardiac surgery,[9] and is rarely associated with other surgical and gynaecological procedures,[10] complications of central vascular access,[11] and inhalation of pressurised helium.[12] CAGE from hydrogen peroxide ingestion is a rare but recognised occurrence with several cases reported in the literature.[1–7]

The patient in this case ingested approximately 30 ml of high concentration H_2O_2 which would liberate up to 3 litres of oxygen into the portal circulation.[8] Any shunt between venous and arterial circulation will allow direct transfer of these gas emboli. In animal models it has been shown that a rate of infusion of venous gas of 0.3 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ will overcome the pulmonary filter and produce arterial gas embolism.[13]

During commercial flights, the ambient pressure decreases during ascent. A recent appraisal of cabin pressures measured an average ambient pressure of 0.78 bar (79 kPa).[14] Using Boyle's law this would result in an approximate 28% increase in gas volume and exacerbate the effects of gas emboli, as seen in this case.

Regarding this patient's abdominal pain and CT findings of colonic thickening, two case reports exist of ischaemic colitis due to arterial gas embolism.[15,16] H_2O_2 peroxide can also cause toxicity by corrosive effects on the gastrointestinal tract (GI) system but two recent reviews found no reports of significant GI morbidity.[17,18]

HBO is the accepted standard treatment of CAGE from any cause. It has been shown that without treatment neurological manifestations may persist or be fatal.[1,4] Recent literature recommends treatment for H_2O_2 ingestion with a US Navy Treatment Table 6.[1] However, delayed treatment has also been shown to be effective with shorter tables.[2] In the case presented, the patient's neurological and abdominal symptoms improved after the first treatment with a USN T5 and had resolved entirely after the second treatment, despite 72 hours elapsing between poisoning and initiation of HBO.

This case highlights the risks of flying post H_2O_2 ingestion. There are no current guidelines on when it is safe to fly following ingestion, but clearly from this case there are inherent risks in transferring a patient via air. In compressed air diving, current guidelines suggest a minimum safe pre-flight surface interval of at least 12 hours after a single, no-decompression dive.[19] Given the lack of evidence that H_2O_2 causes significant GI morbidity, the authors recommend following these guidelines. Aeromedical transfer should be delayed by at least 12 hours unless the patient has already developed neurological symptoms suggestive of CAGE or other urgent need for transfer. In these CAGE cases, we suggest treating these patients as we treat divers with decompression illness and flying without reduction in ambient cabin pressure.

Conclusions

This unusual case of CAGE caused by H_2O_2 ingestion and flying reminds physicians to be alert for such presentations and to be aware that delayed hyperbaric treatment may still be effective. We must also be aware of the risks of aeromedical transfer of patients with a history of H_2O_2 ingestion.

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Letters to the Editor

Iatrogenic cerebral gas embolism

Drs Beevor and Frawley have helpfully added to the relatively sparse literature on iatrogenic cerebral gas embolism.[1] One piece of information that is missing, and which would be helpful for them to add, is the relationship between imaging results and outcome. Table 3 in their paper shows the number of CT and MRI scans, but contains no information as to what was seen.

I completely agree with the authors that it is unwise to delay hyperbaric oxygen therapy in order to obtain brain imaging, and I continue to preach that message. However, imaging is often performed before hyperbaric specialists are consulted, and the information obtained could conceivably be useful. Identification of prognostic indicators, which may include brain imaging results, would be helpful when making decisions as to long-distance transport to a hyperbaric facility. For example, the combined data of Benson et al[2] and Bessereau et al[3] suggest that gas seen on brain imaging confers a poorer outcome. It would be great to see a similar analysis of Drs Beevor and Frawley's data.

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Key words
Cerebral arterial gas embolism (CAGE); clinical audit; radiological imaging; outcome; letters (to the Editor)

Reply:

We thank Professor Moon for his interest in our series. The series highlighted that, whilst early use of hyperbaric oxygen (HBOT) is associated with the best neurological outcome, it is often difficult to achieve this aim.[1] Delays to treatment occurred even when the initiating event was in a hospital with a hyperbaric facility. Further delaying HBOT to obtain cerebral imaging is likely to significantly add to the time between the cerebral gas embolism (CGE) event and effective treatment. This compounds delays imposed by late recognition of CGE diagnosis, the need to complete the surgical procedure and/or the need to transfer patients to a HBOT facility.

In general, magnetic resonance imaging (MRI) or computerised tomography (CT) imaging may support a diagnosis but cannot make the diagnosis. A normal CT or MRI should not be reassuring that no significant neurological insult has occurred. In two cases of witnessed CGE during cardiac ablation surgery which resulted in major CNS dysfunction, initial imaging was reported as normal. In both cases imaging delayed effective treatment and despite treatment with a US Navy Treatment Table 6A only one had a favourable outcome.[2] In a similar incident, 15 ml of air was inadvertently injected into a subclavian artery. Basilar artery air was demonstrated angiographically and the patient showed signs of posterior circulation ischaemia but normal and diffusion weighted MRI did not detect an abnormality.[3]

If CGE occurs at a centre without a hyperbaric unit, imaging may be of benefit to triage patients but should not delay transfer. As you suggest, the presence of widespread gas on brain imaging may be associated with a poorer outcome. In our series, both patients in whom intravascular air was demonstrated on CT died. In both cases, intravascular air was seen in multiple sequences. Detection of intravascular gas by CT, however, mandates some attempt at treatment even if ultimately futile. We believe that delaying HBOT to obtain imaging may impact significantly on neurological outcome.[4] In a retrospective study, better outcomes were reported if the delay between the diagnosis of CGE and HBOT was less than six hours.[5] In a prospective study, a longer time interval between CGE and the first HBOT did not affect mortality but aggravated neurological sequelae at one-year follow-up.[6]

In our series, imaging was performed on 25 of the 36 patients prior to receiving HBOT, totalling 27 studies. 11 patients had no imaging studies prior to HBOT. The tests included 18 CT of the head, five MRI studies of the brain and two combined CT and MRI. Two CTs demonstrated gas in the cerebral circulation, and a normal CT scan and an abnormal MRI was reported in one other patient. Of the 25 exams that did not demonstrate gas, eight had secondary changes consistent with gas embolism (five CT brain, three MRI). Imaging was performed prior to HBOT in 13 patients despite gas entry being observed during the procedure (10 CT brain, three MRI). In our opinion cerebral imaging is of limited value if CAGE is witnessed and usually delays effective treatment.

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Key words
Cerebral arterial gas embolism (CAGE); clinical audit; radiological imaging; outcome; letters (to the Editor)

The effect of scuba diving on airflow obstruction in divers with asthma

Drs Lawrence and Chen presented peak expiratory flow (PEF) results from 19 divers with asthma who were suitable for testing out of 356 divers attending Operation Wallacea in Honduras.[1] They claim from their results that "*open-water scuba diving caused a small decrease in PEF in all populations*" and say that "*asthmatics are more susceptible to airway changes following scuba diving*". I would like to make the following observations:

PEF readings were not taken at similar times of day. Some of the readings were taken after diving at 0900 and some after diving at 1400. The readings at different times of day are not identified in the analysis. It is known that PEF readings vary with the time of day at which they are taken.[2]

Multiple PEF readings were taken from the divers. No account is taken in the statistical analysis of the lack of independence in the multiple readings from the same divers; No analysis has been presented of the power of the study.
I request that the authors take account of these points, perform a reanalysis of their data and present this together with a power calculation for their study.

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Key words
Lung function; statistics; letters (to the Editor)

Reply:

We thank Dr Edge for his interest in the study and the points raised. We have had lengthy discussions and attempts at data reanalysis with a statistician colleague but a full reanalysis has not been possible.

1. As we acknowledge in the discussion, the time of peak flow readings was not recorded and PEF varies through the day. Dive timing may affect the magnitude of any change in PEF while scuba diving, although we do not have the data to support that theory. As we do not have the recorded dive times we cannot be sure that the mix of morning and afternoon dives is identical in each group. This would be an area we will look into in any future study.

2. Each diver was able to contribute up to five pairs of readings (from five separate dives). All of which for the avoidance of doubt are related paired readings, specific to individual dives. Not all divers submitted the same number of paired readings.

As requested we have attempted a data reanalysis taking into account the unequal numbers of repeated measurements. However, this, as we understand, requires a mixed model ANOVA which does not have a non-parametric equivalent. The presence of negatives (an increase in peak flow following scuba) in certain pairs means we are unable to perform a log transformation to normalise the data. As a result we have been unable to complete this.

3. On the original dataset we have performed bootstrap sampling on the before and after groups, and we have performed the Wilcoxon signed ranks test on the bootstrap samples and determined whether the P-value is less than 0.05. This resampling process has been repeated 10,000 times and the quantity of test producing a P-value of less than 0.05 have been totalled. For asthma group 3 (on regular preventative inhalers), where we found a significant difference ($P = 0.039$) in peak flow the power was found to be 8,999/10,000.

We acknowledge the limitations of performing a study with small sample sizes but feel that those limitations were clearly expressed in the original study. We are open to advice as to alternative methods of statistical appraisal.

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Key words
Lung function; statistics; letters (to the Editor)

Consensus Development Conference

Tenth European Consensus Conference on Hyperbaric Medicine: preliminary report

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(Mathieu D, Marroni A, Kot J. Tenth European Consensus Conference on Hyperbaric Medicine: preliminary report. *Diving and Hyperbaric Medicine*. 2016 June;46(2):122-123.)

The tenth European Consensus Conference on Hyperbaric Medicine took place in Lille, France, 14–16 April, 2016, attended by a large delegation of experts from Europe and elsewhere. The focus of the meeting was the revision of the European Committee on Hyperbaric Medicine (ECHM) list of accepted indications for hyperbaric oxygen treatment (HBOT), based on a thorough review of the best available research and evidence-based medicine (EBM). For this scope, the modified GRADE system for evidence analysis,[1,2] together with the DELPHI system for consensus evaluation,[3,4] were adopted. The indications for HBOT, including those promulgated by the ECHM previously, were analyzed by selected experts, based on an extensive review of the literature and of the available EBM studies.

The indications were divided as follows:
Type 1, where HBOT is strongly indicated as a primary treatment method, as it is supported by sufficiently strong evidence;
Type 2, where HBOT is suggested as it is supported by acceptable levels of evidence;
Type 3, where HBOT can be considered as a possible/optional measure, but it is not yet supported by sufficiently strong evidence.

For each type, three levels of evidence were considered:
A, when the number of randomised controlled trials (RCT) is considered sufficient;
B, when there are some RCT studies in favour of the indication and there is ample expert consensus;
C, when the conditions do not allow for proper RCT studies but there is ample and international expert consensus.

Finally, the conference also issued 'negative' recommendations for those conditions where there is evidence not to use HBOT and HBOT is considered as not indicated with a Type 1 recommendation.

Table 1 is a concise summary of the conclusions reached by the ECHM 2016 Consensus Conference. There were no Type 1A indications for HBOT identified by the conference, indicating that much clinical research is still required to clarify the role of HBOT in clinical practice. A full report is being prepared for publication.

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Key words
Hyperbaric oxygen therapy; meetings; abstracts

Table 1

Summary of recommendations and levels of evidence for using or not using hyperbaric oxygen treatment (HBOT) in specific diseases (see text for explanations)

Type 1 indications	**Level of evidence**		
	A	**B**	**C**
Anaerobic or mixed bacterial infections			X
CO poisoning		X	
Decompression illness			X
Gas embolism			X
Open fractures with crush injury		X	
Osteoradionecrosis (mandible)		X	
Prevention of osteoradionecrosis after dental extraction		X	
Soft tissue radionecrosis (cystitis, proctitis)		X	
Sudden deafness		X	
Type 2 indications			
Burns, 2nd degree more than 20% BSA			X
Central retinal artery occlusion (CRAO)			X
Compromised skin grafts and musculocutaneous flaps			X
Crush injury without fracture			X
Diabetic foot lesions		X	
Femoral head necrosis		X	
Ischemic ulcers			X
Neuroblastoma, stage IV			X
Osteoradionecrosis (bones other than mandible)			X
Pneumatosis cystoides intestinalis			X
Radio-induced lesions of soft tissues (other than cystitis and proctitis)			X
Refractory chronic osteomyelitis			X
Surgery and implant in irradiated tissue (preventive treatment)			X
Type 3 indications			
Brain injury in highly selected patients (acute and chronic TBI, chronic stroke, post anoxic encephalopathy)			X
Interstitial cystitis			X
Limb replantation			X
Post-vascular procedure reperfusion syndrome			X
Radio-induced lesions of the larynx			X
Radio-induced lesions of the CNS			X
Selected non-healing wounds secondary to systemic processes			X
Sickle cell disease			X

Type 1 indications for not using HBOT	**Level of evidence**		
	A	**B**	**C**
Autism spectrum disorders		X	
Cerebral palsy		X	
Multiple sclerosis		X	
Placental insufficiency			X
Stroke, acute phase			X
Tinnitus		X	

Critical Appraisal

Pre-emptive treatment with hyperbaric oxygen following radiation therapy for head and neck cancer may prevent the onset of late radiation tissue injury

Clinical bottom line:
1. Early treatment with hyperbaric oxygen (HBOT) was associated with improved Quality of Life (QoL) scores for a wide range of symptoms including dry mouth, swallowing difficulties and pain in the mouth;
2. Early treatment with prophylactic HBOT may prevent the onset of late radiation tissue injury.

Citation:
Teguh DN, Levendag PC, Noever I, Voet P, van der Est H, van Rooij P, Dumans AG, de Boer MF, van der Huls MPC, Sterk W, Schmitz PIM. Early hyperbaric oxygen therapy for reducing radiotherapy side effects: early results of a randomised trial in oropharyngeal and nasopharyngeal cancer. *Int J Radiat Oncol Biol Phys*. 2009;75:711-6.

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Three-part Clinical Question:
For patients who have received radiation therapy for head and neck malignancies, does early treatment with HBOT, versus no specific treatment, prevent late radiation tissue injury?

Search Terms:
Radiation tissue injury, xerostomia, head and neck cancer

The Study:
Non-blinded, randomised controlled trial with intention-to-treat

The Study Patients:
Adult patients diagnosed with oropharyngeal or nasopharyngeal cancer and treated with radiotherapy (46 to 70 Gy)

Control group:
(n = 11; 11 analysed): No specific therapy

HBOT group:
(n = 8; 8 analysed): 100% oxygen breathing at 253 kPa for 90 minutes daily, five days per week to a total of 30 treatments starting within two days after completion of radiotherapy

The Evidence:
See Table 1.

Comments:
1. Very small trial because of slow recruitment rate, and may be subject to considerable bias. In particular, the baseline QoL scores were generally worse in the control group and may explain the observed differences at follow-up.
2. All outcomes are self-reported in non-blinded subjects.
3. No sham treatment given. Authors state that this is unlikely to bias the late treatment effect at follow up.
4. All results given in graphic format and P-values are from regression analysis based on maximum likelihood estimation using Stata 9 software.

Appraised by:
Danielle Wood and Michael Bennett, Prince of Wales Hospital; Saturday, 16 April 2016
E-mail: *<danspace@gmail.com>*

Table 1
Outcomes for symptoms of oral soft tissue radiation injury over 12 months from the completion of radiotherapy; values are mean scores at 12 months (read from graphs), P-values are calculated from regression analysis over the 12 month period; EORTC H&N35 – European Organization for Research and Treatment of Cancer Quality of Life assessment tool for head and neck symptoms, 0 = no symptoms, 100 = worst imaginable symptoms; HBOT – hyperbaric oxygen treatment; VAS – visual analogue scale, 0 = no pain, 10 = maximal pain imaginable

	Outcome at 12 months		
	Control	**HBOT**	P-value
EORTC H&N35 scores			
Dry mouth	90	30	0.009
Swallowing	40	7	0.011
Pain in mouth (VAS)	7	1	<0.001

Book review

DAN Annual Diving Report, 2015 Edition
A report on 2010–2013 diving incidents, injuries and fatalities
Editor: Peter Buzzacott
Soft cover or PDF format; 127 pages
ISBN 978-1-941027-52-3
Divers Alert Network
6 West Colony Place
Durham, NC 27705, USA
E-mail: <dan@diversalertnetwork.org>
Available at: <https://www.diversalertnetwork.org/medical/report/AnnualDivingReport-2015Edition.pdf>

The Divers Alert Network (DAN) is well known to many recreational divers as the provider of a diving emergency medical hotline, diving accident insurance, oxygen first-aid training and diving research. DAN started in the USA in 1980 as the National Diving Accident Network, providing a 24-hour emergency hotline with access to diving physicians for advice on the diagnosis, care, transportation and recompression of injured divers. A dedicated research department was established in 1992 with the start of its flying-after-diving trials,[1] and this group continues to collect and analyse dive profiles from contributing international organisations and divers for statistical analysis of diving injuries.

The 2015 Annual Diving Report was reviewed in hardcopy format. It is an attractive, soft-bound book of 127 pages with a glossy cover and functional layout. All of DAN's Annual Diving Reports are also available as a free download on their website (see above). The research staff at DAN released their first report on diving injuries in 1987. Over that time, data on diver demographics and diving practices have been used to identify trends, at-risk groups and unsafe behaviours. For example, DAN notes from the 2010–2013 data that they are receiving more reports of cardiovascular-related fatalities, in addition to a rise in the number of calls to their Medical Services Call Centre (MSCC) concerning cardiovascular matters. They have also noted that the majority of diving fatalities were over 40 years of age, with more than half over the age of 50.

A further interesting observation made regarding the aging diving population is that every three years, the average age of diver members of DAN has increased by one year. The expected increased prevalence of health problems in an aging diver population can make diving fitness decisions extremely difficult. Cardiovascular events are the most commonly reported cause of death (surpassed only by the 'catch all' diagnosis of drowning). Given that predicting cardiovascular events *a-priori* is an inexact science at best, it is perhaps unsurprising that the unforgiving marine environment tends to unmask previously undeclared or well-controlled cardiovascular insufficiency – something about which I am sure any diving physician working in a busy diving resort area does not need to be reminded! One wonders whether the aging diver trend (in keeping with the population demographics of many developed countries) will raise the priority of research into pre-dive identification of at-risk individuals.

Another area of note from this year's report is a section looking at the differences between divers who died hunting and food gathering versus those who were not. The authors conclude that the physical demographics of the hunting group did not differ greatly from the non-hunters, but that hunters more often ran low or out of air. A link between a higher proportion of out-of-air emergencies and preoccupation with the hunt is proposed, and certainly fits with the old New Zealand diving maxim which describes the scallop as the most dangerous creature in the sea!

The sources of injury data used in the report have changed in recent years. In particular DAN notes increasing difficulty in accessing US injury data from hyperbaric facilities treating recreational divers. They describe a concerning trend of reporting chambers dropping out owing to recent changes in US health information privacy legislation. As a result, there is now a greater reliance on data acquired directly through the DAN MSCC when divers call for help or advice. This has led to greater variability in the type and quality of data collected on diving injuries over time, limiting analyses which require formal diagnoses, as this information becomes increasingly unavailable. News reports, primarily online, are monitored for keywords involving diving deaths and scuba and these reports are correlated against other sources, including reports from families or friends of those involved in a diving incident who are aware of DAN's data collection efforts.

While the diving incidents analysed in the report are sourced internationally, the body of the main report retains a North American focus, in keeping with the intended audience. In recognition of this, the report includes Australian, Japanese and 'Asia-Pacific excluding Australia' diving-related fatality analyses as appendices to the main report. The Australian data is of particularly high quality, due in no small part to the processes developed by Dr Douglas Walker who was the principal researcher for Project Stickybeak from its inception in 1972. More recently John Lippmann and DAN Asia Pacific have become involved, together with a medical team with decades of collective experience in diving medicine and incident analysis. They have continued this valuable effort, a key part of which is the access this team has to the Australian National Coronial Information System. This provides access to a detailed and near-complete record of all diving fatalities that occur in Australia, including autopsy reports where they have been done. The results of these detailed and insightful analyses will be familiar to readers of this journal.[2]

A collection of non-fatal diving incident accounts is new to the report this year. They were collected via DAN's Diving Incident Reporting System, an online system that was introduced in 2012. These make interesting reading for any diver. The descriptions of common mishaps can be a valuable trigger for reflection of one's own diving practices, and one remains hopeful that with DAN's wide readership, such reports might reduce the incidence of future similar incidents.

While this year's report again makes for sobering reading, such analysis of dive accidents has great value, especially given the difficulty in obtaining this type of information. One hopes the work continues; the DAN Report has become an important part of ongoing international efforts to identify accident trends in diving, develop interventions where possible and make diving safer.

References

1 Sheffield P, Vann R, editors. *Flying after recreational diving*. Workshop Proceedings. Durham, NC: Divers Alert Network; 2004. [cited 2016 February 28]. Available at: DAN.org/research/conference/2010FatalityWorkshop/proceedings/index.html.
2 Lippmann J, Lawrence C, Fock A, Wodak T, Jamieson S, Harris R, Walker D. Provisional report on diving-related fatalities in Australian waters 2010. *Diving Hyperb Med*. 2015;45:154-75.

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Key words
Diving deaths; diving incidents; age; book reviews

Published erratum

In a letter to the Editor (Cooper PD, Smart DR. Hyperbaric oxygen therapy for osteoradionecrosis. *Diving Hyperb Med*. 2016;46:55-7.), references 4 and 5 were merged. They should have read:

4. *Medicare Benefits Schedule*. Department of Health and Ageing, Commonwealth of Australia, 2015.
5. *Australian Demographic Statistics, Jun 2015* [Internet]. Australian Bureau of Statistics, Commonwealth of Australia; 2015. [cited 2015 Dec 30]. Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0/.

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 listed 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 some gaps still to be filled).

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)

Notices and news

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

42nd EUBS Annual Scientific Meeting 2016

Dates: 13–16 September
Venue: International Conference Centre (CICG), Geneva, Switzerland

Save the date for the next appointment with our friends from all around Europe to talk about diving and hyperbaric medicine. It will be the occasion to improve and update our knowledge with the latest studies and research in the field. Speakers and guests will be welcomed in the CICG, the perfect venue for our meeting.

Conference website: <http://www.eubs2016.com>
Abstract submission and registration is open.

Hotel selection is possible when going through the registration process; the hotels proposed have been selected carefully for their quality/price ratio and location. However, you might find cheaper prices on the web; usually these cheaper offers come with stricter cancellation policies.

Support the EUBS Conference by providing sponsorship. This way, your company or institution will clearly show its involvement and dedication to advancing the field of hyperbaric/diving medicine and physiology and you will have a perfectly targeted company exposure to potential clients and customers; details on the website <www.eubs2016.com> .

EUBS Young Investigators research and education session

All students and young(ish) researchers (and all other interested scientists and clinicians) are invited to this session at the International Congress Centre Geneva, 13 September, 1400–1700 h

Provisional Programme:

1. C Balestra: Introduction
2. S De Maistre (Toulon, France): A rat model in the assessment of decompression sickness treatments
3. R Pignel (Geneva, Switzerland): RCTs in hyperbaric medicine - attention points and pitfalls
4. SL Blogg (Kirkby Stephen, UK): How to write a paper: the Journal Editor's point of view
5. C Balestra (Brussels, Belgium): Research grants - how does that work?
6. V Papadopoulou (London, UK): PHYPODE experience and post-doc perspectives in hyperbaric and diving research

Please visit the EUBS2016.com website for up-to-date information on the programme.
Attendance is free, but register via e-mail to: <education@eubs.org>

EUBS Annual Scientific Meeting 2017

Preliminary Announcement

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!

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

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

EUBS AGM 2016 Invitation and Agenda

Date: Friday 16 September 2016, 1700-1830 h
Venue: International Congress Centre, Geneva (site of the EUBS 2016 Annual Scientific Meeting)

All EUBS members are cordially invited to the Society's Annual General Assembly. This is your chance to become informed about and discuss the proposals of the Executive Committee and to be directly involved in our Society. Please find below the Agenda of our AGM:

1. Welcome from the EUBS President
2. Meeting Report EUBS2016
3. Awards and Grants
   a. Zetterström Award
   b. Musimu Award (awarded by Belgian Society for Diving Medicine)
   c. Travel Grants
4. Financial Report
5. Membership Report
6. EUBS ExCom composition
   a. EUBS Elections
   b. Composition of EUBS ExCom for next year
7. DHM Journal
8. EUBS Website
9. Next EUBS Meetings:
   a. 2017: Ravenna – presentation by Local Organising Secretary-General
   b. 2018: Joint Tricontinental Meeting - status report
   c. 2019: Israel
   d. 2020: Czech Republic
10. Other business

Safe travels to Geneva on behalf of the EUBS ExCom and the Local Organising Committee. Welcome to Switzerland!

Peter Germonpré, Honorary Secretary

Multiplace recompression chamber fire and explosion, Jakarta

Sadly, the Mintohardjo Naval Hospital in Central Jakarta experienced a serious fire in the hospital's hyperbaric chamber that claimed the lives of four people on 14 March, 2016. Despite vigorous attempts to engage the emergency fire system, the fire rapidly engulfed the chamber, leading to an explosion. The four chamber occupants all died and other personnel were injured.

A Navy spokesperson explained that the chamber "*was first operated in 2013. We always thoroughly maintain the condition of such equipment*."

All members of the SPUMS and the EUBS wish to express to the families of the victims our deep sorrow for their losses

EUBS Executive Committee Elections

An EUBS ExCom Member-at-Large 2016 must be elected by the EUBS Membership. Candidate profiles and short CVs can be found on the EUBS website as from 15 June, 2016. A secure internet ballot will be sent by e-mail to all EUBS members eligible to vote. Please remember to cast your vote immediately, and at the latest before 15 August.

The elected Member-at-Large will be announced at the AGM on 16 September and will serve his/her term as member of the ExCom from 2016 to 2019.

Peter Germonpré, Honorary Secretary

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>

Award to Dr Ingrid Eftedal

The Divers Alert Network RW 'Bill' Hamilton Memorial Scholarship has been awarded to Norwegian scientist Ingrid Eftedal of the Norwegian University of Science and Technology to support a study on occupational saturation divers on the Norwegian continental shelf. The scholarship is funded by The DAN Foundation and administered by the *Women Divers Hall of Fame*.

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>

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

Preliminary announcement
Main theme: Medical Support of Commercial Diving

Dates: May 2017 (exact week to be confirmed)
Venue: To be announced soon

Keynote speaker: Dr Debbie Pestell, 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

For more information: <asm2017@spums.org.au>
Details to follow soon on the SPUMS website

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.

To be eligible to sit the above mentioned examination(s), candidates must have:

- Been registered with ANZCA for the DHM certificate prior to 01 August 2013 and paid all relevant fees;
- Successfully completed a Fellowship with a specialist medical college recognised by ANZCA Council (e.g,. FANZCA, FACEM, FCICM, FRACGP);
- Achieved the SPUMS Diploma of Diving and Hyperbaric Medicine or The University of Auckland Postgraduate Diploma in Medical Science – Diving and Hyperbaric Medicine or equivalent;
- Completed their workbook and/or formal project (for the Auckland diploma this is having completed either MED718 or MED719 as part of the course).

Please note that documentation of the above must be received by ANZCA on or before the closing dates of the nominated examination to allow verification by a DPA Assessor.

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

Closing date for exam registration	Friday 09 September
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).

24 September–01 October: Mini-congress *Diving Medicine* (five plenary lectures by Adel Taher, 10 invited lectures, free contributions, 18 cp); Paradise Bay, Malta
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: John Elliott and his team at Cayman Hyperbaric Services

Main diving theme: The disabled diver

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:
<www.ukhyperbaric.com/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. The course will explore the 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, when divers will be monitored 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
09–10 September: In-depth course "*A life-long diving*" (level 2); Zeist, NL
21–22 September: Basic Course Diving Medicine (level 1 part 1); Al Sifah, Oman
24 Sept–01 October: Basic Course Diving Medicine (level 1 part 2); Al Sifah, Oman
12–13 October: *NEW* Use of ultrasound for decompression research; Karlskrona, Sweden
5–12 November: Basic Course Diving Medicine (level 1 part 1); tbd
12–19 November: *NEW* 24th In-depth Course Diving Medicine; tbd
19–26 November: *NEW* 24th In-depth Course Diving Medicine; tbd

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

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>

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/>

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>

Instructions to authors

A downloadable pdf of the 'Instructions to Authors' (revised August 2015) 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>.

Cancellation of Royal Adelaide Hospital Medical Officer Basic and Advanced Courses in Diving and Hyperbaric Medicine, 2016

The Medical Officers' Course in diving and hyperbaric medicine has run at the Royal Adelaide Hospital (RAH) for more than 25 years. The RAH is moving to a new hospital site, now planned for November 2016. This is a major logistic undertaking and, after much consideration, it seemed prudent to cancel the course for this year. We apologise for any inconvenience that this might create, particularly for those already booked. We have made this decision with regret but wished to provide notice as early as possible.

The next Medical Officers' Course will now take place in late 2017 at the new RAH site. We plan to revise the course with some exciting new developments, and encourage interested doctors to put this in their calendar for future consideration.

David Wilkinson and Suzy Szekely, Course Coordinators
Hyperbaric Medicine Unit, Royal Adelaide Hospital

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>

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

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>

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