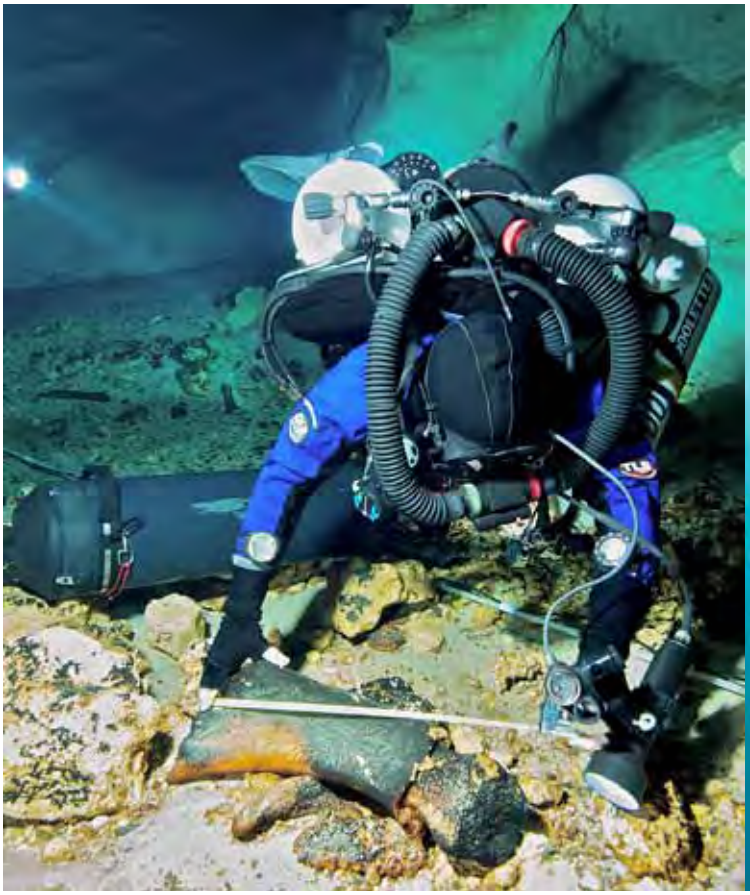
Diving and Hyperbaric Medicine

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EUBS





Recreational technical diving

Oxygen and carbon dioxide toxicity – 1944 revisited

Decompression in recreational technical diving

Recreational closed-circuit rebreather fatalities

Stress responses during breath-hold diving

Can a diver be mechanically ventilated underwater?

Print Post Approved PP 331758/0015

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

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The Editor's offering

"*Technical diving does not contain any greater risk than traditional compressed air diving, as long as the diver is in command of the technology. A precondition for this is that* [s]*he acquires the necessary theoretical knowledge and is prepared to conduct the dive in accordance with the technical requirements.*" So concluded Dr Sonnhild Schiönberg-Schiegnitz in her presentation at the 1995 SPUMS Annual Scientific Meeting.[1] Eighteen years later, Andrew Fock concludes in his report on rebreather fatalities in this issue "*…using a CCR* [closed-circuit rebreather] *is associated with a four- to ten-fold increased risk of death compared to recreational OC* [open-circuit] *scuba diving.*"[2] However, Fock points out that some of this risk is related to higher-risk deep diving, which in itself is "*associated with a three-fold increase in risk of death*" and that "*two-thirds of the reported deaths appear to have some association with high-risk behaviours.*"[2] Whilst CCRs are complex pieces of equipment, the risks of failure appear to be more related to human errors, such as failures in pre-dive maintenance, assembly and preparation, and to high-risk behaviours. Thus, modern CCR fatality data, whilst alarming, probably reinforce the simple message above from two decades ago.

Mixed-gas open-circuit and semi-closed and closed-circuit rebreathers for both shallow and deep diving are not new techniques, but have been around for decades. What has changed is the recent, rapid growth in participation in recreational technical diving worldwide and the increasing range and sophistication of equipment available, alongside improved gas-monitoring techniques and the advent of modern dive computers. In the discussion forums at the 1995 ASM, several participants, of whom this writer was one, predicted recreational technical diving would bring a huge increase in severe, difficult-to-treat decompression sickness, something that does not appear to have eventuated yet. The paper by Doolette and Mitchell helps to explain the intricacies of deep mixed-gas decompression.[3] As diving becomes deeper, longer and more challenging, one wonders whether we may have seen only the tip of a clinical iceberg so far.

"*Because it's there*" applies as much to diving a famous wreck lying in 150 metres of seawater as it does to the peak of Everest or K2. That is not to say that such motivation lacks validity or substance, since adventure and discovery are vital drivers for the human psyche. Nevertheless, defining the purpose of a deep technical dive determines many factors that need to be in place to ensure that such an enterprise is achieved at the least risk.[4] Recently a planned dive to a wreck in deep water swept by strong currents off the northern tip of New Zealand was abandoned because the infrastructure (the support vessel) was deemed inadequate and the weather outlook poor; this despite an extremely experienced diving team, including one of the authors in this issue.

The European Resuscitation Council guidelines recommend in-water rescue breathing during the rescue of a drowning victim, and this was recently endorsed by the Diving Committee of the Undersea and Hyperbaric Medical Society in the USA.[5,6] The recommendations of the UHMS Committee will be summarised in the next issue of *Diving and Hyperbaric Medicine*. Taking this a step further, Winkler and his colleagues have attempted to deliver underwater artificial ventilation to the unconscious diver.[7] Using an immersed ventilator connected via three different devices to a resuscitation manikin, their attempts were essentially a disappointing failure, and highlight one of the comments in the UHMS report in which they state "*In particular there was doubt that a regulator held in place would protect the airway any more than a mouth held closed.*" The German experience supports this even with more sophisticated airway protection devices, such as a full-face mask or a laryngeal tube. One of the rationales for exploring underwater ventilation relates to technical diving, especially in overhead environments, where an immediate return to the surface is not feasible.

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Michael Davis

Key words
Editorials, technical diving, deaths, resuscitation

Front page photos: Inspecting a fossil at 90 metres' depth in the Wakulla-Leon Sinks cave system, Florida (courtesy David Rhea, underwater photographer, Florida, <www.davidrheainc.com>); divers decompressing after diving the *USS Atlanta* in 125 msw, Guadalcanal, Solomon Islands (courtesy Dr Fock).

The Presidents' page

Costantino Balestra, President EUBS
Mike Bennett, President SPUMS

On the eve of the first ever tricontinental scientific meeting, we thought it a great occasion to offer you a joint message from the Presidents.

The unique opportunity for our two societies, together with the Southern African Underwater and Hyperbaric Medical Association and the Réunionese, to join in sharing our scientific programmes represents a cornerstone in the history of baromedicine.

A cornerstone is not a monument – set only to be admired and remembered by those who come after us – but is defined as "*the first stone set in the construction of a masonry foundation, important since all other stones will be set in reference to this stone, thus determining the position of the entire structure"*. The cornerstone sets the future success of the building and is designed to last long after the death of those who set these building marks.

What will this cornerstone set for our societies' futures? What will be the consequence of this time spent together, nurturing new ideas and forming new alliances? As the fortunate Presidents who happen to be around when this historic meeting takes place, we suggest four exciting outcomes for our societies:

Encouraging the development of new scientists

Hatching new talent has always been a central aim in every field of science. In our 'niche' area this seems to be even more important and challenging. We simply do not have the thousands of bright young people working in our multi-million dollar (or euro) research institutes competing to take on the leading roles. Our numbers are small and contracting as further limits are put on human activity in the baromedical field, e.g., with the advent of robotics. Nevertheless, new talents are emerging and need encouragement. At this first joint meeting, a number of younger researchers will attend as postgraduates, PhD students and even undergraduates. This meeting is the primary academic convocation for a number of active young scientists, for example, those involved in the Phypode project, which provides a three-year training programme for 14 researchers and at least as many supervisors. It is vital, therefore, that we continue with events during the meeting like the young investigators' workshop and the DAN Divers Day. These are the activities prone to letting newcomers come forward. More power to them!

The Journal

The Journal is a major achievement of our societies. Its growing impact on the world literature has already set *Diving and Hyperbaric Medicine* at the same level as many much older journals in the field … and we have only just begun. Our societies, advised and assisted by the Editor, need to keep pushing the envelope for the Journal. We need to keep our fingers on the pulse of what our readers really want.

A couple of issues under discussion include the possible downloading of the articles individually for a nominal fee for non-members, or going for more electronic and online subscriptions, just as the *Journal of Applied Physiology* and *Aviation Space and Environmental Medicine* have done.

International cooperation

Putting names to faces and spending time together sharing our points of view is the best way we know to foster new collaborations and new programmes for the benefit of patients and science. The difficulty is in keeping the energy levels up. Inertia and competing interests are our main enemies, but both can be successfully overcome by brisk and continuing dialogue between us. We have already achieved this in part with the EUBS members' forum and the ANZHMG Discussion Group, access to academic resources freely shared. We have further plans to open up each other's websites to reciprocal members. We see a bright future for closer ties between the Antipodes and Europe.

Fostering new ideas

Hyperbaric medicine is a relatively young field and there is an awful lot yet to do if the judicious, evidence-based, use of hyperbaric oxygen is to reach its full potential as a therapeutic agent. Every year, new ideas and new areas of interest emerge from basic research and novel clinical investigations. Some will prove useful and others will not. Whichever the outcome, the tragedy would be that such new ideas simply stop.

With a joint journal, and a joint ASM now and hopefully again in the future, our societies are in a unique position to present the state-of-the art of diving and hyperbaric medicine by a very broad faculty to a very broad audience – the kind of audience where the vital, but as yet unknown, collaborator is waiting to be inspired!

We commend the organizers of the Réunion meeting for both their vision and energy. Neither of us has ever looked forward to a scientific meeting with quite the same feeling of excitement and anticipation. May this be the first of many to come.

See you on Réunion!

Key words
Medical society, meetings, research, general interest

Original articles

Oxidative stress in breath-hold divers after repetitive dives

Sigrid Theunissen, Nicola Sponsiello, Miroslav Rozloznik, Peter Germonpré, François Guerrero, Danilo Cialoni and Costantino Balestra

Abstract

(Theunissen S, Sponsiello N, Rozloznik M, Germonpré P, Guerrero F, Cialoni D, Balestra C. Oxidative stress in breath-hold divers after repetitive dives. *Diving and Hyperbaric Medicine*. 2013 June;43(2):63-66.)

Introduction: Hyperoxia causes oxidative stress. Breath-hold diving is associated with transient hyperoxia followed by hypoxia and a build-up of carbon dioxide (CO_2), chest-wall compression and significant haemodynamic changes. This study analyses variations in plasma oxidative stress markers after a series of repetitive breath-hold dives.

Methods: Thirteen breath-hold divers were asked to perform repetitive breath-hold dives to 20 metres' depth to a cumulative breath-hold time of approximately 20 minutes over an hour in the open sea. Plasma nitric oxide (NO), peroxinitrites ($ONOO^-$) and thiols (R-SH) were measured before and after the dive sequence.

Results: Circulating NO significantly increased after successive breath-hold dives (169.1 ± 58.26% of pre-dive values; P = 0.0002). Peroxinitrites doubled after the dives (207.2 ± 78.31% of pre-dive values; P = 0.0012). Thiols were significantly reduced (69.88 ± 19.23% of pre-dive values; P = 0.0002).

Conclusion: NO may be produced by physical effort during breath-hold diving. Physical exercise, the transient hyperoxia followed by hypoxia and CO_2 accumulation would all contribute to the increased levels of superoxide anions (O_2^{2-}). Since interaction of O_2^{2-} with NO forms $ONOO^-$, this reaction is favoured and the production of thiol groups is reduced. Oxidative stress is, thus, present in breath-hold diving.

Key words

Freediving, breath-hold diving, hyperoxia, free radicals, nitric oxide, exercise

Introduction

At the end of the dive, breath-hold diving may result in hypoxia/hypercapnia, where alveolar oxygen partial pressure can be as low as 20–30 mmHg and arterial oxygen saturation around 50%.[1] Moreover, in order to increase the maximal breath-hold time, some divers perform hyperventilation, which reduces the partial pressure of carbon dioxide (PCO_2) before breath-holding and delays the urge to breathe. This procedure increases the risk of a hypoxic event during the dive. Whilst breath-hold divers may experience hypoxia during the ascent, the compression phase of the dive is associated with the reverse, hyperoxic conditions, because of increasing hydrostatic pressure leading to reduction of the intra-pulmonary gas volume and compression of the chest wall (Boyle's Law).[2] This, in turn, induces a reduction of cardiac output during the dive.[3] Oxidative stress has also been involved in cardiovascular pathologies and hypertension.[4–6]

In a previous study, decreased flow-mediated dilatation (FMD) of the brachial artery was observed after a series of breath-hold dives.[6] Interestingly, circulating nitric oxide (NO) was increased in these conditions. It was hypothesised that the production of reactive oxygen species (ROS) was increased during breath-hold diving, and that these ROS react with nitric oxide (NO) to form peroxinitrites ($ONOO^-$) which, in turn, reduce the ability of NO to achieve vasodilation.[6] The increased NO production could be due to physical exercise.[7] Different factors can be involved in the increased oxidative stress, including transient hyperoxia followed by hypoxia and CO_2 build up and/or an impaired tetrahydrobiopterin bioactivity, as found in hypertension-induced endothelial dysfunction.[8] Alternatively, in the absence of oxidative stress, a decreased FMD could result from alterations in cardiovascular function and autonomic control.[9]

The aim of this study was to observe whether oxidative stress markers are increased in breath-hold diving in order to confirm/refute the hypothesis that NO reacts with ROS to form $ONOO^-$ leading to a decrease in its bioactivity.

Methods

STUDY POPULATION

After written informed consent and institutional ethics committee approval (B200-2009-39), 13 non-smoking, experienced (at least four years of experience) male breath-hold divers volunteered for the study. Prior to entering the study, they were assessed as fit to dive by a qualified diving physician. None of the subjects had a history of previous cardiac abnormalities and none of them was on any cardio-active medication. All participants were asked to refrain from performing strenuous exercise for 48 hours before testing. For all the subjects, the daily diet was controlled by a medical nutritionist (author NS), avoiding nitrate-rich

food. All blood samples were drawn from an antecubital fossa vein during the morning and the last meal was dinner more than 10 hours before. The study was conducted in accordance with the Helsinki Declaration.

DIVE PROFILE AND TIMELINE OF MEASUREMENTS

Each breath-hold diver performed successive dives to a depth of 20 metres' sea water (msw) for a cumulative breath-hold time of approximately 20 minutes. Dives were organised in pairs allowing each diver to act as the safety buddy for the other (the thirteenth diver buddied with a safety diver). The total time in the water was approximately one hour. All dives were performed (after breathing air) in the open sea off Santa Maria di Leuca, Italy. Water temperature at the surface was approximately 30^{O}C, and 18^{O}C at depth. Air temperature was 35^{O}C. A 3 mm wetsuit was used by all divers.

MEASUREMENTS

Blood samples were collected on-shore one hour before diving and soon after the dives, on returning to the dive centre 15 minutes away from the dive site by boat. The samples were drawn into an EDTA tube and centrifuged according to the protocol (1,000 rpm for 15 min for the NO, 3,500 rpm for 10 min for the $ONOO^-$ and 13,400 rpm for 15 min for the R-SH at 4^{O}C) in order to separate blood cells and plasma. The plasma was then stored at -80^{O}C in a fridge installed specifically for this purpose in the diving centre. All analyses were performed within the following six months on the same microplate (one for each test) in order to analyse all the samples at the same time and avoid variance bias.

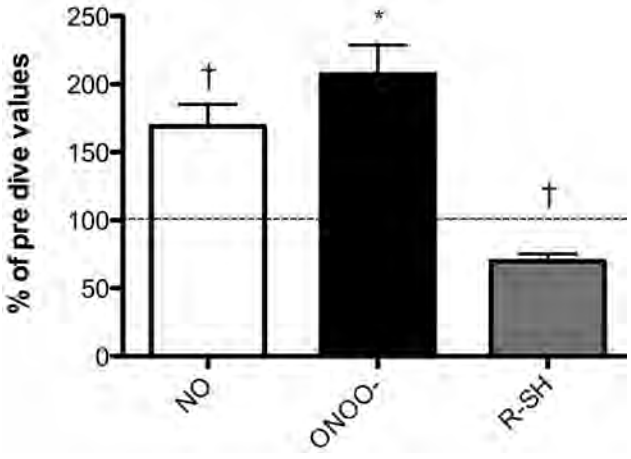
Plasma levels of nitrite and nitrate, NO metabolites, were determined by a colorimetric method (Fluka, Industriestrasse 25CH-9471, Buchs, Switzerland) according to the manufacturer's instructions. Peroxinitrites were measured using the OxiSelect™ Nitrotyrosine ELISA kit. The plasma samples or nitrated bovine serum albumin (BSA) standards were first added to a nitrated BSA preabsorbed EIA plate. After a brief incubation, an anti-nitrotyrosine antibody was added, followed by a horseradish peroxidase-conjugated secondary antibody. The protein nitrotyrosine content in the samples was determined by comparing with a standard curve prepared from predetermined nitrated BSA standards.

Thiols are extremely efficient antioxidants which are able to protect cellular lipids, proteins, and nucleic acids against peroxidative damage owing to their strong reductive capacity and their ability to react with free radicals.[10] The assessment of thiols (R-SH) in plasma was performed by the microanalysis method of Ellman.[11]

STATISTICAL ANALYSIS

Statistical analyses were conducted using GraphPad Prism 5 (La Jolla, CA, USA) on a PC. Data are expressed as a

Figure 1
Evolution of nitric oxide (NO), peroxynitrite ($ONOO^-$) and thiols (R-SH) after repetitive breath-hold dives to 20 msw with a cumulative submergence time of 20.6 +/- 1.5 min; results are expressed in percentage of pre-dive values (* P = 0.0012; † P = 0.0002)



percentage of pre-dive values. The difference between the percentage of pre-dive values and 100% was compared by a two-tailed one-sample t-test when normality of the sample was reached as assessed by the Kolmogorov-Smirnov test. Otherwise, the Wilcoxon Signed Rank test was used. Statistical significance level was set at $P < 0.05$.

Results

The divers (age 29 ± 4.7 years; height 176.5 ± 4.4 cm; weight 73.9 ± 4.6 kg) performed an average of 9 ± 2 dives with a mean cumulative breath-hold time of 20.6 ± 1.5 minutes. The mean individual duration time in the water was 61.47 ± 8.17 minutes. The mean surface interval between successive breath-hold dives was 4.5 ± 1.45 min. Variations in recovery time were dependent on the breath-hold times, which varied amongst the pairs of divers. All divers completed the study and no one developed symptoms of decompression sickness.

The plasma concentration of nitrate and nitrite, a marker of circulating NO, significantly increased after the dives (169.1 ± 58.26% of pre-dive values; P = 0.0002; Figure 1).

Nitrotyrosine, a marker of peroxynitrite level, doubled after the dives. (207.2 ± 78.31% of pre-dive values; P = 0.0012; Figure 1). Thiols were significantly reduced after the dives (69.88 ± 19.23% of pre-dive values; P = 0.0002; Figure 1).

Discussion

We observed an increase in circulating NO and peroxinitrites ($ONOO^-$) concommittant with a decrease in thiols (R-SH). NO derives from the transformation of L-arginine into L-citrulline and NO by nitric oxide synthase. This reaction needs five electrons and is dependent on NADPH

as the electron donor. It is the most important vasoprotector identified thus far. Some of the NO formed in endothelial cells is released into the circulation. Because of its affinity for erythrocytic haemoglobin, circulating NO undergoes multiple reactions with haemoglobin that lead to a decrease in its bioavailability in the vascular compartment.[12]

NO reacts and interacts with ROS, and this crosstalk can also have important effects on cardiac function.[13] To our knowledge, there are limited data on the time course of vascular alterations after breath-hold diving.[14] In scuba diving, decreases in intravascular volume and cardiac preload have been reported commonly after diving.[15] This is concomitant with a moderate increase in vascular resistance and may be the result of an inactivation of NO, probably through oxidative stress.[16] Indeed, plasma nitrite and oxidative stress markers remain altered during the 15-min recovery phase after hyperoxia.[17]

The present results confirm our previous data, which showed an increased circulating level of NO after a series of breath-hold dives.[6] This might be explained by acute moderate physical exercise, which is known to increase NO production.[7] Breath-hold divers have positive buoyancy at the surface and in the first metres of descent; physical effort is required to overcome this. When they ascend at the end of the dive, breath-hold divers have to fin upwards until the depth at which they recover their positive buoyancy.

Oxidative stress is associated with the generation of ROS, including superoxide anion (O_2^{2-}). This free radical reacts with NO to generate peroxinitrite ($ONOO^-$), which causes additional oxidative stress by increasing oxidase activity and inactivating antioxidant enzymes.[18] In this study, more $ONOO^-$ and less thiol (R-SH) were observed, which shows that oxidative stress is present during breath-hold diving.

To our knowledge, this is the first time these changes (in $ONOO^-$ and R-SH) have been reported in breath-hold divers. Hyperoxia found during the deep phase of breath-hold diving enhances the production rate of superoxide anion which is converted into hydrogen peroxide (H_2O_2) or reacts with NO to form $ONOO^-$.[19,20] Reacting rapidly with it, extracellular superoxide anions can decrease the bioavailability of NO.[21] The reduced availability of NO caused by O_2^{2-} leads to vasoconstriction and impairs NO-dependent vasodilation, which is consistent with recent findings on breath-hold divers.[6,22] Although H_2O_2 is a weak oxidant and relatively inert with most molecules, it oxidizes cysteine thiole (R-SH) groups within the protein molecule. This reversible reaction modifies their structure and function.[23] When ROS are present at physiological levels, NO reacts with proteins to form R-SH. But an increased level of O_2^{2-} facilitates its interaction with NO to form $ONOO^-$, instead of R-SH.[24] The total amount of R-SH is therefore reduced, as observed in this study. Superoxide anion also tends to react with itself. This phenomenon is termed 'dismutation' and leads to the production of water and oxygen through the action of superoxide dismutase (SOD).

Trained free divers increase SOD activity during breath-hold diving, and acute changes in antioxidant enzyme activities suggest that they may be protected from excessive antioxidant depletion and oxidative stress during breath-hold diving.[25] Suppression of the post-apnea oxidative stress by an increased concentration of thiobarbituric acid reactive substances after three months of breath-hold training has been reported.[26] In parallel, an activation of the plasma antioxidant system against oxidative stress has been reported in seals and in scuba diving.[27,28]

The increase in PO_2 during breath-hold immersion is so short-lived that it is difficult to believe that it could play a significant role. Nevertheless, it has been shown that for breath-hold divers even short hyperoxic or hypoxic periods act as a powerful trigger for physiological responses with successive breath-hold dives.[29,30] Thus, it seems that $ONOO^-$ is generated during such diving, even if hyperoxia is intermittent. This production leads to an inactivation of NO reducing the bioavailability of NO to participate in vasodilation. This may be a factor contributing to the endothelial dysfunction observed after breath-hold diving.[6]

Conclusion

After breath-hold diving, more circulating NO is observed with an increase in $ONOO^-$ and a reduction of R-SH. NO may be produced by the physical effort of breath-hold diving. Physical exercise, the transient hyperoxia followed by hypoxia and accumulation of CO_2 increase the level of superoxide anion (O_2^{2-}). This facilitates interaction of O_2^{2-} with NO to form $ONOO^-$, opposed to a production of R-SH. Oxidative stress is thus present in breath-hold diving.

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Oxygen exposure and toxicity in recreational technical divers

Andrew Fock, Richard Harris and Michael Slade

Abstract

(Fock A, Harris R, Slade M. Oxygen exposure and toxicity in recreational technical divers. *Diving and Hyperbaric Medicine*. 2013 June;43(2):67-71.)

Introduction: Central nervous system oxygen toxicity is a recognised risk in recreational open-circuit scuba diving with the use of nitrox (oxygen-enriched air mixtures), but other forms of oxygen toxicity in other diving settings are poorly understood. However, divers using constant partial pressure of oxygen closed-circuit rebreathers (CCRs) for multi-day, multi-dive expeditions could potentially experience cumulative oxygen exposures above the current recommended limits.

Methods: We followed a number of technical recreational diving expeditions using CCRs and recorded the cumulative oxygen exposures of the individual divers. Lung function and visual acuity were recorded at intervals during the expeditions.

Results: Over several 8- to 12-day expeditions, divers either approached or exceeded the recommended maximum repetition excursion oxygen exposure (REPEX) limits. Lung function did not show any significant decrement. Changes in visual acuity changes were reported in several divers but were difficult to quantify. Formal testing of one diver's visual acuity on return home demonstrated a myopic change that resolved over the subsequent eight weeks.

Conclusions: Recreational CCR divers conducting multi-dive expeditions of eight days or more may approach or exceed the REPEX oxygen limits. Despite this, there does not appear to be any significant decrement in lung function. Hyperoxic myopia occurs in some individuals. Changes in acuity appear to resolve spontaneously post exposure. Despite the lack of significant changes in respiratory function, divers should be cautious of such exposures as, should they require recompression therapy for decompression illness, this may result in significant pulmonary oxygen toxicity.

Key words

Technical diving, oxygen, toxicity, pulmonary function, vision, diving research

Introduction

Since the introduction of nitrox (enriched-air nitrogen or EAN), in the early 1990s, the use of oxygen-rich breathing mixtures in recreational diving has become increasingly common.[1] While recreational divers will commonly use nitrox mixtures of 28–36% oxygen (O_2), technical divers use mixtures of up to 100% O_2 in order to accelerate decompression after deep mixed-gas dives. With the introduction of commercially available closed-circuit rebreathers (CCRs) in the late 1990s, technical recreational divers were able to optimize their decompression times further by the use of a constant partial pressure of O_2 (PO_2, usually 1.3–1.4 atm (131–141 kPa))* during technical dives. However, the use of such equipment for deep mixed-gas diving with prolonged decompression times has the potential to result in the diver exceeding the National Oceanographic and Atmospheric Administration's (NOAA) recommended limits of central nervous system (CNS) O_2 exposure.[2] Where more than one dive per day is conducted over the course of a multi-day expedition, divers may also exceed the NOAA daily limits for pulmonary O_2 toxicity limits or the recommended repetitive excursion (REPEX) exposure limits over the course of the expedition.[2,3] During a previous observational study of a group of technical rebreather divers, the authors noticed symptoms suggestive of both pulmonary and ocular O_2 toxicity.[4]

Aims

This study aimed to quantify the O_2 exposure of recreational technical divers using CCR scuba during multi-day expeditions where more than one dive per day was conducted. It also aimed to measure the extent of pulmonary and ocular toxicity by assessing the changes in respiratory spirometry and ocular refraction during such expeditions.

Methods

Ethics approval was given by the Alfred Hospital Ethics Committee (project # 41/07) and the study was conducted in accordance with the Helsinki Declaration. Formal written consent was obtained and divers were given information sheets outlining the nature and aims of the study.

Twenty-nine divers participating in mixed-gas, multi-day, multi-dive diving expeditions were recruited between 2007 and 2010. In some cases, individual divers participated in the study during several of the expeditions over several years. All divers, with the exception of one, used CCRs that maintained

*** Footnote:** The units prevalent in the technical diving community are used for pressure measurements in this article. To use kPa would render the paper largely unintelligible to at least part of its intended readership (the divers themselves) and it would also fail to prepare physicians for the language they will hear technical divers using. The agreed format is: atm for partial pressures or gauge pressures (e.g., the typical PO_2 setpoint of a rebreather is 1.3 atm) and atm abs for ambient pressures at depth.

a constant PO_2 between 1.3 and 1.4 atm during the dives. One diver using open-circuit scuba was recruited to gain insight into typical differences in O_2 exposures between open-circuit (OC) and CCR divers on the same expedition. In some cases decompression was accelerated either by increasing the PO_2 in the CCR manually to 1.5–1.6 atm during the final decompression stop or by using surface-supplied (SS) O_2 at the 6 metres' sea water (msw) decompression stop.

Inclusion criteria included:

- participation in multi-day, multi-dive diving on a suitable dive platform using CCRs such that significant O_2 exposure was likely;
- no known pre-existing lung or ocular disease;
- willingness to participate in the study.

The CCRs maintained a setpoint PO_2 of 1.3–1.4 atm for the majority of the dive. The final decompression was conducted between 1.3 and 1.6 atm on either the CCR or SS O_2 at 6 msw. The average depth of the dives was 69 msw. Divers breathed trimix (helium, oxygen and nitrogen) diluent during all dives.

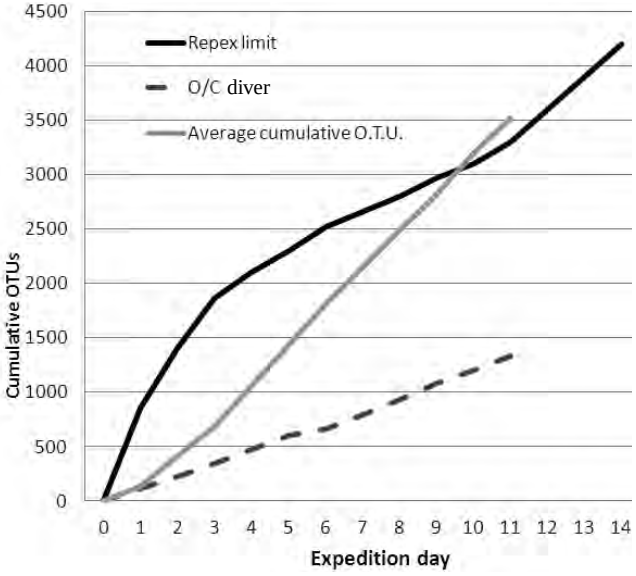
All dives were logged for depth, duration at setpoint and PO_2 during decompression. O_2 exposures were calculated using the method previously described by others and daily cumulative O_2 exposure stored and plotted using Numbers™ spreadsheet software (Apple® 2009).[3,5]

Respiratory function was monitored using an Easy One™ spirometer (Niche Medical®) and stored in the spirometer's proprietary database. This device uses an ultrasonic method of flow detection and does not require calibration either before use or in the field.[6] Tests were conducted pre-expedition and at regular intervals (usually every third day) during the expedition as well as on the day post expedition. Tests conducted during the expeditions were done below deck at the same time each day (usually 3–4 hours after the last dive) to minimize variability. Parameters recorded were limited to those achievable by the device.[6]

Refractive changes were measured using a full-size Snellen chart at 6 metres' distance and a set of corrective lenses. Assessments were conducted on each eye at the same time of day (on deck) to minimize any possible refractive variations secondary to different lighting. Divers were asked to select the lens which produced the sharpest image of the 6/6 line on the Snellen chart. As with the respiratory tests, refractive measurements were carried out pre- and post-expedition as well as at regular intervals during the expedition.

Divers were questioned as to potential respiratory, ocular and decompression sickness (DCS) symptoms at the time that the respiratory tests were conducted. Divers acted as their own controls, allowing the use of the Student paired t-test. Statistical analysis was performed using the integrated statistical package in the Apple® software Numbers™ spreadsheet. Statistical significance was taken as $P < 0.05$.

Figure 1
Average cumulative oxygen exposures during all diving expeditions in the series



Results

SUBJECTS AND DIVE PROCEDURES

Eight divers who conducted only one dive per day on the expedition in which they were participating, as well as the chief researcher, who was forced to leave the expedition for several days for unrelated reasons, were excluded. After exclusions,14 male CCR divers (mean age 46-years, range 34–64; BMI 27 kg m^{-2}, range 23–30) providing 20 data sets over three multi-day diving expeditions and one OC diver were studied. Dives of mean duration 112 minutes (SD 32; range 10–240 min) were conducted twice per day with a surface interval of approximately 4 hours between dives.

PULMONARY OXYGEN EXPOSURE

Cumulative O_2 exposures approached or exceeded the REPEX recommended O_2 limits in most CCR divers by day 8 of the diving expeditions (Figure 1). Where divers elected to take a dive or a day off, this reduced the likelihood of exceeding the limits during the expedition.

The O_2 exposure of the OC scuba diver was substantially different to the CCR divers, despite the OC diver using EAN 50% and 100% O_2 for decompression. Overall, the OC diver conducted shorter dives and had substantially reduced bottom times compared to the CCR divers (OC diver average dive time 44 (SD 14) min versus CCR divers' average dive time 112 (SD 32) min), being constrained by bottom gas duration at the depths experienced (average depth 69 msw).

No significant decrements in forced expiratory volume in 1 sec (FEV_1) and force vital capacity (FVC) were seen, despite almost all the divers approaching or exceeding the REPEX

Table 1
Mean % changes in forced vital capacity (FVC); forced expiratory volume in 1 sec (FEV_1); peak expiratory flow rate (PEFR) and forced expiratory flows at various lung volumes (FEF_{25}, FEF_{75}, $FEF_{25\ 75}$)

	Mean % change	SD	P value
FVC	-0.4%	4.5%	0.42
FEV_1	-3.0%	5.0%	0.32
PEFR	0.2%	6.8%	0.18
FEF_{25}	1.5%	10.3%	0.43
FEF_{75}	-9.0%	20.4%	0.18
$FEF_{25–75}$	-13.0%	13.7%	0.07

O_2 exposure limits (Table 1). Forced expiratory flow 25–75% ($FEF_{25–75\%}$) showed a decrement of 13% which did not reach statistical significance ($P = 0.07$).

Nearly half the divers in the earlier expeditions complained of retrosternal discomfort associated with prolonged O_2 exposure. During the later expeditions in the series where the use of SS O_2 for decompression was less common, these symptoms almost completely disappeared despite total dive times being longer on average. Two-thirds of the divers on the first expedition also complained of a non-productive cough post dive. This symptom was noticeably less common (only one of eight divers) in the last expedition, where divers tended to remain on their CCR, which provided a warm, humidified breathing mixture during decompression.

REFRACTIVE CHANGES

The 14 CCR divers reported subjective difficulty with distance acuity by the end of the expeditions in 18 of the 20 data sets measured. Mean changes in visual acuity are shown in Table 2. Measured refractive changes during the expeditions varied by up to a dioptre from day to day. Measured changes at the end of the expeditions failed to accurately demonstrate the symptomatic decrement in distance acuity described by the divers.

One diver sought formal evaluation post expedition with an ophthalmologist. This demonstrated a 0.75:1.0 dioptre (S:D) myopic change which had resolved to 0.0:0.0 (S:D) eight weeks later. Intraocular pressure was measured as normal at both examinations. Another diver required the use of -1.5 D corrective lenses for six weeks post expedition for driving and distance vision, but did not seek formal evaluation. The oldest diver in the group did not report or experience any myopic refractive changes.

CNS O_2 EXPOSURE

While formal calculation of CNS O_2 exposure was not performed, based on the average dive time per day on 1.3 atm O_2 and the use of increased PO_2 during decompression, the NOAA CNS limits (Table 3) were routinely exceeded.

Table 2
Mean % changes in visual acuity over time of diving expedition ($n = 20$)

Expedition day	Mean change in acuity (dioptres)
1	0.0
6	0.4
9	0.2
12	0.3
13	0.4

Table 3
NOAA CNS allowed oxygen exposure times

Exposure time (min)	PO_2 (atm)	Daily limit (min)
45	1.6	150
120	1.5	180
150	1.4	180
180	1.3	210
210	1.2	240
240	1.1	270
300	1.0	300
360	0.9	360

No diver during this series complained of or experienced any symptoms suggestive of CNS toxicity while in-water; however, a number of divers did mention that they had begun to experience very vivid dreams at night towards the latter stages of the various expeditions.

Discussion

The history of our understanding of both CNS and pulmonary O_2 toxicity has been described previously.[7] Studies conducted during the 1940s using Royal Navy volunteers demonstrated that there was considerable inter- and intra-individual variability to O_2 toxicity (see historical article in this issue, p. 105-8).[8] Whilst, in general, increased pressure reduced the time for the first development of CNS symptoms, convulsions were often the first sign of O_2 toxicity and could occur at any time when the PO_2 exceeded 1.7 atm. In contrast, despite research-based evidence, the US Navy developed a set of recommended O_2 exposures which exceeded this threshold, albeit for short periods of time.[9] As seen in this study, technical divers using CCRs routinely exceed the NOAA imits for CNS O_2 exposures below 1.6 atm, apparently without issue. This would appear consistent with the earlier Royal Navy studies.

In contrast to the CNS O_2 exposure, until recently it has been uncommon for recreational technical divers to receive enough O_2 during a dive to enter into the realm of potential pulmonary O_2 toxicity. This was due largely to the logistical difficulties of carrying enough open-circuit gas to accumulate sufficient dive time to result in toxic exposure, as evidenced in the OC diver in this study. As

with CNS exposure, pulmonary O_2 toxicity is related to time and pressure. Exposure curves with expected reductions in FVC or FEV_1 are the generally quoted end points, and mathematical descriptions of exposure are commonly used describing the exposure in terms of O_2 toxicity units (OTUs) or units of pulmonary toxicity dose.[3,5] Once again, considerable inter-individual variability has been observed and most research has focused on single O_2 exposures.[5]

While it has been long understood that low O_2 or air breaks of 5–10 minutes duration delay the onset of pulmonary O_2 toxicity symptoms, the variability in recovery of the lungs once normoxia has been reestablished has meant that an accurate mathematical description of recovery has largely eluded researchers.[10–12] Instead, the cumulative daily pulmonary O_2 exposure during habitat diving was utilized with an elevated PO_2 by adding the OTUs accrued during excursions to depth and applying an empirical algorithm to determine a daily oxygen exposure limit.[3] These became the REPEX limits which are commonly used by technical divers conducting multi-day dives, despite the fact that they were derived in a rather different diving context (excursion dives from saturation).[3] Nevertheless, the REPEX limits probably represent the best data currently available to technical divers in order to avoid both pulmonary and whole-body O_2 toxicity, given the scarcity of other data.

Perhaps the best studies available on pulmonary O_2 exposure with constant PO_2 diving have been those conducted by the US Navy.[13–15] While the total dive times were similar in their divers to those in our group, the exposure was in a single, four-hour dive with a 20–44 hour surface interval, depending on the study. Divers breathed humidified SS O_2 at the bottom of a pool. They were allowed to surface and breath room air (to eat and drink) for no more than 5 minutes per hour. Divers were assessed for pulmonary function including the diffusion capacity of the lung to carbon monoxide (DL_{CO}), as well as ocular refractive and pressure changes. The divers in these studies showed substantial variability in the effects of these exposures, with some individuals showing decrements in both pulmonary and refractive function during the study, which resolved later.

This is consistent with our results, where we also measured changes that seemed to return to baseline or near baseline by the end of our study. In the US Navy studies, the DL_{CO} decreased by 0.6% per day on average while other parameters seemed to show a variable response, with some individuals oscillating about a mean and others showing decrements or occasionally actually improving. Several of the divers also showed significant decrements in their $FEF_{25–75}$. Unexpectedly, in general, the divers' reported symptoms did not correspond temporally with measured pulmonary changes. The overall conclusions were that this type of exposure caused little in the way of clinically significant changes to pulmonary or ocular refractive function. However, it should be noted that some individual divers did show significant changes. While we attributed our observed variability in refractive and pulmonary function to the limitations of our equipment (necessitated by the requirement to be portable while operating off-shore) the variability of results also seen in a comprehensive respiratory laboratory suggests that our observed variability is, in fact, not artifact. Indeed, this observed variability and the wide normal range of some of the respiratory parameters (e.g., $FEF_{25–75\%}$) brings into question the value to clinicians of the use of respiratory tests (or indeed symptoms) as a predictive measure for the onset of pulmonary O_2 toxicity.

The fact that one of our divers showed significant refractive changes when formally measured post expedition compared to the final measurement during the expedition does bring into question the sensitivity of refractive testing performed during our study. Regardless of this, significant shifts in refraction can occur in divers exposed to this level of O_2 over several days but may vary on a daily basis. A similar myopic refractive change has been reported in a technical diver.[16] In this case, the diver also had a markedly reduced intra-ocular pressure (IOP). In the diver in our series, the IOP was within the normal range. In both cases, the divers' vision returned to baseline over several weeks.

A progressive 0.25D per week myopic refractive change has been reported in patients undergoing hyperbaric oxygen therapy (HBOT).[17] This change is unrelated to changes in axial length or corneal curvature, implying that it is due to lenticular refractive change alone.[18] The changes observed in our study (with only one week of diving at an average of 1.3 atm, versus most HBOT exposures) would seem rather larger and faster than those described in chamber exposures and may reflect the twice-daily exposure as well as the reduced recovery time between dives with our group. It would be interesting to more formally assess such a group pre- and post-dive expedition to better quantify the changes described. Certainly, the myopic changes observed were enough to cause the divers difficulty in seeing clearly the signs in the airport on the way home and may also be a problem with distance vision for driving. As a side benefit, most divers commented that they found it much easier to read their dive computers as the expeditions progressed!

The original impetus for this study was symptoms suggestive of pulmonary O_2 toxicity during a previous study.[4] At that time, dives were conducted on the diver's CCR and the final decompression stop used SS O_2 but, by the time of the last expedition in 2010, almost none of the divers used SS O_2, except for short periods of time, and none of the divers complained of the retrosternal burning or other symptoms which had been common previously. It is possible that the original observations may well have been due to the dry nature of the SS gas rather than the O_2 *per se*, though in the US Navy study, up to 16% of divers reported symptoms despite their SS O_2 being humidified.[14]

Several divers spontaneously reported experiencing vivid dreams during the latter stages of the last expedition. On close questioning, they stated that this was also common during the latter stages of previous expeditions. It is interesting to speculate whether this might be an effect of the raised levels of cerebral oxygen and an effect on neurotransmitter levels.

During more than 850 dives to an average depth of 64 msw using trimix , there were only four cases of "*niggles*" (minor type I DCS symptoms, which were self-treated by the divers by in-water recompression on 100% O_2), all during the early expeditions. Given the already substantial pulmonary oxygen exposures, had any of these divers required a more formal oxygen recompression treatment, it may well have resulted in significant pulmonary oxygen toxicity.

Conclusions

Despite substantial O_2 exposures during multi-day, multi-dive expeditions using CCRs, significant measurable changes in pulmonary function were not observed. Despite this lack of observed change in pulmonary function, divers should be aware of the potential for pulmonary toxicity and should keep track of their exposure. Some divers developed myopic refractive changes that took up to eight weeks post expedition to completely resolve. In individuals who are known to experience refractive changes associated with this type of exposure, it may be prudent to carry a pair of -1.0D corrective lenses for the flight home.

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Rescue of drowning victims and divers: is mechanical ventilation possible underwater? A pilot study

Bernd E Winkler, Claus-Martin Muth, Wataru Kaehler, Gebhard Froeba, Michael Georgieff and Andreas Koch

Abstract

(Winkler BE, Muth CM, Kaehler W, Froeba G, Georgieff M, Koch A. Rescue of drowning victims and divers: is mechanical ventilation possible underwater? A pilot study. *Diving and Hyperbaric Medicine*. 2013 June;43(2):72-77.)

Introduction: In-water resuscitation has recently been proposed in the European resuscitation guidelines. Initiation of mechanical ventilation underwater might be considered when an immediate ascent to the surface is impossible or dangerous. The present study evaluated the feasibility of such ventilation underwater.

Methods: A resuscitation manikin was ventilated using an Interspiro® MK II full-face mask or with an Oxylator® ventilator via a facemask or a laryngeal tube, or with mouth-to-tube inflation. Tidal volumes achieved by the individual methods of ventilation were assessed. The ventilation tests were performed during dives in the wet compartment of a recompression chamber and in a lake. Ventilation was tested at 40, 30, 20, 12, 9 and 6 metres' depth.

Results: Ventilation was impossible with the cuffed mask and only sufficient after laryngeal intubation for a small number of breaths. Laryngeal tube ventilation was associated with the aspiration of large amounts of water and the Oxylator failed during the ascent. Efficient ventilation with the MK II full-face mask was also possible only for a short period. An absolutely horizontal position of the manikin was required for successful ventilation, which is likely to be difficult to achieve in open water. Leakage at the sealing lip of the full-face mask and the cuff of the laryngeal tube led to intrusion of water and resulted in subsequent complete failure of ventilation.

Conclusions: The efficacy of underwater ventilation seems to be poor with any of the techniques trialed. Water aspiration frequently makes ventilation impossible and might foster *emphysema aquosum*-like air trapping and, therefore, increase the risk of pulmonary barotrauma during ascent. Because the limitations of underwater ventilation are substantial even under ideal conditions, it cannot be recommended presently for real diving conditions.

Key words

Drowning, scuba diving, rescue, resuscitation, extraglottic airway devices, ventilators, equipment

Introduction

Drowning is a frequent cause of death in adolescents and young adults with a predominance of males.[1] Drowning accidents are associated with a poor outcome, high lethality and high long-term morbidity, especially when occurring in open water.[2,3] The current resuscitation guidelines of the European Resuscitation Council recommend that ventilation be started in the water during rescue swimming.[4] For the resuscitation of drowning victims, an early onset of oxygenation by bag-mask-ventilation or CPAP with a high inspiratory oxygen concentration has been shown to be beneficial.[5–6] Higher survival rates and a reduction in severe neurological damage have been reported when in-water resuscitation is performed.[7] The feasibility of in-water mouth-to-nose ventilation has been demonstrated in the pool.[8] Several techniques of out-of-water and in-water ventilation with modified scuba regulators and modified closed-circuit rebreathers have been reported previously.[9–12] Our group has previously demonstrated the feasibility of in-water ventilation with the Oxylator® ventilator (CPR Medical Devices INC, Toronto, Canada).[13]

However, in lethal diving accidents the victim is often still underwater and apneic, since drowning has been reported to be the most frequent cause of lethal diving accidents.[14–16] In the rescue of an apneic diver it can take several minutes until the surface is reached and ventilation is initiated. Especially in situations where a direct ascent is impossible, ventilation underwater might be beneficial to bridge the time until the surface is reached. Such scenarios include cave dives or injuries to military divers in hostile areas, in which an ascent could be lethal. In such situations, underwater ventilation could potentially enhance the survival rate by reducing hypoxia. This might further reduce arrest time and improve the outcome of submerged drowning patients.

Rescue and military divers are frequently equipped with full-face masks to protect the face from cold water and pollutants and enable the diver to communicate via a speakerphone. Whenever a diver who is wearing such a full-face mask is unconscious and apneic, the mask might be used to immediately ventilate the diver. When divers are not equipped with a full-face mask or when drowning victims have to be rescued by rescue divers, solutions other than a full-face mask should be considered. Mouth-to-mouth ventilation appears to be impracticable and dangerous. One possible method could be to use a ventilation mask, though this requires some degree of experience to achieve a satisfactory level of competence. Alternatively, supraglottic airway devices, which have become popular in pre-hospital and hospital emergency settings are relatively easy to

Figure 1
Test lung connected to manikin



operate. The laryngeal tube is a supraglottic airway device, some models having a distal cuff in the oesophagus in order to reduce the regurgitation of gastric content.

The aim of the study was to test the efficacy and feasibility of ventilation underwater via three devices: a full-face mask; a ventilation mask and a cuffed laryngeal tube.

Methods

The dives were performed in the diving (wet) compartment of the hyperbaric facility *Hydra 2000* of the German Navy in Kiel-Kronshagen, Germany. In this water-filled section, dives to a maximum depth of 40 metres (m) were performed with stops for further testing during ascent at 30, 20, 12, 9 and 6 m.

TEST SETTING

A Maquet® anaesthetic test lung was connected to a Laerdal Resuscitation Annie® (Laerdal Medical, Stavanger, Norway) via a non-return valve (Figure 1). The trachea-like hose of the manikin was connected to the inlet branch of the valve and a hose for the measurement of tidal volumes to the outlet branch. The tidal volumes were measured using an inverted, scaled cylinder. At the surface, the precision of an inverted cylinder is lower than the precision of spirometric devices. However, re-calibration is required for spirometric devices at all depths and these devices are not designed to work at

Figure 2
The Interspiro® MK II mask (the left hand is not positioned on the forehead as described, so as not to obscure the photo)



40 m of depth (approx. 507 kPa). For this reason, direct measurement of tidal volumes via the cylinder was chosen to provide a robust and fail-safe method. The tidal volumes were recorded by a person placed in the dry compartment of the recompression chamber.

METHODS OF VENTILATION

Ventilation was assessed using three devices: a full-face mask, a ventilation mask, and a laryngeal tube. Ventilation was provided by an Oxylator® ventilator. The Oxylator is a robust pressure-controlled emergency ventilator which had been tested in dry hyperbaric chambers and which is popular with special forces. In the present study, the Oxylator was operated when submerged in the water and obtained the operating air from a scuba cylinder. The peak pressure of the Oxylator was adjusted to 45 hPa and compressed air was used rather than oxygen to avoid a critical increase in oxygen partial pressure in the chamber.

Interspiro® MK II mask (Figure 2)
The Interspiro® MK II mask (Interspiro AB, Täby, Sweden) is one of the most popular full-face masks and, therefore, was used in the present study. The mask was attached to the manikin's head and excess hydrostatic pressure function was activated to avoid the intrusion of water. The left hand of the rescuer pressed the upper part of the mask to the forehead and the right hand pressed the mask to the chin and lifted the chin (Figure 2). Both hands were used to tilt the head. The purge button of the full-face mask was pressed with the thumb of the right hand for five seconds every time an inspiration was required, and released afterwards for exhalation.

Mask ventilation (Figure 3)
The cuff of the ventilation mask (Fortune Medical Instrument Corp, Taipei, Taiwan) was filled with water before the experiment to prevent pressure-dependent changes of the cuff volume. The mask was connected to

Figure 3
Ventilation mask held on manikin's face



the Oxylator for automatic ventilation. The seal between the mask and the manikin's face was maintained by an experienced anaesthetist.

Laryngeal tube® (Figure 4)
A disposable VBM LTS-D laryngeal tube® (VBM Medical, Sulz, Germany) was used for airway protection and the cuff of the laryngeal tube was inflated with water to prevent changes of cuff volume with pressure changes. The insertion of the laryngeal tube was also performed by an experienced anesthetist, and the laryngeal tube was connected to the Oxylator with the same peak-pressure settings. Mouth-to-tube ventilation was also assessed at the shallower depths, when the Oxylator ceased to function.

ASSESSMENT IN OPEN WATER

The MK II full-face mask and the Oxylator in combination with the laryngeal tube were also tested in a freshwater lake at a depth of 10 metres.

Statistical analysis

Microsoft Excel 2007™, Microsoft Inc®, Washington, USA and SPSS 19, SPSS Inc, Chicago, Illinois, USA were used for statistical analysis. The analysis was limited to descriptive statistics because of the small sample size.

Results

The tidal volumes achieved with the different types of ventilation are presented in Table 1.

FULL-FACE MASK

Ventilation with the Interspiro® MK II full-face mask was initially satisfactory. However, large amounts of water

Figure 4
The disposable VBM LTS-D laryngeal tube®



entered the manikin within approximately two minutes of commencing ventilation, even though the full-face mask was used in the activated excess hydrostatic pressure mode. The intrusion of water resulted in a decrease of ventilation efficacy and finally made ventilation impossible. Further ventilation was only possible after removal of water from the lung and airways of the manikin at the surface. The volume of aspirated water exceeded 500 ml every time the lung was emptied.

VENTILATION MASK

The use of the Oxylator ventilator with a ventilation mask consistently failed after a single breath. Major amounts of water entered the mouth and trachea and resulted in a failure of ventilation.

LARYNGEAL TUBE AIRWAY

Ventilation with the laryngeal tube and the Oxylator was only possible for five to 10 breaths at 40, 30 and 20 m. Again, aspiration of water was the reason for the failure of ventilation, and the aspirated water exceeded 500 ml. As with the full-face mask, further ventilation was only possible after the removal of water from the airways and test lung. The Oxylator failed at the 12 m depth. Both the automatic ventilation and emergency gas flow failed. At depth, there was no way to open the top of the ventilator to gain access to the valves and repair them. In contrast, the pressure reducer was still working properly.

Mouth-to-laryngeal tube ventilation was also performed, although not part of the original study design, to maintain ventilation and to evaluate an emergency procedure in the case of a failure of the Oxylator. As with the Oxylator-based laryngeal tube ventilation, the number of successful ventilations was less than 10, and more than 500 ml of water entered the lung.

ASSESSMENT IN OPEN WATER

The open-water experiments at a depth of 10 m confirmed the problem of intrusion of water observed in the hyperbaric chamber. It was technically extremely difficult to achieve a horizontal position of the manikin even when one diver at the manikin's head was managing the ventilation and

Table 1
Tidal volumes, mean (range), measured at various depths using three resuscitation methods; mouth-to-tube ventilation was initiated at a depth of 12 msw as a result of the failure of the Oxylator ventilator

Depth (msw)	Tidal volume (ml)		
	Interspiro® MK II mask	Oxylator with mask/laryngeal tube® (LTS-D)	Mouth-to-laryngeal tube
40	163 (150–225)	356 (150–600)	Not tested
30	193 (150–300)	456 (150–750)	Not tested
20	363 (150–600)	450 (300–750)	Not tested
12	425 (150–750)	Device failure	400 (150–750)
9	214 (150–450)	Device failure	390 (150–600)
6	477 (150–600)	Device failure	400 (300–450)

two other divers were assisting the ascent. The test lung was not inflated if the manikin's thorax was too far below the ventilator and overinflated when the thorax was above the ventilator. Furthermore, expiration frequently failed completely leading to hyperinflation.

Discussion

Ventilation underwater with all devices tested in the present study was difficult and associated with serious problems.

VENTILATION WITH THE MK II FULL-FACE MASK

The Interspiro® MK II full-face mask provided a sufficient seal only at the beginning. A chin lift/head tilt was required to open the airway and achieve ventilation. As a consequence of this manoeuvre, the mask frequently slipped from the ideal position because of the slippery surfaces underwater. The leakages were large enough that the excess hydrostatic pressure feature of the mask was unable to compensate for this. Water entered the pharynx of the manikin, resulting in a failure of ventilation. Moreover, the tidal volumes applied by the MK II mask depended highly on depth.

OXYLATOR-MASK VENTILATION

The use of the Oxylator in combination with a ventilation mask was impossible. Leakage resulted in an intrusion of water, even though a face mask with a soft, water-filled silicon cuff was used and the mask-ventilation was performed by an experienced anesthetist. If an anesthetist with daily practice in mask ventilation is unable to achieve sufficient conditions for ventilation with the ventilation mask, it is extremely unlikely that paramedical and lay persons would be able to ventilate with a mask under realistic open-water conditions.

OXYLATOR-LARYNGEAL TUBE VENTILATION

Ventilation conditions were better with the laryngeal tube, most likely because of a better seal of the cuff of the tube compared to the mask. Nevertheless, there was still intrusion of water into the pharynx, causing the ventilation to fail after five to 10 ventilations. After the ascent to 12 m, the Oxylator ventilator failed completely. The most likely reason for this device failure air is trapped inside the ventilator when it was switched off during the ascent. As a consequence, there was most likely an excessive pressure inside the ventilator.

Even when the Oxylator is operating normally, there are several problems that need to be addressed. First, the PEEP level cannot be adjusted manually and is set to approximately 3–5 kPa which is rather low for drowning victims.[17] Second, the Oxylator is a pressure-controlled ventilator, i.e., the tidal volumes applied depend highly on the compliance of the patient's lungs.[18] Therefore, tidal volumes might vary during the rescue process.[19] Nevertheless, there are also studies which reported less stomach insufflation, more reliable tidal volumes and a greater chance of normocapnia when using the Oxylator compared to bag-mask ventilation.[20,21] Furthermore, hypo- or hypercapnia might be fostered by the fact that the tidal volumes applied by the Oxylator were pressure-dependent with depth.

LEAKAGES AND ASPIRATION

All the ventilation systems tested resulted in major aspiration. In most trials, the volume of aspirated water in the test lung exceeded 500 ml. Furthermore, the transparent hose that connected the pharynx of the manikin to the test lung was completely filled with water and air was unable to pass through it. This indicates that aspiration of water will rapidly result in a failure of ventilation. Under the ideal test conditions of the 'wet' chamber, the manikin could be lifted out of the water easily to remove water from the test lung, the trachea-like connecting hose and the mouth and pharynx, but in a realistic drowning scenario there is no way to remove water from the airways of the patient. Therefore, it is highly unlikely that ventilation would be possible over longer than five to ten breaths.

Even if aspiration did not result in a failure of mechanical ventilation, it would impair pulmonary gas exchange considerably. The average amount of fluid aspiration in drowning is comparatively small, rarely exceeding approximately 2.2 ml kg^{-1} body weight.[22] On the other hand, the amount of aspirated fluid plays a central role in the hypoxia from which drowning victims suffer, since even

small quantities of aspirated fluids – as little as 1–2.2 ml kg^{-1} body weight – will result in a significant decrease of arterial oxygen content.[22–24] Therefore, it will take far longer until adequate oxygenation is restored in the case of aspiration compared to a situation without aspiration of fluid.[25–27]

PRESSURE DIFFERENCES AT DEPTH AND LIMITATIONS OF VENTILATION

Even if an optimal seal could be achieved, the hydrostatic pressure of the water is an important additional problem. In our test setting, a pressure as high as 45 hPa (the maximum pressure achievable with the Oxylator) was used, which is relatively high for an airway not secured with an endotracheal tube. It is uncertain whether the Oxylator actually reached this maximum pressure underwater or whether it cycled from inspiration to expiration earlier. Unfortunately we were unable to measure ventilation pressures underwater. During mask ventilation, peak pressures should not exceed 15–20 hPa because the risks of gastric insufflation, regurgitation and aspiration are increased at higher airway pressures.

In the context of Oxylator ventilation (45 hPa) this means that the resulting pressure in the lung is 25 hPa when the lung is 20 cm below the Oxylator or 65 hPa when the lung is 20 cm above the Oxylator. If the ventilator is set to 45 hPa and the patient is in upright position which is common during the rescue manoeuvre of divers, there will be only a minimal ventilation pressure in the lung and ventilation is likely to fail. If the patient's chest is above the ventilator, pressures in the lung can quickly reach and exceed 70 hPa potentially resulting in pulmonary hyperinflation and barotrauma.

Drowning results in a decrease in pulmonary compliance. Additionally, the diving equipment contributes to reduced chest wall compliance. Based on these two factors, high peak pressures will most likely be required to achieve sufficient tidal volumes. The median leak pressure of the laryngeal tube is only 28 hPa and the leak pressure of the Combi tube – which is the highest among all supraglottic devices – is only 34 hPa.[28] The peak pressures required for underwater ventilation might, therefore, be higher than the maximum leak pressure, which will probably limit the applicability of supraglottic airway devices for underwater ventilation.

Another critical aspect with respect to pulmonary barotrauma is so-called *emphysema aquosum*. *Emphysema aquosum* has been reported by pathologists, radiologists and forensic scientists in drowning victims.[29–31] Water in the bronchioli either causes bronchospasm or works like a valve by limiting the air flow from the alveoli to the bronchioli. If aspiration is aggravated by underwater ventilation, the ventilation efforts might foster *emphysema aquosum*, i.e., air trapping. During ascent, this trapped air could result in pulmonary barotrauma. Because pulmonary barotrauma is associated with a high morbidity and mortality, the advantages of underwater ventilation appear to be questionable, even when aspiration is minimal.

PRACTICAL USE IN OPEN WATER

Given the considerable difficulties in achieving a horizontal position, the aspiration of large volumes of water and low efficacy, underwater ventilation in open water appears to be virtually impossible with the techniques investigated.

Conclusions

The practical limitations encountered are too serious to make underwater ventilation with any of the methods tested feasible and, therefore, they cannot be recommended. The intrusion of water rapidly limits the efficacy of ventilation. Such aspiration could result in a valve-like mechanism leading to *emphysema aquosum*, which might foster pulmonary barotrauma. Furthermore, an absolutely horizontal position of the manikin was required for even a brief period of successful ventilation. This appears to be unrealistic when real drowning victims have to be rescued in open water. Even though underwater ventilation would make theoretical sense under some special circumstances such as cave diving or dives in hostile areas, the practical problems severely limit its applicability. New inventions and approaches might solve the considerable problems that currently limit the applicability of underwater ventilation.

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Analysis of recreational closed-circuit rebreather deaths 1998–2010

Andrew W Fock

Abstract

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Introduction: Since the introduction of recreational closed-circuit rebreathers (CCRs) in 1998, there have been many recorded deaths. Rebreather deaths have been quoted to be as high as 1 in 100 users.

Methods: Rebreather fatalities between 1998 and 2010 were extracted from the *Deeplife* rebreather mortality database, and inaccuracies were corrected where known. Rebreather absolute numbers were derived from industry discussions and training agency statistics. Relative numbers and brands were extracted from the *Rebreather World* website database and a Dutch rebreather survey. Mortality was compared with data from other databases. A fault-tree analysis of rebreathers was compared to that of open-circuit scuba of various configurations. Finally, a risk analysis was applied to the mortality database.

Results: The 181 recorded recreational rebreather deaths occurred at about 10 times the rate of deaths amongst open-circuit recreational scuba divers. No particular brand or type of rebreather was over-represented. Closed-circuit rebreathers have a 25-fold increased risk of component failure compared to a manifolded twin-cylinder open-circuit system. This risk can be offset by carrying a redundant 'bailout' system. Two-thirds of fatal dives were associated with a high-risk dive or high-risk behaviour. There are multiple points in the human-machine interface (HMI) during the use of rebreathers that can result in errors that may lead to a fatality.

Conclusions: While rebreathers have an intrinsically higher risk of mechanical failure as a result of their complexity, this can be offset by good design incorporating redundancy and by carrying adequate 'bailout' or alternative gas sources for decompression in the event of a failure. Designs that minimize the chances of HMI errors and training that highlights this area may help to minimize fatalities.

Key words

Technical diving, rebreathers/closed circuit, deaths, safety, diving accidents

Introduction

While the principles of closed-circuit rebreathers (CCRs) have been well understood for more than a century,[1] the practical problems of accurate control of the oxygen content of the breathing loop largely precluded their widespread adoption until the development of reliable electro-galvanic oxygen cells in the 1980s. Further developments in miniaturisation and reduction in the cost of these oxygen cells allowed the development of CCRs for the civilian market in the late 1990s.

The development of recreational CCRs was spurred on by the rapid advances in technical diving, which had seen the adoption of mixed-gas deep decompression diving in the civilian sector. The high cost and significant gas logistics associated with such dives on open-circuit (OC) scuba meant that rebreathers offered the potential for divers on limited budgets to engage in dives to locations and depths previously unobtainable. However, it was not long before the civilian use of rebreathers was associated with a number of deaths.[2] Given the small number of CCR units in use when compared to the use of OC scuba, the number of deaths associated with CCRs appeared to be out of proportion, and raised the spectre that there may be some factor intrinsic to the use of CCRs that increased the risk of death.

From 2007, Dr Alex Deas and his company *Deeplife* attempted to document all known civilian rebreather deaths in a database published on the internet.[2] The information appeared to be derived largely from the internet forum *Rebreather World* (RBW).[3] Reports in the 'accident forum' of this site were not independently vetted, but nevertheless were published with both details of the victims and an analysis of the event conducted by *Deeplife*. This database is in the public domain. In early 2008, the Divers Alert Network (DAN) USA in conjunction with Duke University conducted a technical diving conference where a number of prominent members of the diving industry were invited to discuss this database and its consequences. Scrutiny revealed significant inaccuracies in several cases known personally to the participants, including cases known not to involve a CCR. Members of this group agreed to review the database and investigate cases reported to have occurred in their local areas. Obvious errors were removed or corrected and information on the remaining cases was sought and corrected where possible. This 'corrected' database was circulated for internal review only.

The aims of this study were to evaluate the available data and, if possible, to answer several key questions:

- What is the rate of rebreather diver deaths compared to normal recreational scuba diving?
- Is one type of rebreather safer than others?
- Is any one brand of rebreather more likely to be associated with a fatality?
- What are the major causes of rebreather deaths?
- What changes should be made to training on or design of CCRs to minimize future deaths?

Methods

The corrected *Deeplife* database was accessed and the following data were extracted for analysis:

- total number of deaths each year
- type of CCR
- CCR brand
- mechanical control or electronic control
- cause of death
- equipment-related
- risk-related
- unrelated to CCR
- unknown.

Discussions with training agencies and manufacturers provided a very rough estimate of the total number of CCRs thought to be in use worldwide (denominator).

The RBW website was accessed and the number of registered users for the various types of CCRs was extracted. This was then compared to the total number of registered users.[3] RBW has approximately 30,000 users of whom 1,554 had 'registered' their type of rebreather at the time of access. These proportions were then compared to similar information from a survey of Dutch CCR users conducted in 2009.[4] Comparison was made of the proportions of various brands of CCRs in use and the proportions of mechanically controlled CCRs (mCCR) relative to electronically controlled CCRs (eCCR).

Mortality data associated with CCR use were obtained from the *Deeplife* database, a British Sub-Aqua Club (BSAC) study covering 1998 to 2009 and the DAN-Asia Pacific (DAN-AP) Australasian diving mortality database.[2,5,6] Mortality data from recreational scuba diving and other sporting activities were obtained from a variety of sources in order to provide a comparator.[7–11]

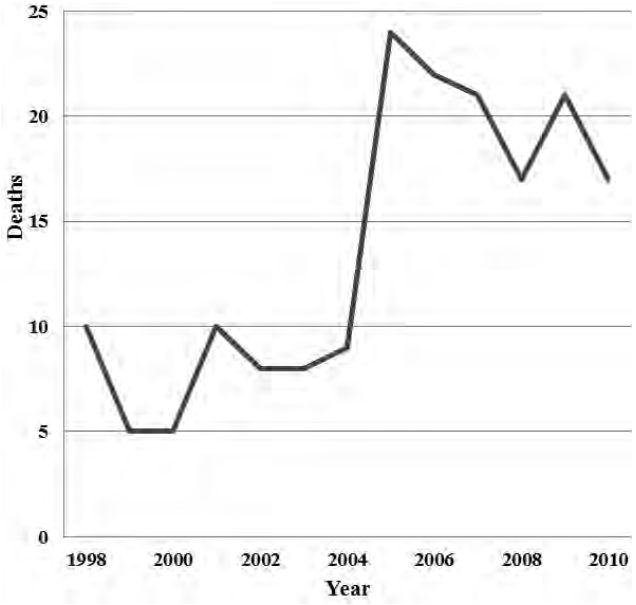
For each case in the database where there was sufficient information to determine a cause, a risk rating from 1 (least risk) to 5 (most risk) for the dive was allocated:

1 low risk, < 40 msw, all checks and tests conducted, no wreck/cave penetration;
2 moderate risk, < 40 msw, all checks done, wreck or cave penetration performed;
3 intermediate risk, > 40 msw, all checks completed;
4 high risk, > 40 msw, all checks and tests done, wreck or cave penetration;
5 extreme risk, > 150 msw or checks not done or alarms ignored.

These data were then compared to a survey conducted in 2002 by Steven Hawkins of users of the Inspiration™ eCCR.[12]

Finally, failure probability trees were constructed using the method described by Stone to attempt to determine the relative risk of mechanical failure of a CCR compared to OC scuba.[13] Further 'fault trees' were constructed for each of the major sub-systems of the CCRs to outline the myriad of potential causes of failure and the multiple corrective measures possible, as well as to demonstrate the relative importance of the various corrective strategies.[14]

Figure 1
Recreational closed-circuit rebreather deaths by year 1998–2010



Results

Between 1998 and 2010, 181 deaths were recorded in the corrected *Deeplife* database. There was a peak of 24 deaths in 2005, which seems to have been something of a watershed year. Prior to 2005, deaths had averaged eight per year, while after 2005 there were, on average, 20 deaths per year.

Between 1995 and 2011, the three major US-based training agencies conducted approximately 18,000 entry-level rebreather certifications with approximately 1,400 per year being conducted between 2001 and 2011.[15] Intermediate and advanced level certifications were achieved during the same period (2001–2011) at approximately half the annual rate for basic certifications (i.e., approximately 500 per year each). Based on these data, discussions with informed members of the diving industry and the data extracted from the RBW website, it was estimated that in 2010 there were approximately 14,000 active CCR divers worldwide.

Based on survey data, it was estimated that an average of approximately 30 dives per year per CCR diver were performed, with most active divers conducting between 20 and 50 dives each year.[3,12] At an annual death rate of 20 divers per year, this equates to an estimated death rate of 4 per 100,000 dives per year or approximately 10 times that of non-technical recreational OC scuba diving.[6–8,10,16]

The causes of the 181 fatalities are listed in Table 1. Of the total of 181 deaths, 57 (31.5%) had insufficient data to form

Table 1
Recreational closed-circuit rebreather deaths by stated cause; note the large number of cases in which there is scant information; in many other cases, while a cause of death is given, little evidence is available to corroborate that analysis

Cause of death	Number	%
Hypoxia	31	17
Hyperoxia	7	4
Hypercapnea	17	9
Acute myocardial infarction	15	8
Arterial gas embolism	12	7
Pulmonary barotrauma	6	3
No training	2	1
Drowning	5	3
Inert gas narcosis	4	2
Entanglement	1	1
Other	24	13
Scant data	57	31
Total:	**181**	

any conclusions; 80 (44%) were attributed to equipment-related problems; 43 (24%) to diving-related problems and the remainder were a mixture of problems such as acute myocardial infarction, loss of consciousness from diabetes mellitus, etc. In the BSAC data (27 deaths), there were scant data in seven cases and 14 cases were associated with either "*equipment failure*" (four cases) or the unit not being turned on correctly (11 cases). In only five cases was the cause of death thought to be unrelated to the type of breathing apparatus in use.

Each brand of CCR in use was represented in the mortality figures roughly in proportion to its market share from 2005 on. Analysis of data prior to 2005 was not performed as only one recreational CCR, the Inspiration™ (Ambient Pressure Diving®, Cornwall UK), was available up to this time. The only major brand not represented in these mortality data is the rEVO® (Paul Raymaekers, Belgium) which, while holding a significant market share from 2010, had, at the time of analysis, not been associated with any deaths. However, fatalities on this unit have been reported since this analysis was made.

Comparing the brand market share in the *Rebreather World* group to that of the Dutch survey, there is an apparent over-representation of CCRs that hold a CE certificate (Conformité Européene; i.e., compliance with European Union legislation and testing) in the latter, presumably because in Europe there is a requirement for CCRs to hold this certificate before they can be sold commercially. Nevertheless, given the broad confidence intervals of the data from the *Deeplife* database, the mortality by brand is comparable in these two data sets.

In the RBW survey, mCCRs represented 22% of units, while in the Dutch survey, the proportion was 15% mCCRs, accounting for 20% of deaths overall and 16% of deaths after 2005, roughly in proportion to their usage. The type of rebreather being used was not available in the BSAC data.

Table 2
Recreational closed-circuit rebreather risk behaviour index vs. mortality (see text for explanation; cases with sufficient data)

Risk rating	# cases	%
1	41	33
2	7	6
3	42	33
4	24	19
5	12	10
Total:	**126**	

If a risk rating is applied to the cases in the database with sufficient information (n = 126) using a similar methodology to Hawkins, then two-thirds of cases would appear to be associated with high-risk behaviours (Table 2).[12]

Discussion

The numbers of active rebreather divers worldwide are difficult to estimate and any such estimates can only be approximate. Manufacturers are unwilling to divulge the numbers of units sold, perhaps because of concerns about potential litigation if their unit were to be associated with a high proportion of accidents and deaths. Furthermore, for units such as the Inspiration™ that have now been available for more than a decade, the number of units sold will no longer represent the number of units in active use. Without a good estimate of the total number of rebreathers in active use, the risk associated with each unit or user is difficult to quantify and, even if manufacturers were to reveal the number of units produced, this would not account for the number of scrapped units, units not in active use, nor the number of dives done per year per unit.

Various estimates of fatality rates have been suggested, ranging from one in 10 users (Heinerth J, personal communication during a television documentary, period not specified),[15] to 360 per 100,000 divers per year, based on 20 deaths per annum and 5,000 units in regular use.[16] Others have suggested the total number of rebreather divers lies between 5,000 and 15,000 worldwide.[11,15] The data on CCR certifications beyond the initial training skill level would tend to indicate a high retention rate of CCR divers.[16] This is not altogether unexpected given the high purchase costs of CCRs and the commitment required to perform this type of diving. These figures do not include certifications from BSAC or SSI, two agencies assumed to have certified technical divers in Europe, the UK and Australasia for several years.

Assuming (as in the results section) 14,000 CCRs in current use and that CCR divers conduct approximately 20–50

Table 3
Comparison of fatality rates of various high-risk sports

Sport	Death per activity	Deaths per 100,000 activities
Base jumping	2,317 jumps	43.16
CCR diving	18,750 dives	5.33
Sky diving	101,000 jumps	0.99
Hang gliding	116,000 flights	0.86
Horse riding	175,418 rides	0.57
Scuba diving	200,000 dives	0.50

dives per year, one can calculate a mortality rate of between 3/100,000 dives and 7/100,000 dives, approximately 10 times that for recreational OC scuba diving.[4–8,10,12,17] If confidence intervals in arriving at these figures were able to be constructed, they would be expected to be very wide indeed. If a mortality rate of 5 per 100,000 dives was proven to be correct, this would make CCR diving approximately five times more dangerous than hang gliding and 10 times more so than horse riding, although 8 times less dangerous than base jumping (Table 3)![8]

BSAC data from 1998–2010 would indicate that CCR divers in the UK were approximately four times more likely to be involved in a fatal accident than open-circuit divers, representing 14% of fatalities but only 4% of dives. These are probably some of the more robust data available but must be considered in the context of the small numbers involved. It is also interesting to note that in these data 38% of deaths were associated with diving to depths greater than 40 msw, independent of the equipment used. Diving beyond 40 msw represented 11% of dives in this study, equating to a three-fold increase in risk of death associated with increased depth alone. If we assume the majority of CCRs are used for deep, mixed-gas diving this raises the issue as to what extent the breathing apparatus itself is responsible for increased risk and to what extent it is a function of a dangerous (deeper) environment. In the BSAC mortality data for OC diving, there were 13 cases of equipment failure in OC divers and 36 cases (24%) where the victim ran out of gas, a rare problem with CCR divers.[5,9] Despite the perceived simplicity and reliability of OC diving equipment, almost 9% of the deaths were attributed to equipment failures. This compares to approximately 30% attributed to CCR equipment failure in the *Deeplife* database.

When CCRs first became available to recreational divers, they were largely limited to 'high-end' technical divers conducting deep, mixed-gas expeditionary dives. Not surprisingly, with new technology in the hands of civilians who were accustomed to conducting high-risk dives, deaths began to be reported soon after.[2] The attitude at that time was exemplified by photos of some of these divers on the wreck of *HMHS Britannic* at 110 msw without any visible OC bailout.[18] A survey of registered Inspiration™ CCR users conducted in 2002 identified high-risk behaviours in CCR divers, such as continuing with the dive or commencing the dive with alarms sounding or entering the water with one or other gas turned off.[12] Divers were allocated a 'risk rating' score of 0–9 based on these behaviours. Divers who reported a score of 9 subsequently had a greater than 80% two-year mortality.[19]

There was a sudden doubling of the number of annual rebreather-associated deaths in 2005. It is unclear whether this was associated with a sudden increase in the variety of units becoming available or a sudden adoption of CCRs by the wider diving community. Anecdotally, CCR divers were much more commonly seen on commercial dive boats after this time, but data from the major US-based training agencies does not show any sharp increase in numbers of certifications at or just before this time. From an Australian perspective, all the recorded deaths have been after 2005 and, while the numbers are thankfully small, they would seem to reflect the broader pattern of deaths, with one from entrapment (unrelated to the type of scuba), one from narcosis (diving-related) and one each from hypoxia and hyperoxia (CCR-related). In the latter two cases, lack of training and experience played an important role.[6]

The author's experience as a medical advisor to the DAN-AP Australian diving mortality study has emphasized the difficulty of ascertaining causality in diving deaths from the limited information that is often available, even with access to police and coronial service records. The information in the *Deeplife* database by comparison is often uncorroborated and scant in its detail. As such, the associated accident analysis must be undertaken in a very guarded fashion. However, certain types of cases do seem to appear rather more frequently. In particular, cases of divers attempting very deep dives with limited experience and divers continuing to dive despite the CCR alarms indicating problems with the unit seem to recur in reports. Despite more than a decade of warnings, the dangers of overconfidence do not seem to have been taken to heart by many new CCR divers. Furthermore, there have been a number of near misses reported on RBW forums that seem to arise from misinformation promulgated via the internet. These issues continue to be a challenge to those who wish to promote safety in this area.

While it would appear that some (indeed, much) of the increased mortality associated with CCR use may be related to high-risk behaviour and the risks of diving at depth, the complexity of CCRs means that they are by nature more prone to failure than OC equipment. In his analysis of mechanical failure risk on the Wakulla Springs Project, Stone derived 'failure trees' for various equipment configurations.[13] In this model, the risk of system failure in a linear system, such as a standard OC scuba system, is the result of the addition of the probabilities of the failures of individual components. If a parallel or redundant system can be introduced, then the probabilities are multiplied, resulting in a substantial reduction in overall risk. His modelling suggests that by using a manifold twin-cylinder

Figure 2
Probability failure tree for a standard open-circuit scuba system

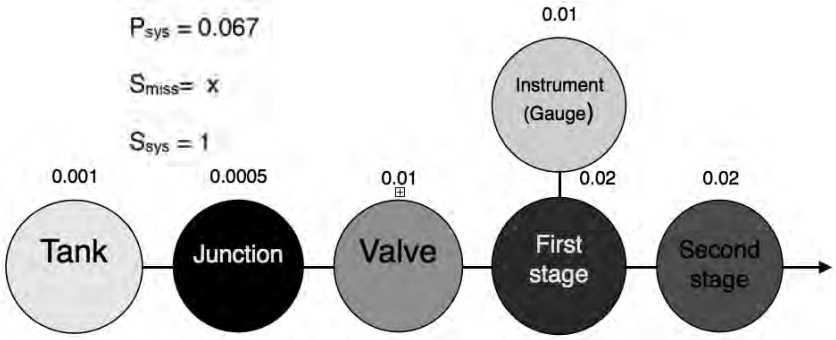
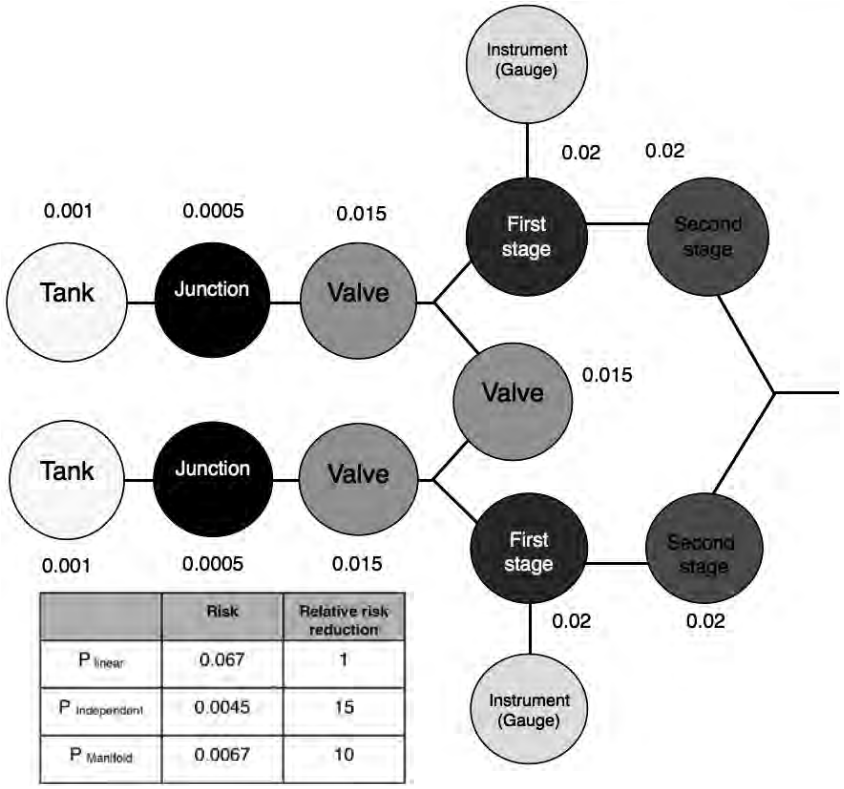


Figure 3
Probability failure tree for open-circuit manifold twin cylinder



	Risk	Relative risk reduction
P_{linear}	0.067	1
$P_{independent}$	0.0045	15
$P_{Manifold}$	0.0067	10

OC configuration the risk of mission-critical failure could be reduced by eleven-fold, whereas reduction in the risk of a single component only resulted in a small overall reduction in risk (Figures 2 and 3).

When such modelling is applied to CCRs, the risks of purely mechanical failures result in a theoretical overall risk increase of failure of 23 times compared to a manifold twin-cylinder OC (Table 4). Redundancy in some subsystems can reduce this risk of failure, particularly in key areas such as electronics. Indeed, where the CCR has two redundant computers with twin redundant batteries, the overall risk of failure of the unit is actually less than that of the simpler mCCR, with its single O_2 display. Further, the ability to 'plug-in' off-board gas via a totally independent mechanism, as exists on some CCRs, reduces the overall risk of mission-critical failure by three-fold.

For the purposes of the analysis, the assumption is made that a single-point failure in a CCR is mission-critical, unless there is a redundant system. While for OC scuba this is true, for many CCR failures the failure of a single subsystem may not result in the need to seek an alternate source of breathing gas. An example of this type of failure is the loss of all diluent when at depth. Diluent is not required during the bottom phase or during ascent, therefore, loss of this gas would not require the diver to 'bailout' to an alternative source of breathing gas, and ascent could be conducted as per normal on the CCR.

Table 4
Recreational closed-circuit rebreather (CCR) mechanical failure analysis: probabilities for linear systems are additive and those for redundant systems multiplied; note the overall very low probability of computer failure where there is a redundant computer and battery arrangement

Subsystem	*P* for component failure	*P* for critical failure
Electronics		
Battery	0.05	0.003*
Computer	0.01	0.0001
Oxygen cells	0.02	0.0004†
Total:		**0.003**
Gas O_2		
Tank	0.01	0.001
Junction	0.005	0.001
Valve	0.015	0.015
First stage	0.02	0.02
Gauge	0.01	0.01
Manifold	0.005	0.005
Manual add	0.015	
Solenoid	0.03	0.0005
Total:		**0.52**
Gas diluent		
Tank	0.01	0.001
Junction	0.005	0.001
Valve	0.015	0.015
First stage	0.02	0.02
Gauge	0.01	0.01
Manifold	0.005	0.005
Manual add	0.015	
ADV	0.02	0.0003
Total:		**0.61**
Loop		
Scrubber	0.01	0.01
Hoses	0.02	0.02
DSV	0.01	0.01
Total:		**0.04**
eCCR with no bailout failure probability		0.156
OC twin-cylinder system failure probability		0.007
Relative Risk CCR/OC: 23		

* 2 batteries; † 2 cell failure

Table 5
Recreational closed-circuit rebreather (CCR) vs. open-circuit (OC) decompression dive risk analysis (OC diver requires two stage cylinders to complete decompression schedule): risk of mechanical failure comparable as the CCR diver carries a redundant scuba system (bailout) while the OC diver must use each of his cylinders for the dive; in practice, OC divers reduce this risk by calculating to have 1/3 of gas in reserve in each cylinder and diving in a team

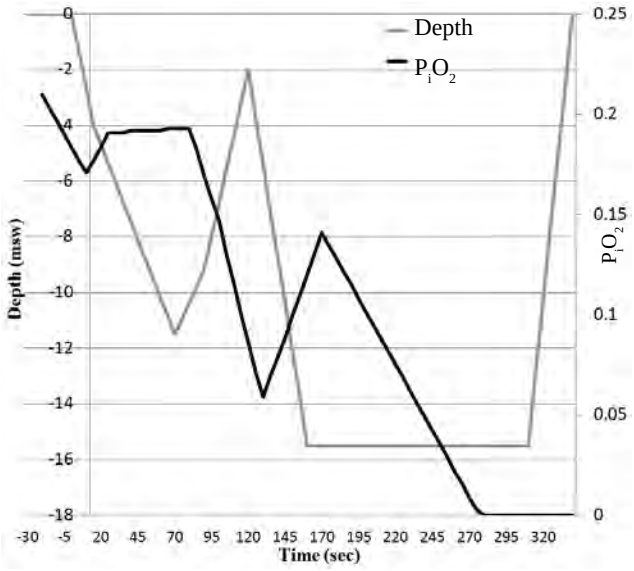
OC scuba	*P* subsystem failure
Risk manifold system failure	0.007
Risk Stage tank 1 failure	0.067
Risk Stage tank 2 failure	0.067
Risk mission critical failure	0.140
(Probabilities are additive)	
eCCR + 2 OC bailout cylinders	
Risk eCCR failure	0.156
Risk bailout tank 1 failure	0.067
Risk bailout tank 2 failure	0.067
Risk mission critical failure	0.021
(OC risk probably additive, CCR/OC risk multiplied)	
Relative risk eCCR versus OC scuba	0.15

The assumption that CCRs are less mechanically reliable is widely held, and most CCR divers carry OC cylinders for 'bailout' in case of CCR failure. In contrast to OC divers conducting decompression dives, where the cylinders form part of the decompression gas requirements, these cylinders represent a redundant scuba that is not used except in emergencies. When the presence of a redundant scuba is included in the failure risk calculations and compared to an OC diver conducting a decompression dive with two decompression gases, then resultant risk of overall mission-critical equipment failure becomes similar (Table 5). This is predicated on the CCR diver having ample gas to complete the dive using the OC gas carried. For deeper dives where logistics dictate that carrying complete bailout is impractical, divers will often utilizes a buddy system for bailout. This again is predicated on the buddies staying together rather than adopting the 'same ocean' buddy system conducted by some technical divers! It is interesting to note that, in this purely mathematical analysis, buddy diving offers a reduction of risk of almost an order of magnitude, strongly supporting the proponents of this behaviour.

There are few or no data on the actual mechanical failure rates of either OC scuba or CCRs. However, personal experience would indicate that mechanical failure of OC scuba is a rare event. While the theoretical risk of mechanical failure of a CCR is certainly higher than for a manifold OC twin-cylinder arrangement, the overall risk of failure in a correctly maintained and checked CCR system would still be expected to be low overall. Nevertheless, failures are commonly reported on internet forums. In an analysis of human factors in CCR failures, more than half the failures were attributed to poor training or poor pre-dive checks.[14] The experienced OC diver who takes up CCR diving was identified as being at particular risk of overestimating their ability. With OC scuba systems, there is usually only one correct response to failure. The complexity of CCR diving and the interaction of physics, physiology and equipment mean that there may be many possible responses that allow the diver to continue breathing, not all of which will result in a successful outcome. The following case is illustrative (Figure 4).

This diver entered the water with his CCR turned off. The diver had pre-breathed the unit before entering the water,

Figure 4
Dive depth and inspired oxygen partial pressure profile of a fatal recreational closed-circuit rebreather dive; unconsciousness occurs 130 sec into the dive due to ascent hypoxia and failure of oxygen addition because the unit had not been turned on



but for insufficient time for the PO_2 to fall to a critical level. Descent resulted in an increase in PO_2 despite the consumption of O_2 from the loop. At approximately 14 msw, the diver became aware the CCR's electronics were not turned on. Options at this time included:

- bailout to OC scuba;
- ascent to 6 msw and flushing the CCR with O_2 to provide a known breathing mix that was non-hypoxic on the surface;
- turning on the electronics (not recommended as the unit would attempt to calibrate the O_2 cells underwater; however, possible if the correct sequence was followed).

While the PO_2 in the breathing loop of the CCR at 14 msw was still 0.2 atm and hence quite breathable, an understanding of physics and physiology would have told the diver that ascent without the addition of O_2 would result in a rapid fall in the PO_2 in the breathing loop. This diver was a very experienced OC diver and his first reaction was to return to the surface to correct the problem. As one might predict, he became unconscious from hypoxia just below the surface and drowned. The entire event occurred in less than 150 seconds from the commencement of the dive.

In this case, there was nothing wrong with the CCR, rather, the failures were in the pre-dive checks to show the CCR's electronics were turned off and in undertaking insufficient pre-breathe time. This type of problem may occur where the diver has completed the standard checks and then the dive is delayed for a short time while some adjustment is made, e.g., the shot line is re-sited. The diver may respond by turning off the unit in a misguided attempt to save battery life, and then fail to turn it back on in the distraction of 'getting on with the dive' subsequently. The situation was eminently salvageable without the need to go 'off the loop', but a failure to understand the consequences of the various options resulted in a tragic outcome.

The use of basic check-lists and of 'good design' have been advocated to eliminate wherever possible the chance of human error.[14] Such design should:

- minimize perceptual confusion;
- make the execution of action and response of the system visible to the user;
- use constraints to lock out the possible causes of errors;
- avoid multimodal systems.

Training should provide for acquisition of basic skills so that these become 'hard-wired', thereby allowing clear mentation in times of stress while making critical decisions.

One potential method of providing this would be to stage rebreather training such that initial certification did not allow for decompression diving and only allowed for limited failure response in a way similar to OC diving, e.g., OC bailout as the only option. Only once the actual CCR diving skill set and basic CCR management was well ingrained would more complex teaching concerning rebreather physics and physiology be introduced in conjunction with discussions on alternative bailout options and decompression diving.

Conclusions

In the period from the introduction of the first mass-market CCR in 1998 to 2010, there have been 181 reported deaths. While the number of rebreathers in use remains unknown, best-guess figures suggest that using a CCR is associated with a four- to ten-fold increased risk of death compared to recreational OC scuba diving. Some of this risk may be associated with the use of CCRs for higher-risk deep diving, which in itself is associated with a three-fold increase in risk of death. Two-thirds of the reported deaths appear to have some association with high-risk behaviours including commencing or continuing dives with alarms activated or with known faults to the CCR.

There does not seem to be any particular brand of CCR over-represented in the mortality data and, despite popular perception, mCCRs are not associated with a lower mortality than eCCRs.

CCRs have an intrinsically increased risk of mechanical failure because of their complexity; however, this risk is probably small, and many of the failures seen appear to be related to training issues, failures of maintenance and failure to conduct adequate pre-dive checks. While good design can help reduce the chance of human error in maintenance and pre-dive assembly, the major emphasis should be on reducing human error, including modification of high-risk behaviours. Modifications to training, education and certification of CCR divers may be one way of achieving this.

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Review articles

Recreational technical diving part 1: an introduction to technical diving methods and activities

Simon J Mitchell and David J Doolette

Abstract

(Mitchell SJ, Doolette DJ. Recreational technical diving part 1: an introduction to technical diving methods and activities. *Diving and Hyperbaric Medicine*. 2013 June;43(2):86-93.)

Technical divers use gases other than air and advanced equipment configurations to conduct dives that are deeper and/or longer than typical recreational air dives. The use of oxygen–nitrogen (nitrox) mixes with oxygen fractions higher than air results in longer no-decompression limits for shallow diving, and faster decompression from deeper dives. For depths beyond the air-diving range, technical divers mix helium, a light non-narcotic gas, with nitrogen and oxygen to produce 'trimix'. These blends are tailored to the depth of intended use with a fraction of oxygen calculated to produce an inspired oxygen partial pressure unlikely to cause cerebral oxygen toxicity and a nitrogen fraction calculated to produce a tolerable degree of nitrogen narcosis. A typical deep technical dive will involve the use of trimix at the target depth with changes to gases containing more oxygen and less inert gas during the decompression. Open-circuit scuba may be used to carry and utilise such gases, but this is very wasteful of expensive helium. There is increasing use of closed-circuit 'rebreather' devices. These recycle expired gas and potentially limit gas consumption to a small amount of inert gas to maintain the volume of the breathing circuit during descent and the amount of oxygen metabolised by the diver. This paper reviews the basic approach to planning and execution of dives using these methods to better inform physicians of the physical demands and risks.

Key words

Technical diving, enriched air – nitrox, trimix, cave diving, wreck diving, rebreather, review article

Introduction

A recent and important trend in recreational diving is the use of specialised techniques to explore deeper depths for longer durations than are possible with the single-cylinder, open-circuit air diving configuration typically used by recreational divers. Exponents refer to themselves as 'technical divers'. There is no universally accepted definition of 'technical diving' but the term commonly refers to the use of helium-based 'mixed-gases' to conduct deeper dives with optimised decompression using self-contained underwater breathing apparatus (scuba). This is an important development for diving physicians for several reasons. Firstly, technical divers involve themselves in activities with a different risk profile to normal recreational air diving, and understanding what they do will inform evaluations of medical suitability. Secondly, a technical diving accident may differ from a recreational diving accident. For instance, deep, mixed-gas divers are at risk of omitting substantial decompression, and consequently of presenting with severe decompression sickness. Such mixed-gas diving has previously been the province of occupational diving and conducted with immediately available medical support, whereas technical divers are likely to present at a hospital. Understanding their activity will facilitate evaluation of diving histories and circumstances in accident scenarios.

The authors, both experienced technical divers, presented on various issues related to technical diving at the South Pacific Underwater Medicine Society Annual Scientific Meeting in 2011. These presentations are summarized here in two papers, of which this is the first. This paper explains the basic aims and methods used, thus providing an introduction for those unfamiliar with the field. The second paper discusses the controversial issue of optimal decompression from the short, deep dives typically undertaken by technical divers.[1]

An incomplete history of technical diving

There are no definitive resources describing the history of technical diving. This account has been constructed largely from the authors' own knowledge and may contain minor inaccuracies. Technical diving grew out of the drive to explore deep shipwrecks and underwater caves. Sporadic accounts of individual explorers experimenting with nitrox (nitrogen-oxygen mixes with a higher fraction of oxygen than air) to shorten decompression obligations began to appear in the mid-1970s. Similarly, individuals began experimenting with helium-based mixes (helium is non-narcotic and light) for deep diving around the same time. The first attempts to 'mainstream' recreational use of a breathing gas other than air came in the mid-1980s with the formation of two training organisations dedicated to nitrox diving. The International

Footnote: The units prevalent in the technical diving community are used for pressure measurements in this article. To use kPa would largely render the paper largely unintelligible to at least part of its intended readership (the divers themselves) and it would also fail to prepare physicians for the language they will hear technical divers using. The agreed format is: atm for partial pressures or gauge pressures (e.g., the typical PO_2 setpoint of a rebreather is 1.3 atm) and atm abs for ambient pressures at depth.

Association of Nitrox Divers (IAND) and American Nitrox Divers Inc (ANDI) remain active today, though IAND has become IANTD (T – technical) and both have broadened the scope of their teaching to include courses in which the use of helium-based gases is taught.

There are isolated, early accounts of deep, heliox scuba dives in caves: Hal Watts in 1970 (122 metres' freshwater (mfw), Mystery Sink), Dale Sweet in 1980 (110 mfw, Mystery Sink) and Jochen Hasenmayer in 1982 (205 mfw, Fontain de Vaucluse).[2] However, technical diving in its most common form at present (the use of trimix breathing gas mixtures and oxygen-accelerated decompression with multiple open-circuit scuba) can be traced to the mid-1980s in northern Florida where cave divers began developing these techniques to explore downstream from Sullivan Sink (part of the Wakulla-Leon Sinks cave system).[3] The late 1980s saw an increase in the use of mixed-gas techniques on some dives that were spectacular for the time. Well-documented examples include the exploration of the Andros Blue Holes by Rob Palmer, the early deep dives (90–95 mfw) in Wakulla Springs, and a record deep dive to 239 mfw in Nacimiento Mante by Sheck Exley.[4–6]

The early 1990s were a period of great controversy and change, with momentum slowly swinging in favour of the broader adoption of these advanced diving techniques. This was in no small part helped by the publication of the first dedicated magazine, *Aqua-Corps*, in the United States. Indeed, it was the editor, Michael Menduno, who in 1991 first coined the term "*technical diving*". Whereas nitrox training had been available through IAND and ANDI for some years, training programmes for diving with helium-based gases emerged around this time, with Billy Deans in Key West often credited with the first of these. However, opposition remained. Conspicuous examples include the initial banning of nitrox training providers from the 1992 DEMA show in Houston, Texas; a British Sub-Aqua Club ban on the use of any gas other than air in the same year; and a 1993 series of articles in *Skin Diver* magazine condemning nitrox and mixed-gas as unsafe in sport diving.

This opposition had little effect on motivated explorers for whom the advantages of mixed-gas techniques were simply too great to ignore, and throughout the 1990s the associated successes continued to be reported. One conspicuous example, the identification of the German submarine U-869 in 70 metres' sea water (msw) off the New Jersey Coast by John Chatterton on a difficult penetration dive using mixed gas, was notable because it was contrasted against earlier disastrous dives performed on the same wreck using air.[7] By the mid 1990s, even the large mainstream recreational training organisations such as the Professional Association of Diving Instructors (PADI) were starting to offer nitrox or 'enriched air' courses which, over time, has resulted in nitrox diving no longer being considered 'technical'. However, this era of growth was punctuated with high-profile setbacks, such as the deaths of Sheck Exley in 1994 and Rob Palmer in 1997. The naysayers were not entirely wrong about risk.

The mid 1990s also saw a development that would revolutionise technical diving: the mainstream emergence of rebreathers whose use had hitherto largely been limited to military applications. The Dräger® Dolphin and Atlantis were the first devices available. Both were semi-closed-circuit units designed for nitrox diving, although many owners modified them for use with other gas mixtures. Around 1999, UK company Ambient Pressure Diving Ltd® released the first mass-produced, commercially available electronic closed-circuit rebreather (eCCR): the Inspiration Classic™. This device, and its subsequent generations became (and remains) the most prevalent eCCR worldwide.

In the new millennium, technical diving has become progressively mainstream. By the middle of the first decade, PADI was teaching mixed-gas diving, and recently they entered the rebreather training market for the first time. There has been a proliferation of new rebreather manufacturers and in 2012 there is a new initiative to produce and teach 'recreational' rebreather devices for use in the shallow depth range usually associated with open-circuit, air scuba diving. In the meantime, extreme exponents are pushing the boundaries deeper and longer all the time (see "*current scope of technical diving*" below).

It is not possible to outline the history of technical diving without noting that its recent development has been coincident with widespread adoption of communication via the internet. Early internet user-group lists were forums for free exchange of ideas (and insults) between various groups or individuals worldwide. These internet forums and others that have subsequently appeared, can be credited for aiding the development and popularization of technical diving despite the fact that much of the information presented on them is unreliable or inaccurate.

Technical diving methods

Mainstream recreational divers conduct no-decompression dives using air in open water (that is, not in enclosed spaces) to a maximum depth of about 40 msw. These are dives that can be conducted 'safely' with a single cylinder of compressed air with an open-circuit demand valve. However, this equipment configuration significantly limits underwater duration at the deeper end of the recreational diving range because of the limited gas supply and the decompression obligation that accrues with extended bottom times. Moreover, the use of air for diving to depths greater than 40 msw would become progressively less appropriate because of its density and the high nitrogen and oxygen contents, which cause narcosis and an increase in the risk of oxygen toxicity respectively. Technical divers circumvent the disadvantages of single-cylinder air diving by using a variety of strategies that are described below.

NITROX DIVING

Nitrox diving was the first widely adopted departure from traditional recreational air diving and is now so widely accepted that it is generally no longer considered to be technical diving. The term nitrox refers to mixtures of oxygen and nitrogen in which there is more oxygen than found in air and, indeed, is usually a blend of oxygen and air. For these reasons, nitrox is often referred to as 'enriched air' or 'enriched air–nitrox' (EANx). By convention, the mix is described by reference to its oxygen content. Thus, if a nitrox mix contains 36% oxygen, then it is referred to as nitrox36 or EANx36.

Nitrox diving offers the following advantages over air, all of which relate to the reduced inspired nitrogen fraction. First, since the fraction of inspired nitrogen is lower, there is less uptake of nitrogen than would occur if air were used at the same depth. The nitrox diver can thus use a no-decompression limit or decompression plan calculated for air at a depth shallower than the actual depth of the dive. This shallower depth is referred to as the equivalent air depth (EAD) and can be calculated from:

$$EAD\ (msw) = ([FN_2 \times (depth + 10)] \div 0.79) - 10 \quad (1)$$

Where: FN_2 = the decimal fraction of nitrogen in the nitrox mix; depth = the depth (msw) at which the nitrox is being used and 0.79 = the fraction of nitrogen in air.

Second, the nitrox diver could refrain from calculating an EAD and plan the decompression aspects of a dive as though he or she were breathing air. The resulting reduction in nitrogen uptake would reduce the risk of developing decompression sickness.

Third, as will be described later, nitrox is often breathed during the shallower (approx. < 40 msw) phase of decompression from a deep dive because the high inspired fraction of oxygen will accelerate inert gas elimination. The use of nitrogen avoids the consumption of costly helium at shallower decompression stops when its benefits (e.g., low density) are unnecessary.

Fourth, based on the assumption that oxygen is non-narcotic, nitrox may cause less narcosis than air at equivalent depths. The magnitude of this advantage is uncertain. Oxygen probably is narcotic, though not to the extent predicted by its lipid solubility because it is metabolized in tissues.[8]

Finally, there is controversy over whether nitrox dives result in less post-dive fatigue than air dives with identical time and depth profiles. In one tightly controlled randomized and blinded study involving pressure exposures in a hyperbaric chamber, there was no difference in post-dive fatigue between nitrox and air dives.[9] In contrast, a recent non-blinded field study did report an advantage for nitrox in this regard.[10] The underlying basis for any reduction in fatigue by nitrox is unknown, but a reduction in bubble formation from dissolved inert gas and some other non-specific oxygen effect are possibilities.[10]

Table 1
NOAA oxygen exposure limits over a range of oxygen partial pressures (P_iO_2)

P_iO_2 (atm)	Single exposure (min)	24-hour exposure (min)
1.6	45	150
1.5	120	180
1.4	150	180
1.3	180	210
1.2	210	240
1.1	240	270
1.0	300	300
0.9	360	360
0.8	450	450
0.7	570	570
0.6	720	720

The use of nitrox mandates extra care on several fronts. First, the scuba equipment (cylinder and regulator) usually need to be 'oxygen clean' to minimize the risk of oxygen fires or explosions, especially during blending of the gas. Second, because the inspired fraction of oxygen is greater, an inspired oxygen partial pressure (P_iO_2) high enough to cause cerebral oxygen toxicity will be encountered at shallower depths than when using air. Nitrox diving consequently limits depth in comparison to air. Because the first symptom of cerebral oxygen toxicity may be a grand mal seizure, this is an issue of significant clinical importance in technical diving.

Experimental evidence and anecdote suggest that cerebral oxygen toxicity is very rare if the P_iO_2 is less than 1.3 atm (133 kPa).[11] Many technical divers have consequently adopted this value as their maximum safe inspired P_iO_2 for routine use, although it is relatively common for divers to breathe a P_iO_2 up to 1.6 atm if at rest during decompression. A crucial skill is to be able to calculate the deepest depth at which a gas can be used so that the chosen maximum safe P_iO_2 is not exceeded. This is known as the maximum operating depth (MOD) for the gas given by:

$$MOD(msw) = ([P_iO_{2max} \div F_iO_2] - 1) \times 10 \quad (2)$$

Where: P_iO_{2max} = the maximum safe inspired PO_2 (atm) and F_iO_2 = the inspired fraction of oxygen in the mix.

Another influence on risk of cerebral oxygen toxicity is the duration of exposure. Nitrox divers (and indeed all technical divers) are taught the concept of the 'oxygen clock' and the associated safe durations for exposure to a range of P_iO_2. A set of exposure limits was published by the National Oceanic and Atmospheric Administration (NOAA) (Table 1).[12] It is not widely appreciated that these limits were based on best judgment rather than objective data, and

they can only be seen as a guideline.[11] The table provides limits for the P_iO_2 well below the risk threshold cited above for cerebral oxygen toxicity, reflecting a shift in emphasis from prevention of cerebral toxicity to that of pulmonary toxicity as one progresses to a lower range of P_iO_2. An additional use of these guidelines is tracking of the accrued exposure as a percentage of the recommended maximum, if necessary, by adding percentages from different P_iO_2 exposures. For example, if a diver breathes oxygen at 1.2 atm for 105 minutes and then 1.4 atm for 75 minutes (50% of the recommended exposure at both P_iO_2 levels; Table 1), the total represents 100% of the recommended exposure. It is common practice to degrade these percentage exposures with a half-life of 90–120 minutes between dives. There are few data to establish the validity of any aspect of this oxygen dose management paradigm, but those that exist have been expertly reviewed elsewhere.[11]

MIXED-GAS DIVING

If the maximum safe P_iO_2 during diving is considered to be 1.3 atm, then the MOD for air (calculated as above) is 52 msw. For deeper dives, the inspired fraction of oxygen must be lowered below that of air. Similarly, below 40–50 msw, the narcotic effect of nitrogen in air increases to progressively less tolerable levels. Air is also very dense at these depths, which increases both the work of breathing and the risk of carbon dioxide (CO_2) retention. The problems associated with the narcotic and density effects of nitrogen can both be ameliorated by substituting helium, a low-density, non-narcotic gas, for nitrogen in the breathing mix. This typically results in the diver breathing trimix: a combination of oxygen, helium, and nitrogen. Technical divers designate trimix by the fraction of oxygen and helium present. For example, trimix 8:60 would consist of oxygen 8%, helium 60%, and the balance (32%) nitrogen.

Nitrogen is rarely substituted completely with helium for several reasons of which the most important is the cost of helium. This is less of an issue when using a rebreather which recycles exhaled gas (see later), but in open-circuit diving pure oxygen-helium mixtures (heliox) would be very expensive to use. In addition, some decompression models tend to penalize the use of high helium fractions by mandating longer decompressions. Although this may be unnecessary (see the second paper in this series)[1] it remains a consideration for many divers in planning their gas mixes. Finally, in very deep bounce dives beyond 150 msw it is likely that the inclusion of nitrogen in the breathing mix helps to ameliorate the high pressure neurological syndrome (HPNS), which can cause troublesome tremors and cognitive impairment.[8]

The 'recipe' for the optimal trimix for use during the deepest portion of the dive (bottom gas) is based on the planned depth, the duration of the dive, the diver's perception of the maximum safe P_iO_2, and, if cost is a consideration, the maximum tolerable narcotic effect. To illustrate this, we will consider planning an appropriate trimix for a dive using open-circuit equipment to 90 msw where the ambient pressure is 10 atmospheres absolute (atm abs).

The first decision is how much oxygen the mix should contain. Divers will usually aim to breathe as much oxygen as is considered safe, since more oxygen means less inert gas uptake and therefore less decompression. For a very long dive, the diver may defer to consideration of the oxygen clock (see above) and choose a lower PO_2 for their various gases. However, assuming a maximum safe P_iO_2 of 1.3 atm is chosen:

$$\text{Ideal } O_2 \text{ fraction in mix} = 1.3 \text{ atm} \div 10 \text{ atm abs} = 0.13 \quad (3)$$

The mix would therefore contain 13% oxygen for breathing at 90 msw. It is notable that such a lean oxygen mix should not be breathed at the surface, and so it would be necessary to start the first part of the descent using a 'travel gas' with more oxygen (air, for example). Once the diver has reached a depth where the trimix provides an P_iO_2 the same as breathing air at the surface (0.2 atm approximately), it will be safe to change to the trimix and continue the descent. This depth can be calculated as follows:

$$\text{Min. safe depth (msw) for hypoxic mix} = ([0.2 \div FO_2] - 1) \times 10 \quad (4)$$

Where: 0.2 = minimum safe P_iO_2 in atm and FO_2 = fraction of oxygen in the mix.

For the 13% oxygen mix (FO_2 = 0.13) this gives:

$$\text{Min. safe depth for mix} = ([0.2 \div 0.13] - 1) \times 10 = 5.4 \text{ msw} \quad (5)$$

Thus, the diver could safely change to the trimix once at 6 msw (rounding deeper) during the descent. More typically, the travel gas will be used to a greater depth to conserve the bottom gas. The travel gas is also often used during decompression.

The amount of N_2 in the mix is largely dependent on the degree of narcosis that the diver is prepared to tolerate, and is usually based on a comparison with air diving. Thus, assuming a diver is comfortable with the level of narcosis experienced during air diving at 40 msw, they might aim to breathe an equivalent PN_2 during the deepest phase of a trimix dive. This is easily calculated by multiplying the fraction of nitrogen (FN_2) in air (0.79) by the ambient pressure at 40 msw (5 atm abs) which gives a PN_2 of 3.95 atm. Therefore:

$$FN_2 \text{ in the mix} = 3.95 \text{ atm} \div 10 \text{ atm abs} = 0.4 \quad (6)$$

The trimix should therefore contain 40% N_2. This calculation assumes oxygen is not narcotic, but a more conservative approach assuming equal narcotic potency for O_2 and N_2 yields only a small difference.

Table 2
Dive plan for 90 msw for 15 minutes based on a proprietary implementation of the Buhlmann ZH-L16 model with gradient factors 50/80 (see part 2 for explanation of gradient factors)[1]

Depth (msw)	Stop time (min)	Run time (min)	Gas mix
90	n/a	15 (bottom time)	Trimix 13:47
Ascent to 42	5 (ascent time)	20	Trimix 13:47
42	1	21	Trimix 13:47
39	1	22	Trimix 13:47
36	1	23	Trimix 13:47
33	1	24	Nitrox 32
30	1	25	Nitrox 32
27	1	26	Nitrox 32
24	2	28	Nitrox 32
21	2	30	Nitrox 32
18	2	32	Nitrox 32
15	4	36	Nitrox 32
12	6	42	Nitrox 32
9	9	51	Nitrox 32
6	15	66	Nitrox 32
4.5	19	85	100% O_2

Having calculated the ideal FO_2 and FN_2 for the trimix, the helium content (FHe) simply makes up the balance, thus:

$$FHe\ required = 1 - FN_2\ (0.4) - FO_2\ (0.13) = 0.47 \quad (7)$$

This planning process has determined that an appropriate trimix for a dive to 90 msw is 13% oxygen, 47% helium and 40% nitrogen, designated trimix 13:47. Another parameter often ignored in such planning is the density of the resulting gas at the target depth. There is an increasing risk of CO_2 retention as the inspired gas density increases, and this can result in debilitating dyspnoea and mental obtundation.[13] Hypercapnia also increases the risk of cerebral oxygen toxicity, probably because it causes cerebral vasodilatation and the consequent delivery of a bigger dose of oxygen to the brain.[14] While there is no clear consensus on where the upper density limit should lie, proposed criteria for design and testing of underwater breathing apparatus, based on physiological limitations which include a gas density of 8g L^{-1}, seem reason enough to draw the line at this point.[15] Calculation of gas density at a target depth is easily achieved based on proportions and adjustment for ambient pressure if given the following densities (g L^{-1}) at 1.0 atm abs: air 1.29; oxygen 1.43; nitrogen 1.25; helium 0.18. In the above example, trimix 13:47 at 90 msw (10 atm abs) would have a density of 7.7g L^{-1}.

Planning of mixed-gas dives

The nitrox and mixed-gas methods described above are typically combined in the execution of a deep dive. A decompression obligation rapidly accumulates in such dives, and decompression can be accelerated by making gas switches to mixes with less inert gas and progressively more oxygen during the ascent. There are many combinations and permutations of gas choice for decompression but, continuing with the example of a 90 msw dive using trimix 13:47, one simple but plausible example would be to decompress back to 33 msw using the trimix, then switch to nitrox32 (PO_2 = approx. 1.3 atm at 33 msw) for stops between 33 and 6 msw (inclusive), and then complete a final decompression stop at 3 msw breathing 100% oxygen (PO_2 = 1.3 atm). The issue of whether there is a decompression advantage of substituting nitrogen for helium in the shallower stage of the decompression is addressed in the second paper in this series.[1]

Having decided on a basic gas plan such as the above, the next step is to input the depth, bottom time, and gas plan into technical diving decompression planning computer software to obtain the decompression regimen. There are multiple decompression algorithms and computer implementations available and few issues are debated as hotly as the optimal approach to decompression from deep technical dives. This is discussed further in the second paper in this series.[1] The output of one such algorithm, based on a bottom time of 15 minutes at 90 msw, is shown in Table 2. Note that even this relatively short bottom time results in a substantial period of prescribed decompression and, although obvious, it is worth stating that this decompression profile forms a virtual ceiling through which the diver should not pass. If problems occur which necessitate omission of decompression, then serious decompression sickness is possible. Technical divers must train, plan and equip themselves to minimize the possibility of such events.

Once the depth, bottom time, gas plan and decompression plan are known, the diver can calculate the actual gas requirements for the dive. Many of the decompression planning algorithms will do this for the diver, though they all require the provision of an estimation of the diver's surface respiratory minute volume (RMV) for the level of exercise expected during the dive. Early in their careers all technical divers must conduct an exercise in which they measure gas consumption during typical underwater swimming at a known and constant depth. This is indexed back to surface pressure, and becomes the surface RMV. It is an important number that they will use many times. Many divers calculate the RMV during typical underwater swimming and at rest, with the resting number used for calculating gas consumption during decompression. For a given segment of the dive, the gas consumption is given by:

$$Gas\ consumption\ (L) = P_{amb} \times surface\ RMV \times duration \quad (8)$$

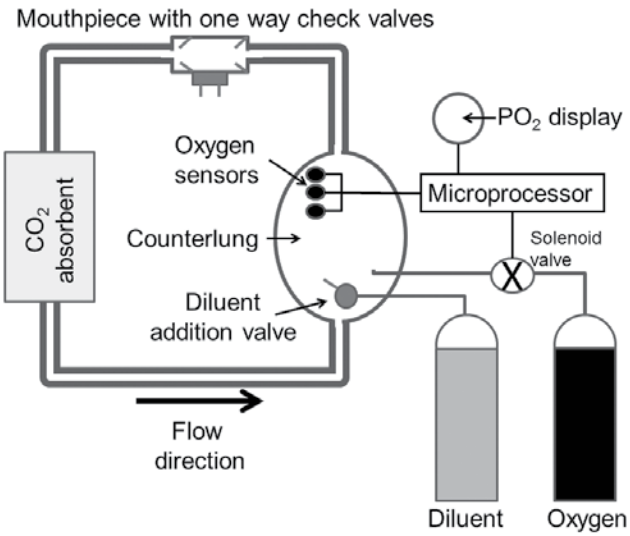
Where: P_{amb} is the ambient pressure in atm abs; surface RMV is the respiratory minute volume (L min^{-1}) for equivalent activity at 1 atm abs and duration is the duration of the dive segment in minutes.

Once the gas requirements are established in this manner, the diver must decide on the cylinder configuration required for its carriage. In the above example, one plausible plan would be to carry the trimix in twin cylinders worn on the back,

Figure 1
Technical diver configured with multiple open-circuit scuba systems for carrying different gases



Figure 2
Simplified functional layout of an electronic closed-circuit rebreather (see text for explanation); this is highly stylized, for example, the oxygen cells are not actually placed in the counterlung in a real rebreather.



and to carry one cylinder of each of the decompression gases (nitrox32 and oxygen) slung on either side. The gas-carrying capacities of the cylinders must be carefully compared to the calculated gas requirements, and it is customary to build in a substantial safety margin for unexpected events. Such safety margins are often a variation of the basic cave diving 'rule of thirds' in which one third of breathing gas is retained for emergencies, notionally because if one third is used to enter a cave and one third to exit, the remaining third can be shared to rescue an out-of-gas buddy. An illustrative multi-cylinder configuration is shown in Figure 1.

REBREATHERS

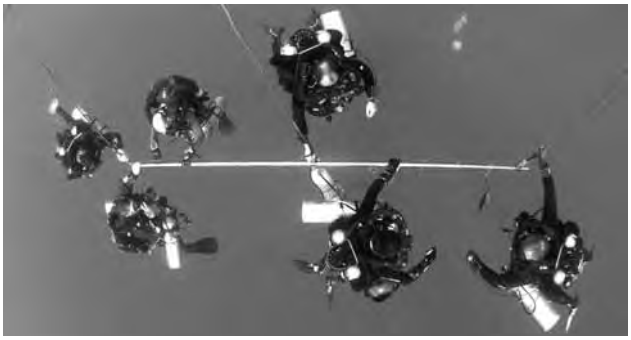
The increasing use of rebreathers is arguably the most important development in technical diving over recent years. A rebreather is a circle circuit containing one-way check valves, one or more counterlungs, a CO_2 absorbent canister, and systems for maintaining both the volume of the circuit and an appropriate P_iO_2. Rebreathers are categorized by the nature of the system for maintaining the P_iO_2 and it is beyond the scope of this article to detail the operation of all of them. The most prevalent is the so-called electronic closed-circuit rebreather (eCCR). The typical (and simplified) functional layout of one of these devices is shown in Figure 2.

During use, the diver exhales into the counterlung through a CO_2 absorbent, and then inhales from the counterlung. The one-way check valves ensure that flow around the circuit is unidirectional. Three galvanic fuel cells are exposed to the gas in the circuit. These are essentially oxygen-powered batteries that produce an electric current directly proportional to the PO_2 to which they are exposed. After calibration against a known PO_2, the averaged output of the three cells indicates the circuit PO_2 and this is constantly monitored by a microprocessor. A target P_iO_2 (PO_2 'setpoint') is selected by the diver, and as oxygen consumption reduces the circuit PO_2 below this target the microprocessor opens an electronic solenoid valve to allow oxygen into the circuit to restore and maintain a relatively constant PO_2 near the setpoint. This setpoint is typically 0.7 atm at the surface, and is increased to a higher target (such as 1.3 atm) once the dive is underway.

The volume of the circuit is maintained during descent by the addition of a diluent gas. When the counterlung is compressed by increasing ambient pressure, the diver will begin to generate a negative pressure in the circuit during inhalation. This opens a mechanical diluent addition valve (Figure 2) allowing diluent gas into the circuit and restoring its volume. For safety reasons, the diluent gas typically contains a FO_2 high enough that the gas is breathable, but low enough that the circuit PO_2 can still be lowered to the desired setpoint at the deepest point in the dive. Thus, for a dive to less than 50 msw with a PO_2 setpoint of 1.3 atm, air could be used as the diluent gas. Its oxygen fraction of 0.21 still allows a circuit PO_2 of approximately 1.3 atm at 50 msw (ambient pressure of 6 atm abs x 0.21 = 1.26 atm) and at shallower depths the rebreather will add oxygen to maintain the PO_2 at 1.3 atm. The diver will be breathing a nitrox mix whose oxygen and nitrogen content varies with depth, but whose PO_2 remains constant. For a deep dive, the diluent gas (usually trimix) is chosen using virtually the same principles as described earlier (mixed-gas diving).

It should be obvious that the crucial advantage of a rebreather is the recycling of exhaled gas thus preserving expensive components like helium. Indeed, in theory, the use of diluent gas effectively ends on arrival at the deepest depth provided there is no up-and-down depth variation from that point on. In contrast to open-circuit diving, gas consumption changes

Figure 3
Decompression stage with multiple rebreather divers decompressing at the same depth; note that all are carrying an open-circuit 'bailout' cylinder in case of rebreather failure



little with depth, and the absolute amounts of gas used are vastly smaller.

Another major advantage is the breathing of optimal gas mixes for minimizing inert gas uptake and for accelerating decompression throughout the dive. In open-circuit diving, for each gas carried, the F_iO_2 can only be optimal at one depth. Thus, in the example shown in Table 2, as the diver ascends shallower than 30 msw breathing nitrox32 they are no longer breathing the pre-defined maximum safe F_iO_2 (required to produce a PO_2 of 1.3 atm) until they switch to 100% oxygen at the 3 msw stop. In contrast, an eCCR will raise the F_iO_2 to maintain the 1.3 atm PO_2 setpoint throughout the ascent.

Other rebreather advantages include the breathing of warm, humidified gas, and production of few or even no bubbles. The major disadvantages are that the devices are complex, costly, maintenance intensive, provide numerous opportunities for user error and have many potential failure points. This potential for failure mandates the requirement for access to open-circuit gas supplies (commonly referred to as 'bailout') appropriate for all depths visited, and adequate to allow decompression from any point of the dive plan. Planning the carriage of bailout gases is very similar to the planning of an open-circuit deep dive as described above. Notwithstanding this precaution, it is perhaps not surprising that crude estimates suggest that rebreather diving is associated with higher mortality (perhaps an order of magnitude higher) than open-circuit diving.[16]

Logistics of technical diving

Technical diving frequently involves complex logistics to support these ambitious dives. Deep wrecks usually lie in open ocean and diving them requires large boats for safe and reliable surface support in weather conditions that are rarely optimal. Accurate GPS and sounding equipment are vital, and teams develop considerable skill in accurately dropping a shot line down on to a wreck in deep waters. Divers usually descend and ascend on these shots lines, but strong currents can complicate such plans and necessitate the use of drifting decompression shots underneath large buoys so that the divers can complete long decompressions without having to hold onto a shot line against the force of the current. Purpose-built decompression stages with bars at the depths of the long stops help divers accurately maintain stop depths and allow multiple divers to comfortably occupy the station at the same depth (Figure 3). To enhance safety, teams often arrange themselves into bottom diver and support diver roles. Bottom divers actually visit the wreck, and support divers help with surface logistics and visit the bottom divers during decompression. This allows any developing needs to be met and messages to be relayed to the surface.

The exploration of long and frequently deep caves has a different set of logistical challenges. Sequential dives, often very dependent on the use of battery-powered diver propulsion vehicles, are used to penetrate progressively further into the cave and to lay lines into new sections. As there is progress to greater distances, it may become necessary to stage gas supplies at strategic points on the way in before 'pushing' the cave further. In this setting, divers may arrange themselves into large teams with specific roles for each individual. Lead divers perform the long pushes. The support divers may be required to stage gas prior to the dive, and visit the lead divers during their decompression which, as in deep wreck diving, allows any developing needs to be met and messages to be relayed to the surface. In some major cave penetrations, support divers may even install dry underwater habitats (such as an upside-down rain-water tank filled with air) in which the lead divers can actually leave the water whilst still under pressure in order to rest, eat, drink and warm up.

In both wreck and cave settings, there are numerous logistical considerations which are vitally important but too numerous to discuss here. These include thermal protection and temperature management, hydration and nutrition, gas logistics, medical support and evacuation plans. It should be obvious from this discussion that merely training in the technical diving methods described above is only the start of the process of becoming an exploration-level technical diver.

Current scope of technical diving

The boundary between technical diving and mainstream recreational diving is fluid because technical diving methods and equipment are being adopted by and becoming part of recreational diving.[17] It is difficult to imagine now but the use of nitrox, presently considered 'mainstream' in recreational diving, was viewed as highly technical and fiercely opposed by the recreational diving industry in the early 1990s. In what may prove to be a similar development, there are current plans to develop and promote simplified closed-circuit rebreathers for mainstream recreational diving.[18]

Open-circuit and rebreather trimix dives to a maximum of

about 90 msw for bottom times of 30–60 minutes represents the current state of typical technical diving. Several training agencies specialize in training for this type of diving and several of the large recreational training agencies have also entered this market. Depth record-setting dives (now in excess of 300 msw on open-circuit equipment) typically involve immediate ascent from the maximum depth. However, technical divers are conducting purposeful exploration dives in excess of 200 mfw with substantial bottom times. A notable recent example is the exploration of the Pearse Resurgence cave system in New Zealand to 221 mfw. In addition, some dives of remarkable duration are now being undertaken to explore caves over long distances. The most conspicuous are those conducted by the Woodville Karst Plains Project in northern Florida. This team has conducted exploration out to 7.9 km in Wakulla Springs: a dive requiring 11 hours of bottom time at an average depth of 80 mfw, followed by 16 hours of decompression.

Summary

Technical recreational divers tailor gases to target depths and for optimised decompression, and utilise specialised equipment configurations to extend their gas supply. This has markedly enhanced depth, duration, and range capabilities in recreational diving. This paper has provided a basic outline of these methods for the non-technical diver or diving medical officer. The second paper in this series discusses the optimization of decompression in more detail.

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David Oliver
Executive Director

Recreational technical diving part 2: decompression from deep technical dives

David J Doolette and Simon J Mitchell

Abstract

(Doolette DJ, Mitchell SJ. Recreational technical diving part 2: decompression from deep technical dives. *Diving and Hyperbaric Medine*. 2013 June;43(2):96-104.)

Technical divers perform deep, mixed-gas 'bounce' dives, which are inherently inefficient because even a short duration at the target depth results in lengthy decompression. Technical divers use decompression schedules generated from modified versions of decompression algorithms originally developed for other types of diving. Many modifications ostensibly produce shorter and/or safer decompression, but have generally been driven by anecdote. Scientific evidence relevant to many of these modifications exists, but is often difficult to locate. This review assembles and examines scientific evidence relevant to technical diving decompression practice. There is a widespread belief that bubble algorithms, which redistribute decompression in favour of deeper decompression stops, are more efficient than traditional, shallow-stop, gas-content algorithms, but recent laboratory data support the opposite view. It seems unlikely that switches from helium- to nitrogen-based breathing gases during ascent will accelerate decompression from typical technical bounce dives. However, there is evidence for a higher prevalence of neurological decompression sickness (DCS) after dives conducted breathing only helium-oxygen than those with nitrogen-oxygen. There is also weak evidence suggesting less neurological DCS occurs if helium-oxygen breathing gas is switched to air during decompression than if no switch is made. On the other hand, helium-to-nitrogen breathing gas switches are implicated in the development of inner-ear DCS arising during decompression. Inner-ear DCS is difficult to predict, but strategies to minimize the risk include adequate initial decompression, delaying helium-to-nitrogen switches until relatively shallow, and the use of the maximum safe fraction of inspired oxygen during decompression.

Key words

Technical diving, deep diving, trimix, decompression, decompression tables, models, decompression sickness, inner ear, review article

Introduction

Some scuba divers use gases other than air and specialized equipment configurations to explore deeper depths for longer durations than are possible with the single-cylinder, open-circuit air diving configuration typically used by recreational divers. These divers refer to themselves as 'technical divers'. In the preceding article, we provided an introduction to the methods used by technical divers.[1] Technical divers typically perform 'bounce dives'; that is, dives lasting minutes to hours in which a short period of descent and at the target depth ('bottom time') is immediately followed by decompression back to the surface, and in which any increase in bottom time results in increased absorption of inert gas and a longer decompression obligation. This distinguishes their activities from many occupational dives to similar depths in which the divers effectively live under pressure in a dry chamber environment, and make periodic excursions into the sea to perform underwater work. This is referred to as 'saturation diving' because, after a certain period, the inert gas in all tissues is in equilibrium with inspired inert gas partial pressures (saturated). The divers can subsequently spend an indefinite period under pressure and their decompression obligation will remain the same. In comparison, bounce diving is very inefficient in respect to the amount of time spent at depth versus the time spent decompressing. Not surprisingly, in technical diving there is invariable tension between the desire to spend more time at the target depth and a desire to minimize decompressions, which take place in the water, possibly exposed to cold, strong currents and other hazards. The optimisation of decompression from these deep bounce dives is, therefore, one of if not the most debated and controversial issues in technical diving. This paper focuses on decompression methods and selected controversies.

Decompression from technical dives

As discussed in the first paper in this series, helium-based breathing gas mixtures are used for deep diving to avoid the narcotic effects of high nitrogen partial pressures and to reduce gas density. Technical divers typically use trimix breathing gas (He-N_2-O_2) instead of heliox (He-O_2) for deep diving. The reasons for this are historical, financial and logistical. Early technical divers had limited infrastructure to handle and mix helium into high-pressure scuba cylinders.[2] Also, helium is expensive, a particular concern for open-circuit diving, but less so in rebreathers; and there is a perception that larger fractions of helium in the breathing gas result in an increased decompression obligation. These issues motivate some divers to use the minimum helium fraction consistent with managing nitrogen narcosis and gas density. The use of trimix breathing gas presents challenges. Whereas, recreational divers were able to adopt readily

available military air decompression tables, which were validated against databases of dives with known outcomes, no such trimix tables were available to technical divers.

GAS-CONTENT DECOMPRESSION ALGORITHMS

The earliest technical divers used custom trimix decompression tables prepared for them by RW Hamilton using a proprietary software (DCAP) implementation of the Tonawanda II decompression algorithm and the 11F6 M-values matrix (see below).[2] Almost immediately thereafter, technical divers began implementing the Buhlmann ZH-L16 decompression algorithm, descriptions of which were readily available in the open scientific literature.[3–5] Both Tonawanda II and ZH-L16 are 'gas-content' decompression algorithms. Gas-content algorithms track the uptake and elimination of inert gas in notional tissue compartments with different gas kinetic properties, and schedule decompression stops according to ascent rules that limit the degree to which the sum of dissolved gas pressures in the compartment exceeds the ambient pressure: a state referred to as supersaturation. Supersaturation is a requirement for bubble formation from dissolved gas, and the principle of limiting supersaturation (and thereby bubble formation) to schedule decompression was introduced by Haldane and colleagues.[6] A widely used format for the ascent rules which define acceptable compartmental supersaturation is:

$$P_{tis.k} < a.k \cdot P_{amb} + b.k \quad (1)$$

Where: P_{amb} is the ambient pressure; P_{tis} is the gas tension in k theoretical compartments that represent body tissues with different gas exchange rates, and a and b are constants for each of the k compartments.[7]

If P_{amb} is expressed in depth-of-water gauge pressure at specified decompression stops, the left-hand side of the equation is the maximum permissible tissue tension, or 'M-value', at that depth.[7] To apply the ascent rules, the depth/time/breathing-gas history of a dive is used to calculate P_{tis}, usually by assuming that the tissue-to-arterial inert gas tension difference declines mono-exponentially according to a half-time notionally determined by the blood flow to the tissue, and the relative solubility of the gas in the blood and tissue compartments. To accommodate trimix diving, each compartment may have a different half-time for helium and nitrogen and these gases are tracked independently. P_{tis} is compared to a matrix of M-values for each compartment at predefined decompression stop depths to determine if or when ascent to those depths is permissible.

BUBBLE DECOMPRESSION ALGORITHMS

There are two general classes of bubble decompression algorithms, although they have overlapping aspects. One class calculates bubble size using complex equations of bubble growth and resolution due to gas diffusion between bubbles and the surrounding tissue.[8,9] The second class of algorithms is much simpler, focusing on predictions of the number of bubbles that form during decompression.[10] These latter bubble-counting algorithms will be outlined here because they are widely available to technical divers.[11,12]

The smallest radius spherical bubble (R_{min}) that can grow for any particular supersaturation (P_{ss}) is given by re-arranging the LaPlace equation:

$$R_{min} = 2st/P_{ss} \quad (2)$$

Since the growth of small bubbles requires a large supersaturation, it seems likely that bubbles in the body result from accumulation of gas into or around pre-existing gas nuclei. One theoretical form of gas nucleus is a spherical 'proto-bubble' coated with surface active agents that counteract surface tension and render the gas nucleus relatively stable. The varying permeability model (VPM) assumes a population of spherical gas nuclei and a theoretical distribution of their radii that, along with equation (2), is used to calculate the number of gas nuclei activated into growing bubbles by the maximum supersaturation encountered during decompression.[10] In the simplest form of VPM algorithm, decompression can be controlled by a predicted maximum allowed number of bubbles and, therefore, a maximum allowed supersaturation. Alternatively, the number of bubbles is converted to a simple index representing the number of bubbles and their growth by multiplying the number of bubbles by the time integral of supersaturation. The allowed supersaturation is that which, if sustained throughout the ascent, results in the target value of this bubble index. The parameters of the VPM algorithm were originally adjusted to give decompression times similar to existing military decompression tables.[10] Some of these parameters may be user-adjustable, resulting in longer or shorter decompression times, in computer implementations available to technical divers.

UNTESTED SCHEDULES

The decompression procedures promulgated by well-resourced organizations (e.g., the US Navy) are developed and validated in conjunction with human dive trials in which the conditions that influence the risk of decompression sickness (DCS) are well-documented and dive outcomes (typically DCS or not) are known. In the development phase, decompression algorithm parameters are found by prospective trial-and-error testing, or by formal statistical fit of decompression models to existing databases of dives. The final decompression algorithm is validated by comparison to other man-dives. The development and validation man-dives are conducted under conditions similar to the intended use of the procedures, both in terms of depth/time/breathing-gas histories and other DCS risk factors not accounted for in the algorithms (such as diver work rate and thermal status). The

resulting decompression algorithms are embodiments of the development data and are not intended for and, indeed, do not extrapolate well to all types of diving.

Many decompression schedules used by technical divers are untested because they are generated using decompression algorithms that have not been developed and validated with the types of dives conducted by technical divers. Both the Tonawanda II – 11F6 and the ZH-L16 decompression algorithms were developed in conjunction with laboratory dive trials but had limited testing specific to trimix diving at the depth ranges typical for technical diving. Development of ZH-L16 included many man-dives although most were substantially shallower or deeper than the 60–90 metres' sea water (msw) typical of technical diving, and there were few trimix dives.[5] In a carefully monitored technical diving project using the ZH-L16 algorithm for decompression guidance, two cases of DCS requiring treatment occurred in the course of 122 trimix dives (95% confidence limits 0.2%, 5.8% incidence).[13] Anecdotally, other technical diving projects had similar incidences of DCS, and the ZH-L16 algorithm may be modified by the end-user to be more conservative.

A popular, but untested end-user modification is the use of 'gradient factors'. In this usage, gradient refers, unconventionally (because it is not a gradient), to the difference between ambient pressure and an algorithm M-value.[12,14] Supersaturation is limited to less than permitted by the original M-value by allowing only a fraction of the difference between ambient pressure and the original M-value. These fractions have come to be known as gradient factors.[14] Thus, if a diver elects to limit supersaturation to 80% of the usual difference between ambient pressure and the M-value, this is referred as 'gradient factor 80' (GF 80). Typical proprietary implementations of the gradient factor method require the diver to select two gradient factors: the first modifies permitted supersaturation at the deepest decompression stop and the second controls supersaturation at the point of surfacing. The algorithm then interpolates a series of modified M-values in between these two user-specified points. Not surprisingly, lowering the first gradient factor forces deeper stops to limit supersaturation in the fast tissues early in the ascent, and lowering the second will produce longer shallower stops to reduce supersaturation in the slower tissues in the latter phase of the ascent.

To our knowledge, there has been no formal testing of VPM-based technical diving decompression schedules; however, many thousands of dives have been conducted by technical divers using this algorithm (V-Planner Live & Multideco Dive Database [Internet]. Kingston (ON, CAN): HHS Software Corp. [2004]-2012 [cited 2012 Aug 01]. Available from: http://database.hhssoftware.com/database.html). This fact, of itself, is often used by proponents as evidence of the algorithm's efficacy. However, this sort of anecdote deserves very cautious interpretation. Firstly, there is concern over positive reporting bias for dives of good outcome. Secondly, many such dives are not conducted to the limits of the algorithm and therefore do not validate the algorithm: tabulated schedules assume the full bottom time is spent at the maximum depth whereas the actual dive may be shallower and shorter; the conservatism of the algorithm is user-adjustable and many divers indulge in idiosyncratic 'padding' of their decompression for extra safety.

Deep stops

A characteristic of bubble algorithms is that they typically prescribe deeper decompression stops than gas-content algorithms[10,15–17] The potential benefit of these bubble-algorithm-prescribed 'deep stops' has been hypothesized since the 1960s.[15] In simple terms, the aim is to limit supersaturation (below levels normally accepted by gas-content algorithms) early in the decompression in order to limit bubble formation.

Deep stops came to the attention of early technical divers in the form of empirical 'Pyle stops', a practice serendipitously developed by ichthyologist Richard Pyle, arising from a requirement to vent the swim bladders of fish specimens collected at great depth before arriving at his first decompression stop.[18] There followed a strong trend toward the adoption of bubble algorithms, and also for the use of manipulation of gradient factors (see earlier) to force gas-content algorithms to impose deep stops. Based largely on supportive anecdote, there is a widespread belief among technical divers that deep-stop decompression schedules are more efficient than shallow-stop schedules. It is perceived that, compared to a decompression profile prescribed by a traditional gas-content algorithm, a deep-stop schedule of the same or even shorter duration has a lower risk of DCS. Recently, however, evidence has been accumulating from laboratory man-trials that shows deep stops are not more efficient than shallow stops for air or trimix dives.[17,19]

NEDU DEEP STOPS TRIAL

The largest of these trials was conducted at the US Navy Experimental Diving Unit (NEDU).[17] Submerged divers breathing surface-supplied air were compressed to 170 feet sea water (fsw, approx. 51.5 msw) for a 30-min bottom time, during which they performed 130 watt work on a cycle ergometer. They were then decompressed at 30 fsw per min^{-1} (approx. 9 msw min^{-1}) with stops prescribed by one of the two schedules shown in Figure 1A. Divers worked while on the bottom and were at rest and cold during decompressions. The shallow-stop schedule, with a first stop at 40 fsw (approx. 12 msw) and 174 min total stop time, was prescribed by the gas-content VVAL18 Thalmann algorithm. The deep-stop schedule, with a first stop at 70 fsw (approx. 21 msw), was the optimum distribution of 174 min total stop time according to the probabilistic BVM(3) bubble algorithm.[9] A higher incidence of DCS was observed on the deep-stop schedule (10 cases of DCS in 198 dives) than on the shallow-stop schedule (three cases

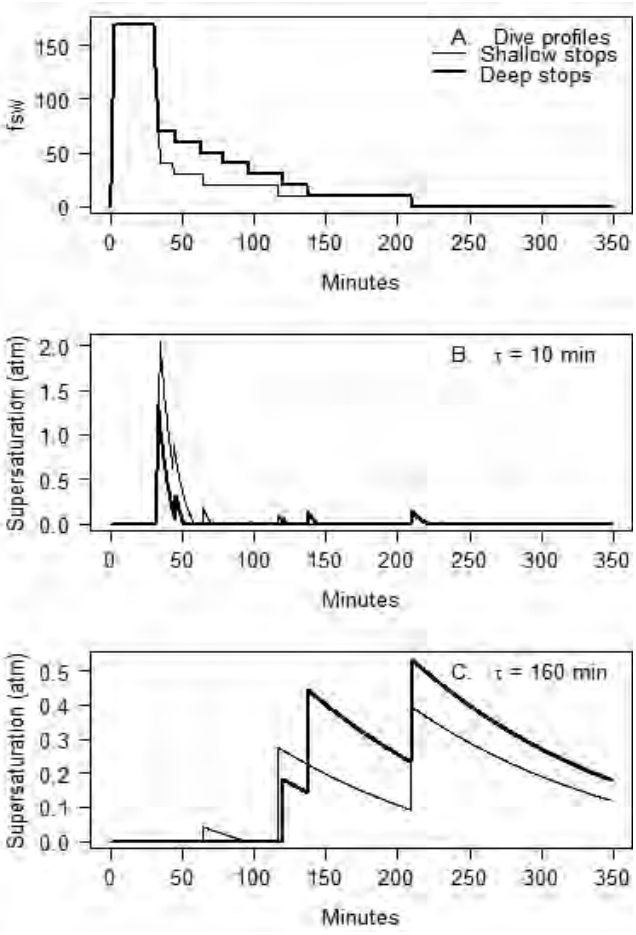
Figure 1

Supersaturation (ΣP_{tis_j} P_{amb} > 0) in fast and slow compartments for the tested shallow-stop and deep-stop schedules.

A. Overlay of the two 170 fsw / 30 min air decompression dive profiles tested.

B. Supersaturation in a modelled compartment with fast (τ = 10 minutes) mono-exponential inert gas exchange.

C. Supersaturation in a modelled slow (τ = 160 minutes) compartment (redrawn from reference 17)



of DCS in 192 dives, P = 0.0489, one-sided Fisher's Exact test). Divers were also monitored for venous gas emboli (VGE) with trans-thoracic cardiac 2-D echo imaging, at 30 minutes and two hours after surfacing, both at rest and after limb flexion. The maximum VGE grade observed was significantly higher after the deep-stop schedule (median = 3) than after the shallow-stop schedule (median = 2; Wilcoxon rank sum test, W = 12967, P < 0.0001).

The BVM(3) bubble algorithm, used to produce the NEDU deep-stop schedule, predicts growth and dissolution of bubbles in three theoretical tissue compartments. It indicated substantial bubble growth on the shallow-stop schedule in the fast compartments (1- and 21-minute half-times) that required 'repair' with deep stops.[16] This is clearly at odds with the NEDU results. However, interpretation of the NEDU result simply requires a clear understanding of the relationship between tissue gas kinetics and bubble formation. In this regard, there are four important facts to keep in mind:

- bubbles form and grow only if the tissue is gas supersaturated, and the greater the supersaturation the more bubbles will form and the faster they will grow;
- supersaturated tissue has higher inert gas tension than the blood flowing into the tissue, so there is a net diffusion of inert gas from supersaturated tissue into the capillary blood, i.e., tissues that contain bubbles are losing, not taking up, inert gas;
- once inert gas washout has reduced inert gas partial pressure in tissue below that inside the bubble, the bubble shrinks;
- inert gas uptake and washout occurs at different rates in different body tissues. These different rates can be represented by compartments with different half-times.

Figure 1B shows gas supersaturation in a fast inert gas exchange compartment for the tested shallow- and deep-stop dive profiles illustrated in Figure 1A. This fast compartment (time constant, τ = 10 min, equivalent to half-time = 7 min) is notionally representative of all compartments that have comparatively fast gas exchange and in which an ascent to the shallow first decompression stop results in gas supersaturations greater than those produced by an ascent to a deeper first stop. The fast compartment in Figure 1B displays markedly lower and less sustained gas supersaturation (and therefore less driving force for bubble formation) during the deep-stop than during a comparable period of the shallow-stop schedule. This is consistent with the observation that a brief deep stop results in fewer Doppler-detectable VGE during decompression.[20] However, the NEDU results indicate that this reduction of gas supersaturation in fast compartments does not manifest in reduced DCS incidence. Put another way, the large ascent to the first stop in traditional schedules is not a flaw that warrants repair by deeper initial stops.

Figure 1C shows supersaturations in a notional slow compartment (τ = 160 min, half-time = 111 min) representative of all compartments having comparatively slow gas exchange and which are not gas supersaturated upon ascent to the deep first decompression stop. Inert gas will either wash out slowly or continue to be taken up into these slower compartments on the deep-stop schedule. Therefore, the deep-stop schedule results in greater and more persistent gas supersaturation in slow compartments on subsequent ascent than during the comparable period in the shallow-stop schedule. The observed differences in gas supersaturations in slower compartments late in the decompression are in accord with the present results from the tested dive profiles. The higher VGE scores and DCS incidence following the deep-stop schedule compared with the shallow-stop schedule may be a manifestation of bubble formation instigated by conditions in slower compartments.

Although the tested shallow- and deep-stop schedules are the optimal distributions of stop time under the VVAL18 Thalmann and BVM(3) algorithms, respectively, this does

not mean that either schedule is the true optimal distribution of 174 minutes total stop time. Of interest is how alternative deep-stop schedules might have performed against the traditionally shaped shallow-stop schedule. Deep-stop schedules prescribed by VPM-based decompression software available to technical divers have deeper and shorter initial decompression stops than the tested deep-stop schedule (see, for instance, reference 10). However, analysis of half a million possible alternative distributions of stop times (which inevitably included profiles matching those more typical of technical diving) showed the same patterns as illustrated for the tested schedules in Figure 1: deeper stops reduced supersaturation in fast compartments at the expense of increased supersaturation in slow compartments compared to shallow-stop schedules.[17]

The impact of the technical diving practice of switching to a high fraction of oxygen for the decompression gas, or diving with a constant partial pressure of oxygen (PO_2) closed-circuit rebreather (see the first paper in this series) is relevant here. This accelerates decompression by faster washout of inert gas from all compartments, but will also result in less uptake of inert gas into slow compartments during deep stops. For instance, if the NEDU schedules in Figure 1 incorporated a switch to 50% O_2 / 50% N_2 at 70 fsw (21 msw), the supersaturations in slow compartments in panel C would be greatly reduced for both schedules. The risk of DCS would be reduced for both schedules, probably so that it would not be possible to distinguish a difference in DCS incidence between them.[16]

OTHER (NON-NEDU) DATA

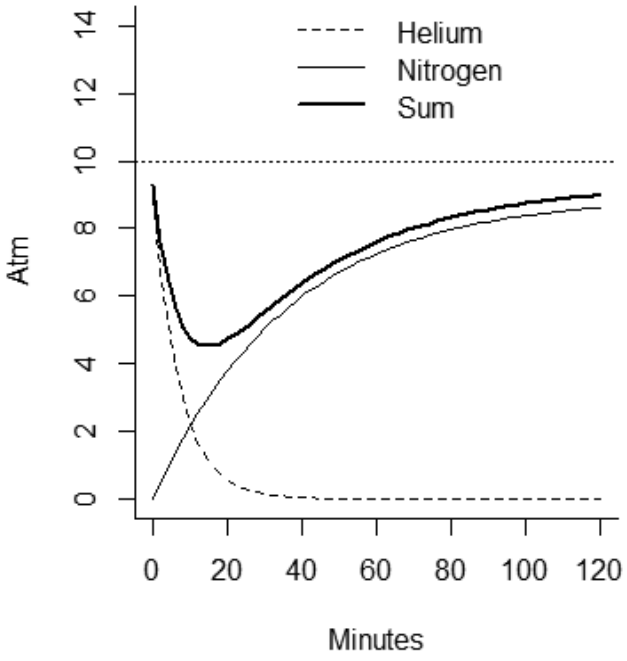
Several air and trimix schedules with brief deep stops more like those conducted by technical divers have been compared to traditional gas-content algorithm schedules using venous gas emboli (VGE) counts as the endpoint in a limited number of man-dives. Despite longer decompression times, the deep-stop schedules resulted in the same or more VGE than the shallow-stop schedules, and some deep-stop dives resulted in symptoms of DCS.[19,21]

Diving with multiple inert gases

Owing to differing physicochemical properties, in some body tissues, helium is taken up and washed out faster than nitrogen. This difference can be seen in the whole-body washout of helium or nitrogen and appears to be important in tissues with slow gas kinetics (probably fat).[22–24] This slower washout of nitrogen in slowly exchanging tissues is manifest in a slower required rate of decompression from nitrox saturation dives (where the body has completely equilibrated with the elevated nitrogen partial pressure) than from heliox saturation dives of similar depth.[25–27]

A similar phenomenon is thought by some to be relevant in all bounce diving. In many decompression algorithms, helium is assumed to have faster exchange than nitrogen

Figure 2
Isobaric exchange of helium and nitrogen in a compartment with faster half-time for helium than nitrogen. Simulation of a compartment at equilibrium with 90% He/10% O_2 inspired gas at 10 atm abs ambient pressure and a switch to 90% N_2/10% O_2 inspired gas at time zero. Dashed and thin lines indicate partial pressures of helium and nitrogen. The thick line indicates the sum of both inert gases and metabolic gases. The compartment is transiently undersaturated while the sum of gases is below the equilibrium value (adapted from reference 24).

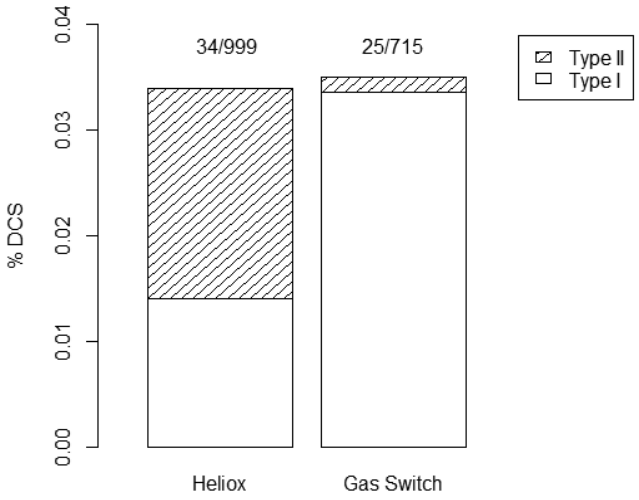


in all compartments. For instance, in the Buhlmann ZH-L16 gas-content decompression algorithm each of the 16 compartments has a half-time for helium that is 2.65 times shorter than the corresponding nitrogen half-time.[4] These, or similar, compartment half-times are used in most decompression algorithms available to technical divers. As a result of these compartment half-times, such decompression algorithms will prescribe shallower decompression stops and less total decompression time for a bounce dive conducted breathing nitrox than for a dive conducted breathing trimix or heliox because of a slower uptake of nitrogen than of helium.[5] Similarly, such decompression algorithms will prescribe shorter decompressions if switching to nitrox breathing during decompression from a heliox or trimix dive.[5] The reason for this latter effect is illustrated in Figure 2, which shows that faster helium washout than nitrogen uptake in a compartment will result in a period of under-saturation (making the safe ascent depth shallower) following a heliox-to-nitrox gas switch.

HELIOX TO NITROX GAS SWITCH MAY NOT ACCELERATE DECOMPRESSION FOR BOUNCE DIVES

It is not clear that the apparent differences in bounce diving decompression resulting from different inert gases are real.

Figure 3
Comparison of incidences of Type I and Type II DCS during development of constant 1.3 atm inspired PO_2-in-helium decompression schedules:[30,31] left (Heliox) and during development of surface supplied (84/16 He/O_2) decompression schedules;[32] right (Gas Switch). Only the latter employs a switch to air breathing during decompression. Although there are substantial differences between these two types of diving, dives were across a similar range of depths and bottom times and resulted in similar overall incidences of DCS (actual number DCS/dives indicated above bars). Although these studies were not designed for this purpose, the different incidences of Type II DCS are noteworthy.



Direct measurement of helium and nitrogen exchange rates in faster exchanging tissues relevant to bounce diving indicates very similar rates of exchange for nitrogen and helium.[24] These latter data suggest heliox, nitrox, and trimix decompression from bounce dives of the same depth and duration should be similar. This is supported by the finding that wet, working no-stop dives to 60 fsw (18 msw) for bottom times of 70 to 100 minutes showed a similar incidence of DCS whether breathing air or heliox (21% oxygen), indicating a similar rate of helium and nitrogen uptake and similar decompression requirement.[28]

The scant data relevant to actual decompression diving can be interpreted as 'conflicting'. The oft-cited work supporting accelerated decompression by switching from heliox to nitrox in fact shows nothing of the sort.[29] This work presents several dives with changes in inert gas composition and increases in oxygen fraction up to 100% during decompression and compares decompression time to schedules from (or extrapolated from) the US Navy 1957 Standard Air Tables that were not actually tested. Later experiments comparing dives with heliox-to-air gas switching to dives with all heliox decompression are confounded by different decompression schedules and small numbers of dives, particularly on the schedules that provoked DCS.[5] On the other hand, a US Navy man-trial indicated that a heliox to nitrox switch does not accelerate decompression.[30] In that study, 32 man-dives to 300 fsw (approx. 90 msw) for 25 min breathing 1.3 atm inspired oxygen partial pressure (P_iO_2)-in-helium for the entire bottom time and throughout the 190 minutes of decompression resulted in only one case of DCS, whereas 16 man-dives with an identical depth-time profile and P_iO_2 but a switch to nitrox at the first decompression stop (110 fsw, approx. 33 msw) resulted in three DCS. This difference in incidence does not reach statistical significance, but there is a strong trend indicating no advantage (and perhaps even a disadvantage) for the gas switch.

In very long decompressions, nominally over 10 hours, a switch from heliox or trimix to nitrox late in decompression may accelerate decompression. This is because the long shallow stops of such 'sub-saturation dives' are governed by the slow compartments that govern saturation decompression in a similar way, in which helium exchanges faster than nitrogen. However, there is no direct experimental evidence to support this. Another possible advantage of a heliox-to-nitrox gas switch is that it may result in less Type II DCS (Figure 3).

Inner-ear decompression sickness

Although a heliox-to-nitrox breathing gas switch may accelerate decompression in a very long dive, and may result in less Type II DCS, such switches have also been associated with the onset of DCS involving the vestibulocochlear apparatus (inner ear).[33–36] Though infrequent, inner-ear DCS is of particular concern to technical divers because debilitating symptoms characteristically onset during decompression and are life-threatening for a scuba diver with substantial remaining decompression obligation.[36]

A physiological model of the inner ear indicates that at great depths, following a switch from a helium-based breathing mixture to one containing nitrogen, transient supersaturation can develop in the vascularized membranous labyrinth without any further change in depth, principally due to diffusion of helium from the endolymph and perilymph exceeding the counter-diffusion of nitrogen in the opposite direction.[36] However, the same model demonstrates substantial pre-existing supersaturation in the inner ear during decompression from typical technical bounce dives, and that the counter-diffusion of gases following a helium-to-nitrogen mix gas switch makes only a small contribution to the total supersaturation at the depths where such switches are usually made.[36] The actual contribution of gas switches to inner-ear DCS in this setting is, therefore, uncertain. During sub-optimal decompression of the inner ear, gas switches could conceivably act as "*the straw that broke the camel's back*". Otherwise, such switches will usually not result in problems. Indeed, heliox-to-air breathing gas switches at 30 msw during decompression have been demonstrated to have low risk of DCS.[37] Thus, inner-ear DCS that seems related to gas switching in technical divers is more likely to be due to inadequate decompression *per se* prior to the breathing gas switch.

Isolated inner-ear DCS has also been described early after surfacing in divers visiting more modest depths (50 msw or less).[38,39] Interestingly, among such cases there is an unexpectedly high prevalence (100% in one series of 9 divers) of major right-to-left shunting demonstrated using transcranial Doppler sonography after administration of venous bubble contrast.[38,39] The nature of the right-to-left shunt in these studies was not established, but right-to-left shunting of VGE through a patent foramen ovale (PFO), which is present in about 25% of the population, has been identified as a potential risk factor for some forms of DCS, including inner-ear DCS.[40–42] Indeed, the contribution of PFO to the risk of DCS is an article of faith among technical divers. However, recent evidence indicates that 30–60% of divers without PFO also shunt venous bubbles to the arterial circulation after routine asymptomatic dives, presumably via intrapulmonary routes.[43–45]

Whatever the means by which they reach the arterial circulation, if VGE reach the labyrinthine artery, they must also distribute widely in the brain because the labyrinthine artery is usually a tiny branch of the much larger basilar artery. Despite this, these divers frequently do not develop cerebral manifestations. The selective vulnerability of the inner ear in this setting may relate to slower inert gas washout, and therefore more prolonged supersaturation, in the inner ear than the brain. Under these circumstances, small arterial bubbles reaching the inner ear are more likely to grow and cause symptoms than bubbles reaching the brain.[46]

This mechanism may also be relevant to the onset of inner-ear DCS at depth during decompression, which is when inner-ear symptoms characteristically occur in technical diving. It is notable that arterial bubbles (presumably shunted from the veins) have been detected in 70% of divers following typical, asymptomatic VPM-planned technical dives.[45] It is not known if such arterial bubbles would also be detected during decompression, but, if so, the passage of bubbles into a supersaturated inner-ear microcirculation provides another possible explanation for DCS in this setting.

Supportive but admittedly circumstantial evidence for a role for arterial bubbles in inner-ear DCS during decompression can be inferred from saturation diving. In one study, arterial bubbles were detected in all six participating divers between one and four hours following 10 msw min^{-1} upward excursions from a 300 msw saturation storage depth to 250 msw.[47] There were no symptoms of serious DCS in these divers, but isolated inner-ear symptoms are an infrequent but characteristic manifestation of DCS following rapid (8–18 msw min^{-1}) upward excursions (38–50 msw) from deep (200–430 msw) heliox saturation dives.[48] The previously described model of the inner ear indicates these excursions could produce sufficient supersaturation in the inner ear to cause local tissue bubble formation.[36] Nevertheless, the presence of arterial bubbles raises the possibility that isolated inner-ear DCS following upward excursions from heliox saturation could also result from passage of arterial bubbles into a supersaturated inner-ear microcirculation.

Although inner-ear DCS occurs relatively unpredictably, the putative pathophysiology described above suggests several goals to mitigate the risk of inner-ear DCS during decompression from technical dives. First, the chosen algorithm should adequately decompress the inner ear which has a half-time of about 8.8 minutes.[36] Second, if gas switches are made, they should be made at points during the decompression that avoid peak supersaturation of the inner ear and the shallower the better with no undue risk found with switches at 30 msw.[37] Third, since the right-to-left shunting of bubbles via either a PFO or the trans-pulmonary route is associated with high-grade VGE, the chosen algorithm should not consistently produce high VGE grades. Finally, since trans-pulmonary passage of VGE is potentially reduced by oxygen breathing, utilization of the highest safe inspired oxygen fraction at all times, and particularly after gas switches is likely to be beneficial.[36,44]

Summary

Technical divers use a variety of decompression algorithms although many are modifications of the ZH-L16, Tonawanda II and VPM algorithms. These modifications have generally not been validated by conduct of human dive trials comprising well-documented dives and outcomes. Many thousands of dives have been conducted safely in the field but the incidence of DCS in technical diving is unknown, and it is unknown if technical diving decompression procedures are optimal. Scientific evidence supports some technical diving procedures although not always for the reasons they were originally adopted.

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Historical articles

The following two articles are taken from reports of the Royal Naval Personnel Research Committee during World War II. They are seminal works that describe in detail oxygen and carbon dioxide toxicity in military rebreather diving of 70 years ago. Their messages are as pertinent today as they were then. In addition, the report on carbon dioxide intoxication identifies the original, and correct, usage of the term "*shallow water blackout*", often used incorrectly to describe 'apnoeic hypoxia' (or 'ascent hypoxia') in breath-hold diving. Minor editing and re-formatting have been undertaken in both articles. **These reports are reproduced with the kind permission of the Royal Naval Medical Institute, Haslar, United Kingdom**.

Diving – effects of breathing oxygen under pressure

Admiralty Fleet Order AFO 4565/44 (promulgated 24 August 1944)

1. Diving – Effects of breathing oxygen under pressure

The effects of breathing oxygen under pressure have recently been the subject of considerable investigation and experiments. The following information is promulgated as a guide to diving carried out by the Admiralty Experimental Diving Unit. When oxygen is breathed under pressure for too long a time or at too great a pressure, undesirable symptoms may occur. These symptoms are referred to hereafter as "*oxygen illness*".

2. Principal findings of the experiments

i. That danger of oxygen illness exists at any time when the depth of the diver exceeds 33 ft. of sea water;
ii. the time at a given depth before symptoms appear varies greatly between individuals;
iii. a given individual may vary greatly from day-to-day for no apparent reason.

3. Special warning

From the above it will be seen that previously accepted figures for safe times on oxygen (*see* B.R. 241 (40) "*Handbook of DSEA*". p. 24) are misleading and should not be used as a guide to oxygen diving. *A depth of 5 ½ fathoms is never to be exceeded in normal diving when breathing pure oxygen*. In time of war, however, or in cases of exceptional emergency, it may be that the advantages to be gained as a result of the dive may be such that some risk to the diver must be accepted. The instructions which follow are for guidance in such cases and if studied and followed should reduce such risks to the minimum. Should it be decided that depths greater than 5 ½ fathoms are to be exceeded, only divers experienced in oxygen diving should be employed.

4. Difference between diving underwater and breathing oxygen in a chamber of compressed air

It has been demonstrated that when breathing oxygen under water (in the "*wet*") the symptoms of oxygen illness appear sooner than when oxygen is breathed from an apparatus whilst in a compressed air chamber (in the "*dry*"). Depth and time limitations given herein should not therefore be taken as affecting the times for oxygen decompression given in Table II of B.R. 155/43 – *Diving Manual* which remain unaffected. Watch should always be kept, however, for the man who is unusually sensitive to oxygen, and if symptoms appear at the higher pressures, oxygen breathing must be delayed until the pressure can be reduced and decompression correspondingly prolonged.

Conversely, it must not be assumed that because such times are possible in the decompression chamber, they can be used as a guide for under-water work, since quite clearly they cannot. No definite relation can be given between "*wet*"and "*dry*" times, but the "*wet*" may well be as little as one quarter of the "*dry*".

5. Effects on the body and symptoms

The actual cause of oxygen illness, i.e., what happens inside the body, has not yet been sufficiently determined to allow of any simple explanation. The diving officer must accept the fact that it does exist and constitutes a very real menace to the diver.

The symptoms are varied, and those experienced during the trials are given below in the order in which they most frequently occur. They may usually be expected to give some warning before the final stage of the convulsions and unconsciousness is reached, but it must be emphasised that "*no definite warning period can be laid down*". While some divers have shown that it is possible even to lose the symptoms altogether and carry on, others have lost consciousness without any warning at all.

The rule, therefore, must be that if any diver breathing oxygen experiences any of the symptoms shown below, he must be brought to the surface immediately.

SYMPTOMS

(1) Lip twitching
Starting with a slight twitch of the upper lip it increases in severity, at descending intervals, until it becomes an uncontrollable movement of the whole month. Convulsions

will follow almost immediately on this last stage unless the diver is surfaced.

(2) Loss of control of lips
As opposed to definite twitching of the lips, some divers have experienced difficulty in retaining the mouthpiece just before convulsing. This is easily detected from the surface since it leads to loss of oxygen past the lip-seal and consequently bubbles appear on the surface. The diver should be called up if this is observed to be happening continuously, though it must be remembered that if the diver is not working, excess oxygen from the reducer will probably escape past his lips in a thin steady trickle of bubbles. It is when this trickle suddenly increased and stays increased that the diver may be considered to be in danger.

(3) Vertigo (dizziness)
If the diver feels dizzy underwater, it is a definite warning. In cold water, particularly if the head is not enclosed, a slight dizziness may be felt on entering the water, which should not be confused with oxygen illness.

(4) Nausea – a feeling of sickness
Here again, some people may feel slightly sick if not accustomed to wearing oxygen apparatus. With both nausea and vertigo, the depth should be the deciding factor. If the diver is below 33 ft. they should be regarded as warning symptoms, otherwise they should be ignored, so far as oxygen illness is concerned.

(5) Unpleasant sensations concerning breathing
The onset of oxygen illness may be heralded by strange sensations concerning breathing. The diver may feel that he is getting too much or too little oxygen, he may feel "*his breath coming in waves*" or even be under the false impression that his apparatus is flooded. Cases have occurred of divers' diaphragms going into a state of contraction preventing him from taking a full breath. This is extremely unpleasant and a dangerous symptom, though it is not very common. Again, while such sensations may be due to defective apparatus, or inexperience of the diver, they should not be ignored when the diver is at dangerous depths.

(6) Twitching of parts other than lips
Sometimes other parts than the lips will develop a warning twitch. Usually the affected part is under uncomfortable strain due to ill-fitting apparatus or undue exertion of the muscles. For example:
(a) a diver wearing tight DSEA goggles had violent twitching of the upper face and top of his head;
(b) a diver struggling with a difficult job at 46 ft. had severe twitching of one leg which he ignored, and very soon afterwards he had violent convulsions.

(7) Sensations of abnormality
Divers on oxygen have also experienced drowsiness, numbness, exhaustion, confusions and general malaise.

(8) Visual disturbances and acoustic hallucinations
Such troubles as dazzle, loss of vision (temporary) and hearing imaginary noises, such as bands playing, have occasionally occurred.

(9) Tingling of fingers and toes
This symptom, frequently described as a common one, has been met with only once during the present series of experiments.
(*Note* – in case it may be thought by some that experimental conditions are misleading, it should be noted that most of the above symptoms have been reproduced in actual diving operations in open water.)

6. Alleviation of symptoms

Generally speaking, if the pressure under which the diver is working is reduced, the symptoms will tend to disappear, but it has been found that convulsions may occur even after the diver has been brought out of the water and is breathing atmosphere air.

A technique has been tried out experimentally with some success which, should it be absolutely necessary, will enable a diver to prolong his total time at depths where the danger of oxygen illness exists. This consists of bringing a diver up to a depth of 10 ft. or less at given intervals, while the rest period must be increased. This technique should allow a diver to complete at least four periods on the bottom without the risk of oxygen illness.

Should a diver, however, get symptoms during this procedure, he must come to the surface since it has been found that he cannot get rid of them by coming shallow once they have started. The periods on the bottom should be carefully timed in accordance with the following table and should not be exceeded:-

	Time of each period (min)	
Depth (ft)	At maximum depth	Time at 10 ft or less
50	15	30 seconds
60	10	2
70	7	5

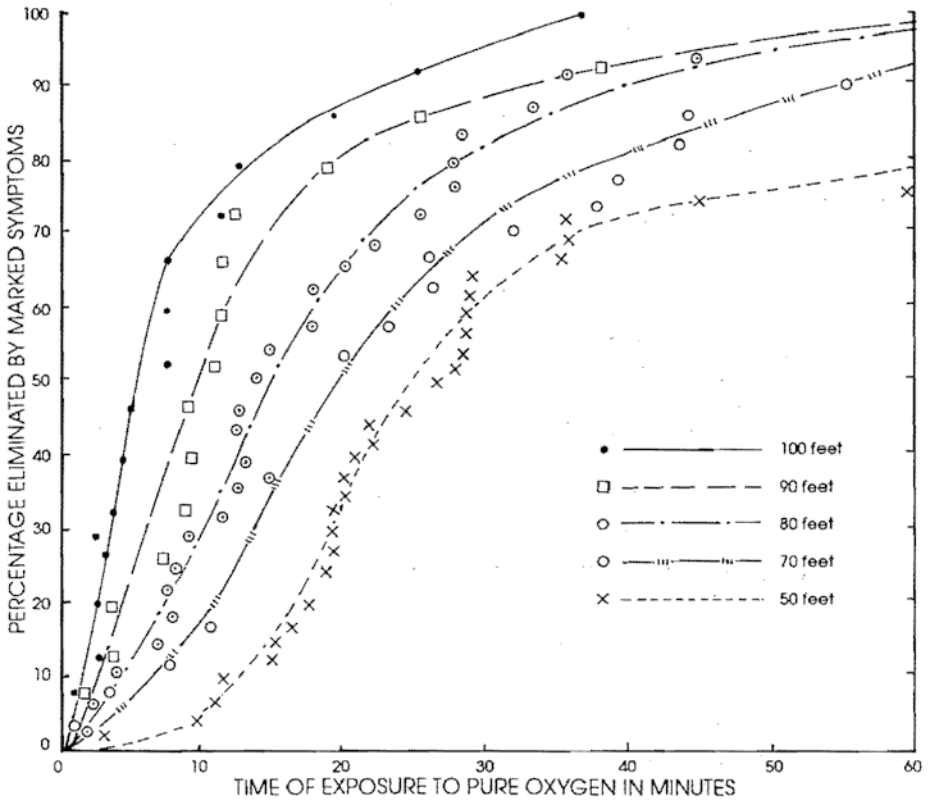
7. Acute stages of oxygen illness

The convulsions experienced in the acute stage of oxygen illness are very similar to an epileptic fit. If breathing oxygen under these conditions is continued, the result will be fatal.

8. Treatment

A diver having convulsions should be brought to the surface at once and put on air-breathing, and his head got clear of any dress or apparatus he is wearing. He should be treated like an epileptic patient and the usual precautions against choking etc., taken. The convulsions will last only a few minutes when the diver will appear to go into a deep and stertorous sleep. He should be kept warm and allowed to

Figure 1
Survival of divers on pure oxygen at various depths underwater (Figure taken from Donald K. *Oxygen and the diver.*)



sleep this off and very little serious after effects will be felt. There may be headache, vomiting and loss of memory, all of which should disappear in 48 hours. In view of the loss of memory, which is sometimes acute immediately after recovering consciousness, the patient should be escorted to sick bay and kept under observation for at least 24 hours. He should have a minimum of 72 hours' stand-off from diving.

There is no danger of any permanent injury being sustained from oxygen illness.

9. The effect of work done by the diver

The effect of work on oxygen tolerance has not been investigated in detail. It is, however, sufficiently obvious that oxygen tolerance is greatly reduced by hard work.

10. The effect of water temperature in oxygen illness

No significant change was found in human subjects over a range of 49^{O}F. to 88^{O}F. It is unlikely that any marked effects will be found until the body temperature of the diver is appreciably altered.

11. Variation in resistance to oxygen illness

It is extremely important that diving officers should appreciate the significance of the two facts stated in paragraph 2 (ii) and (iii) above. The fact that individual divers vary greatly in their resistance and that a given diver varies from day to day means that it is not possible to draw up a table or curve giving safe times on oxygen at various depths below 33 ft. Also, although certain divers are permanently more resistant than others, it must not be assumed that because a diver "*gets away*" with a deep dive one day, he can necessarily repeat the performance again.

As an illustration, 100 operational divers were 'tested' for oxygen tolerance on a single dive to 50 ft. for 30 minutes; 50 percent convulsed or had symptoms, and the party was consequently graded accordingly. Subsequent experience, however, showed that this grading was quite erroneous and misleading.

12. Graph showing probable danger of oxygen illness

The attached graph A.F.O. Diagram No. 263/44 (Figure 1), shows the probable percentage of a group of divers who will be more or less severely affected by oxygen under pressure at various times and depths. Put in another way, it shows the chances of a given diver being able to remain safely at a given depth for a given time. Thus, officers in charge of a diving operation can judge for themselves whether the object to be achieved from the dive justifies the risk to the diver. The figures given are for dives without hard work, and due allowances must be made for a reduction in tolerance if hard work is anticipated. Depths are taken from surface to the diver's chest and assume normal sea densities.

13. To use the graph

The curves represent the depth, the time is shown along the bottom and the probable percentage eliminated by marked symptoms is shown vertically. Follow the curve up till it cuts the vertical line representing the maximum time the diver will have to spend on the bottom, then the horizontal line will give the chances of the diver being affected. To allow for the possibility of the onset of symptoms after the pressure has been reduced (*see* first sub-paragraph of paragraph six above) the estimated time for the *ascent* should count as time on the bottom.

Example
A certain job at 50 ft. is estimated to take 25 minutes from the time the diver is on the bottom to the time he reaches surface again. The 50 ft. curve cuts the 25 minute line at 52%, i.e., there is slightly less than a "*50-50 chance*" of it being a safe dive. Obviously, if it is only a question of retrieving some article lost overboard, it is hardly worth it. If, however, it is a vital examination or repair, or a question of saving other people's lives, the risk could well be taken.

It will be seen that the 90 and 100 ft. curves give very little chance of immunity for more than a few minutes at most, and oxygen diving should not be used for such depths except in extreme circumstances.

14. Sensitivity to oxygen illness

In spite of the variations encountered during the experiments, it has been possible after considerable experience to assess the experimental divers as "*weak*" or "*tough*" oxygen divers. There is no apparent guide as to whether a diver is going to prove one or the other; physical fitness, athleticism, smoking and ingestion of alcohol all appear to have no regular effect, nor do the height, weight or age. All that can be said is that some men will consistently show symptoms at depths shallower than normal and at shorter times. It might be possible to work out a routine of selection if divers could be made available for long periods, but this is obviously impossible and in addition there is a risk of shaking a diver's '*nerve'* during the selection period.

If during training, especially for special work where oxygen diving is a primary consideration, such men do manifest themselves, serious consideration must be given to discharging them as unfit for the work. It is unlikely that they will cure themselves "*when they get used to it*".

15. Instruction

When instructing new divers, some mention of oxygen illness is unavoidable. Great care should, however, be taken not to over-emphasize or to give the impression that oxygen diving is dangerous.

If proper precautions are taken, as outlined above, oxygen diving is not only safe and harmless, but in view of the compactness of the gear, the speed with which a diver can be got ready, and his comparative mobility when under water, it can and has proved itself immensely valuable for certain types of work.

The recent experiments have shown that the alleged possibility of lung damage or pneumonia after prolonged oxygen breathing is non-existent for divers of five or six hours at shallow depths.

It has also been demonstrated that carbon dioxide accumulations of a degree which may be expected in properly designed and correctly functioning apparatus, do not affect oxygen illness. Oxygen tolerance is not affected until the percentage of carbon dioxide in the inspired air approaches 3 per cent, and this should not normally occur.

The present wide extension of oxygen diving has given rise to some cases of divers being incapacitated at depths less than 33 ft. where oxygen illness can definitely be ruled out. In these cases, the symptoms are altogether different, the diver usually experiencing something similar to an ordinary faint or even only a mental black-out or confusion, from which he rapidly recovers. Such incidents are usually associated with hard work by inexperienced divers and are probably due to inefficient ventilation of the whole breathing system, possibly accentuated by "*dead-space*" or resistance to breathing. The subject is a complicated one, and is being fully investigated but in the meantime divers, particularly those without too much experience, should be cautioned against sudden spasms of violent activity under water, and should be warned to keep their breathing at a steady controlled rate throughout the dive.

16. Reports

All information that can be collected is of great assistance to the experimental work. Any cases of divers being incapacitated whilst breathing oxygen should be reported direct to:

The Chairman, Admiralty Diving Committee, HMS Dolphin, c/o GPO London

Such reports, apart from giving a general description of the occurrence, should particularly include the following:
1 depth and time at that depth;
2 diver's previous training and experience;
3 type of apparatus and any defects found therein;
4 whether work was being done or not;
5 diver's own account of his feelings and when possible, a medical report.

Key words
Hyperbaric oxygen, central nervous system, toxicity, military diving, historical, reprinted from

Shallow water black-out

Report to the Sub-Committee on Underwater Physiology of the Royal Naval Personnel Research Committee. Aug 1944. RNP 44/125; UPS 48.

Barlow HB and MacIntosh FC
National Institute for Medical Research, Hampstead, NW3, London (reprinted from copy no. 8a)

1. Summary

1.1 Loss or impairment of consciousness at shallow depths ('shallow water black-out', SWBO) has been reported in divers using self-contained breathing sets. We have considered circulatory disturbances, anoxia, oxygen intoxication, acapnia and carbon dioxide (CO_2) intoxication as possible causes of these incidents.
1.2 The circumstances in which the incidents occurred, and the signs and symptoms described, appear to rule out the first four of the possible causes mentioned above. Carbon dioxide intoxication remains as the most likely source of trouble.
1.3 The signs and symptoms of carbon dioxide intoxication, experimentally produced, are described: they closely resemble those reported in divers. We have shown, moreover, that the absorption of carbon dioxide in the breathing sets worn by these divers may be grossly inadequate when hard work is being done.
1.4 It is concluded that the chief factor in shallow water black-out is carbon dioxide intoxication.

2. Introduction

Several cases of impairment or loss of consciousness of divers using self-contained breathing sets have recently been reported. The following is a typical example of a moderately severe shallow water black-out.

2.1 TYPICAL CASE

(a) Diver: Well experienced in use of neck-ring breathing set.
(b) Details of dive
i 14 minutes on oxygen.
ii Roughly the first 8 minutes 0–5 ft; rest of the time 15–25 ft.
iii Very hard work for last 4 minutes.
iv Water 47°F; diver not cold.
(c) Equipment
v Diving dress UWSS.
vi Breathing gear. Dunlop neck-ring breathing set.
vii Both O_2 bottles freshly changed before dive.
viii No defects found in equipment. Protosorb dry.
ix Bag not flooded.
(d) Medical report

The diver was searching for a submerged object. He swam around near the surface, and when it was located dived to about 25 ft., caught hold of the rope attached to it and started to swim up with it. He was working hard, using both legs and his one free arm. When nearly at the surface, he started to feel light-headed and hazy. His head felt as though it was swelling. He was breathing in plenty of oxygen, and says it did not seem to satisfy him. He dropped the object and surfaced at once in rather a panic. He was only just conscious, but gave the emergency sign, and was immediately hauled on board the attendant boat. He remembers his arms being caught, and then nothing more. At this time, he thinks he could move his limbs satisfactorily. Attendants say that his mask was pulled off straight away, and that he collapsed quite limply for two or three minutes. When he came round he felt extremely weak and unable to move for some five minutes. Became nauseated, but did not vomit, and had no headache. There was a slight trickle of blood from his left nostril. After ten minutes' rest he felt "*perfectly alright*".

2.2 CHARACTERISTIC FEATURES

Divers doing different kinds of work, and using breathing sets of different patterns, have had similar experiences. The conditions under which they occurred, and the symptoms observed, were by no means identical, but the following features were characteristic of a large number of the more severe cases.

(a) Occurrence

Most of the incidents occurred after a short time at depths less than 25 ft. They were usually preceded by a period of hard physical work.

(b) Warning symptoms

Most of the divers have reported subjective sensory disturbances and confusion; "*haziness, muzziness, sleepy feeling*" were some of the terms used. At this stage a few felt breathless, but others were not aware of any respiratory difficulty. The diver, unless he was aware of the risk of blacking out, usually had no immediate desire to stop work and surface: the sensation was not an unpleasant one. In some cases the symptoms became temporarily worse a few seconds after the diver had been turned onto air.

(c) Objective appearance

In some cases the diver reached the surface unconscious, or lost consciousness soon after being turned on to air. More often, he was still conscious, but appeared helpless and confused, and hard to communicate with. Speech was sometimes slurred, and respiration was sometimes rapid and shallow.

(d) After-effects

Recovery from loss of consciousness and disorientation was rapid, and the diver appeared normal after a few minutes on air. Nausea and frontal headache, commencing soon after the diver was turned to air, and persisting for an hour or more, were the only common sequelae.

2.3 MILDER CASES

Milder cases are likely to be more frequent. In these, the diver may not complain of any symptoms other than slight

dizziness; an experienced observer can, nevertheless, detect, in the diver who was just surfaced, slurring of speech, disorientation, undue elation, and other signs more commonly associated with alcohol indulgence. It is essential that such cases should be recognised both by divers and observers; they should be regarded as a warning that more severe cases are likely to occur.

3. Possible causes

3.1 CIRCULATORY DISTURBANCES

We think it unlikely that circulatory disturbances alone are of much importance in the production of shallow water blackout. The common fainting or vasovagal attack could produce symptoms resembling in some ways those encountered in these incidents. Fainting associated with the redistribution of blood can be produced in healthy men by the prolonged maintenance or sudden assumption of the erect posture. The occurrence of such a phenomenon in divers, is, however, rendered unlikely by the fact that the difference in venous pressure between the heart and higher and lower parts of the body is compensated by the different water pressures at those parts. Furthermore, if mere submersion in water can produce loss of consciousness by interfering with the circulation, helmet divers should be equally liable to this accident, but so far as we know helmet divers do not black out during shallow dives as long as they are receiving an adequate supply of air.

The circulation through the lungs may be impeded by a high intrapulmonary pressure. It is possible to produce loss of consciousness in most people by making them try to expire forcibly against a resistance, after a period of over-breathing to wash out O_2 from the lungs and blood. A diver may well have a high intrapulmonary pressure, either by having an unduly high pressure in his counterlung or, more especially, when clearing his ears by blowing against his nose clip. Hemingway (personal communication, 1943) has shown that consciousness is not lost as a result of such a manoeuvre unless a considerable amount of CO_2 has first been removed by over-breathing, and it is unlikely that a diver working in any existing breathing set could do this. It must be pointed out, however, that the transient circulatory disturbance caused by a high intrapulmonary pressure might, by restricting the cerebral circulation, sum with any other cause of loss of consciousness.

3.2 DISTURBANCES OF BLOOD GASES

We have, therefore, sought the explanation of these b1ackouts in some disturbance of the blood gases. There are four possibilities:
(a) oxygen want;
(b) oxygen intoxication;
(c) acapnia (carbon dioxide deficiency);
(d) carbon dioxide intoxication.
These are considered separately below.

(a) Oxygen want

Overt symptoms of anoxia do not occur if the partial pressure of O_2 inspired by the diver is above 130 mmHg (17% of one atmosphere). These blackouts have occurred at total pressures greater than 760 mmHg. The proportion of inert gas (N_2, etc.) would, therefore, need to have been above 80% to account for any symptoms of anoxia. Inert gas comes from three sources.
i. There will always be some left after the initial flushing-out drill, both in the counterlung and canister and in the diver's lungs.
ii. There is always some N_2 in oxygen cylinders. As oxygen is admitted to the counterlung, a small amount of N_2 is admitted also.
iii. About 1 litre of N_2 is dissolved in the body of a man breathing air. Some of this may enter the gas space when the proportion of N_2 is low, but it will tend to redissolve in the body tissues as soon as the proportion of N_2 rises high enough to cause anoxia. This source of N_2 can, therefore, be neglected.

Nitrogen is only eliminated from self-contained breathing sets by venting. Provided that the oxygen in the bottles is reasonably pure, however, a low rate of venting suffices to keep the N_2 concentration in the system from rising. In most of the current types of self-contained breathing gear, O_2 is supplied through a reducing valve at a rate more than sufficient for the diver's average requirement, and enough gas is vented through the relief valve in the counterlung to eliminate all risk of N_2 accumulation. In the DSEA and Dunlop sets, oxygen is supplied through a hand-operated tap, and a skilled diver vents little or no gas. The percentage of N_2 thus tends to rise during the dive; but a simple calculation shows that the risk of anoxia from this cause is small, so long as the tidal volume remains at a normal level and the oxygen in the bottles is nearly pure. The appropriate calculations for sets with and without venting are given in Appendix I.
[**Editor's note:** Appendices not re-printed]

The question of N_2 accumulation in sets which supply O_2/N_2 mixtures at constant flow has been discussed by Haldane and Spurway (1943).

In addition to the factors above enumerated, the N_2 tension in the lungs may appreciably exceed that in the counter-lung in one-way breathing sets which have a large soda lime canister interposed between the mouth and the bag. The only breathing sets of this description in current use, however, incorporate reducing valves, and sufficient gas is doubtless vented to eliminate any risk of anoxia.

We do not believe that the accidents reported to us have been caused by anoxia for the following reasons:
i Fall of the O_2 content of the respired gas to a dangerous level has been shown above to be unlikely.
ii Cyanosis has not been reported by medical observers who have witnessed incidents;
iii Some cases have improved on surfacing before breathing air. Surfacing will reduce the total pressure, and therefore the partial pressure of O_2. Anoxia would therefore get worse,

not better on surfacing.

(b) Oxygen intoxication
The features of shallow water blackout which are inconsistent with those of typical oxygen poisoning are:
i Their frequent occurrence at depths and times less than those at which oxygen intoxication is likely to occur;
ii The absence of overt convulsions;
iii The quick recovery.
Some of the earliest reported cases of blackout from undetermined causes probably were cases of oxygen intoxication; but to account for the rest on this basis it would be necessary to suppose that some other factor was greatly hastening the onset, and modifying the symptoms of oxygen intoxication.

(c) Acapnia (CO_2 deficiency)
It is possible to induce loss or impairment of consciousness by overbreathing and so washing CO_2 out of the body. We do not, however, believe that this is at all likely to occur to a diver who is (i) working, (ii) breathing through an appreciable external resistance and (iii) wearing a breathing set which (like all those now in use) does not remove all the expired CO_2.

(d) CO_2 intoxication
The normal physiological response to any factor tending to raise the partial pressure of CO_2 in the alveolar air is an increase in the depth of respiration. This will wash out more CO_2 and so compensate more or less completely for the rise in partial pressure.

A diver wearing a self-contained breathing set always inspires a certain amount of CO_2 since the CO_2 absorbent is generally not perfectly efficient, and some CO_2 is rebreathed from the 'obligatory dead space' of the set without ever reaching the absorbent. If the diver fails to increase his breathing sufficiently or if the absorption of CO_2 fails to keep pace with its production, CO_2 will tend to accumulate and might eventually reach a level high enough to cause intoxication. If such a train of events can occur at all, it is obvious that it would be more likely to happen during hard work.

The frequent absence of any acute respiratory distress appears at first sight to be inconsistent with the view that shallow water black-outs are due to CO_2. Most physiologists would agree with the statement that "*poisoning with CO_2 can never happen inadvertently because of the immediate choking sensation aroused*" (Samson Wright, *Applied physiology*, 7th ed. 1942). In the dyspnoea of suffocation or over-exertion, however, oxygen deficiency is present as well as CO_2 excess, and we are not aware of any complete account in the physiological literature of the effects of high concentrations of CO_2 on human subjects in the absence of O_2 lack. We have, therefore, produced a state of CO_2 intoxication in the laboratory under conditions more closely imitating those met with by divers, i.e., with the O_2 tension maintained at a level of 20% of an atmosphere, or higher.

4. Symptoms of acute CO_2 intoxication
The results of this investigation will be reported fully elsewhere. The conditions under which CO_2 intoxication has been produced and the symptoms observed are summarised.

4.1 PRODUCTION
(a) Rebreathing 50 litres of oxygen without absorption of CO_2 eventually produced severe objective and subjective disturbances without any notable respiratory distress, or any very large increase in the rate of pulmonary ventilation, in all the subjects whom we have so far examined. Rebreathing the same volume of air under the same conditions led to acute respiratory distress and increased the respiratory minute volume to a level approaching the subjects' maximum.
(b) Subjects were made to perform rapidly fatiguing work at a constant rate on a bicycle ergometer, while breathing oxygen through either a small (50 cc) or a large (800 cc) external dead space. The time for which the task could be continued was of the order of 5 10 minutes; it was considerably shorter with the larger dead space. With the small dead space, the symptoms were those of fatigue only. With the large dead space, most subjects reported disturbances of consciousness; two, however, lost consciousness completely after less than 3 minutes. Both of these men were divers who had had shallow water black-outs.
(c) Some subjects increase their ventilation rate much more than others when required to breathe 5% CO_2 in oxygen. Subjects with a poor response usually have mild symptoms of intoxication (giddiness, tingling of limbs, visual disturbances, etc). Each of the two subjects who lost consciousness in the test described in 4.1 (b) was so disturbed by his symptoms that he pulled out his mouthpiece soon after he began to breathe the mixture.

Thus, CO_2 intoxication, without severe respiratory distress, can be produced in all or nearly all subjects …
[**Editor's note:** A line of text is missing here from copy 8a]

4.2 SIGNS AND SYMPTOMS
The objective and subjective effects produced by these three methods are similar. They are not, however, the same in all individuals.
(a) Subjective
Haziness, light-headedness, or sleepiness are reported by most individuals, soon after the first subjectively noticeable increase in breathing. In CO_2-sensitive subjects or in subjects who are working, these symptoms may occur without any noticeable increase in breathing. At a later stage, some subjects notice muscular tremor. If the inspired CO_2 is allowed to rise further, the subject is aware of a definite clouding of consciousness and impairment of vision and hearing. In spite of this, however, many subjects cheerfully continue with the experiment until consciousness is lost. The subject is aware, especially if he thinks about it, that he is breathing more deeply than normal, but at no stage is he conscious of any considerable respiratory distress. On

occasion, the subject has reported an increase in the severity of his symptoms after starting to breathe air again.

(b) Objective

The observer sees little change in a subject suffering from mild CO_2 intoxication, though he may be experiencing subjective symptoms; flushing of the face and sweating are fairly common. Muscular trembling, when it occurs, is mainly visible in arm, shoulder and neck muscles. In some subjects this is hardly detectable, but in others it is coarse, violent, and spreads to all parts of the body. As the intoxication becomes severe a subject on the bicycle ergometer becomes unsteady and sways from side to side; the rhythm of pedalling may become erratic. Several subjects in the later stages of an experiment have broken into feverish activity and have at least doubled the normal steady rate of pedalling. A noticeable feature has been the tendency of many subjects to disregard instructions from the observers, and to continue pedalling in a stuporous condition after repeated and clear orders to stop.

(c) After-effects

If he has lost consciousness, the subject recovers in less than a minute, and appears quite normal after less than 15 minutes. He may, however, complain of frontal headache, nausea, or general malaise, for an hour or more.

5. Discussion

The conditions under which most shallow water black-outs have occurred, and the experiments summarised above, leave little doubt in our minds that the condition is attributable to accumulation of CO_2 in the breathing set. The primary cause would appear to be the failure of the canister to absorb adequately the large amounts of CO_2 produced during muscular work, confirming the original suggestion made by *HMS Bonaventure*. A secondary factor which must be borne in mind is that some men are exceptionally susceptible to CO_2 intoxication, and have little warning of its onset in the form of respiratory distress.

A continuation of our experiments with the Kenometer (Barlow & MacIntosh, 1944) has shown that certain types of breathing apparatus do not absorb CO_2 sufficiently well to be able to cope with the output of a man doing severe or prolonged muscular work. The canisters of some of these sets are too small for the performance expected of them, and during the course of a dive become inefficient (rise of 'effective dead space'). It is certainly possible for a diver wearing such a set to be breathing through an effective dead space of greater than 800 cc [ml] before he has used all the oxygen in his bottle. It is evident, however, that a breathing set with the most perfect canister would be of little value if other factors restricted the access of the expired CO_2 to the absorbent. Such restriction can be brought about by such factors as:

i the existence of a large volume of airway common to inspired and expired gas (large obligatory dead space);
ii resistance to breathing resulting from incorrect positioning of the counterlung or from narrow airways;
iii incomplete or improper filling of the absorbent canister, allowing 'channelling' to occur;
iv Partial flooding of the canister.

It follows that the incidence of SWBO can best be avoided by so designing breathing apparatus that these faults are avoided. The canister, furthermore, must be able to absorb CO_2 properly over the fu1l life of the oxygen supply, and at the greatest rate of CO_2 output which is likely to be encountered in the operation for which the set is designed.

In the event of any type of breathing set being suspected of deficiency in the above requirements, divers should be warned against the danger of severe exertion. It would, moreover, be desirable to familiarize divers with the symptoms of CO_2 intoxication. Surgeon Lt. Commander HM Balfour has suggested that this can readily be achieved by the diver wearing, in air, under the supervision of a medical officer, a set charged with oxygen but without absorbent in the canister; the diver can then safely rebreathe the oxygen until the CO_2 has accumulated to a sufficient level to produce symptoms. A diver who has had this experience should be able to recognise the onset of CO_2 intoxication if it occurs during the course of a dive.

We are indebted to our colleagues at the National Institute for Medical Research for their advice and cooperation, and to Surgeon Lt. Commander HM Balfour, RNVR, Surgeon Lt. Commander KW Donald, DSC, RN and Surgeon Lt. DA Thomson, RNVR, for discussion of the problem and for supplying us with subjects.

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Note added in proof

Since the writing of this report, one of us (HBB) has had the opportunity of observing, with Surgeon Lt. Commander Donald, at the Admiralty Experimental Diving Unit, the reactions of several divers doing hard work on an underwater bicycle ergometer devised by Commander WO Shelford, RN. The divers, wearing the DSEA, filled with Protosorb, and consuming oxygen at rates of 2 L min^{-1} *or higher, were never able to continue their task for more than a few minutes. There were no complete blackouts, but their appearance on surfacing, and the symptoms they reported presented the essential features of* CO_2 *intoxication in the dry, as described in para. 4.2.*

Key words

Carbon dioxide, toxicity, rebreathers/semi-closed circuit, military diving, historical, reprinted from

Reprinted from other sources

Skin burns as a result of using commercial hand warmers in a drysuit using nitrox as a breathing gas. A case report

GP Anderson

Abstract

Background: This is a case report of burns suffered by a diver when commercial hand warmers were used in the feet of a dry-suit while using EAN32 (nitrox32 percent).

Case report: A forty-one-year-old female assistant instructor with 1,300 logged dives dove in cold water off the coast of Vancouver Island in 2003. She was using a drysuit and 32 percent nitrox as breathing gas. During a surface interval, she used two commercial hand-warmer pouches to warm her hands and she then slipped them into her drysuit feet to stay warm diving. The maximum depth on the next dive was 135 fsw at the base of a wreck. After only two minutes at 135 fsw, she ascended to 90 fsw and her feet began hurting. Thinking it was due to a squeeze, she added more gas into her drysuit, and her foot pain worsened. She aborted the dive. On board, she noted that she had second-degree burns on the arches of her feet. She continued diving that and the next day without the warmers, and eventually healed without complications.

Results: Commercial hand warmers oxidize iron powder to produce heat. At atmospheric pressure, 1ATA, the heat is not excessive. At 135 fsw, however, the partial pressure of oxygen was 1.63 ATA and increased the oxidation to cause the burns. An UHMS literature search failed to discover previous citations regarding this problem, although it is known that hyperbaric chamber fires have been caused by these products as ignition sources.

Conclusions: Commercial hand warmers should not be used in drysuits especially when hyperoxic breathing mixtures are used. This is the first reported case of burns caused by this combination, and divers should be aware of this danger.

Reprinted with kind permission from: Anderson GP. Skin burns as a result of using commercial hand warmers in a drysuit using nitrox as a breathing gas. A case report. (Abstract) *Proceedings of the 2005 Annual Scientific Meeting of the Undersea and Hyperbaric Medical Society, Inc*. Durham NC: UHMS Inc.; 2005. [cited April 01, 2013]. Available from: http://archive.rubicon-foundation.org/1655

Key words

Thermal problems, injuries, deep diving, reprinted from

A case of deep burns, while diving the *Lusitania*

JN Curran, KG McGuigan, E O'Broin

J Plast Reconstr Aesthet Surg. 2010;63:e579-81. Epub 2010 Jan 8.

Editor's summary

In 2009, a 31-year-old male diver sustained 35% total body surface area full-thickness burns whilst diving the wreck of the *Lusitania* in 90 metres' sea water off the coast of Ireland. He was wearing a nylon under-suit and a trilaminate (nylon/butyl rubber/polyester) drysuit. Between these, he had placed small air-activated thermal pads on his chest and hips. For some reason, the gas mix he was using to inflate his drysuit was a nitrox mix with 70% oxygen. Early in the dive, he experienced excessive heating and then burning. He abandoned the dive, bravely completing the two hours of decompression the dive required. Fortunately his suit breached during the ascent and flooded, thus extinguishing the fire. He was air evacuated to a tertiary referral burns unit where, on arrival, he was hypothermic (core temperature 33^{O}C) but lucid, cardiorespiratory status was unremarkable and there was evidence of rhabdomyolysis. He underwent aggressive fluid resuscitation and early debridement and skin grafting over six operating sessions.

Air-activated warming devices generally contain cellulose (used as a filler), a fine powder of iron, water and salt (as catalysts for the exothermic reaction), activated carbon (to accelerate the reaction and to disperse the heat) and vermiculite (which acts as a water reservoir and insulator) contained in a gas-permeable polypropylene pouch. They produce heat from the exothermic oxidation of iron when exposed to air. Given the high oxygen content of the suit-inflation gas and the high ambient pressure, the heat generated would have increased very rapidly and this ignited the clothing he was wearing, which melted and adhered to his skin.

Anecdotal evidence suggests these devices are quite popular in recreational technical diving. However, they should not be used in this situation, and a high O_2-content in suit-inflation gas mixes should be avoided.

Key words

Thermal problems, injuries, deep diving, reprinted from

Continuing professional development

Cerebral oxygen toxicity. CME activity 2013/2

Neil Banham

Accreditation statement

INTENDED AUDIENCE
The intended audience consists of all physicians subscribing to *Diving and Hyperbaric Medicine* (DHM), including anaesthetists and other specialists, who are members of the Australia and New Zealand College of Anaesthetists (ANZCA) Diving and Hyperbaric Medicine Special Interest Group (DHM SIG). However, all subscribers to DHM may apply to their respective CPD programme coordinator or specialty college for approval of participation.

This activity, published in association with DHM, is accredited by the ANZCA Continuing Professional Development Programme for members of the ANZCA DHM SIG under Learning Projects: Category 2 / Level 2: 2 credits per hour.

OBJECTIVES
The questions are designed to affirm the participant's knowledge of the topics covered, and participants should be able to evaluate the appropriateness of the clinical information as it applies to the provision of patient care.

FACULTY DISCLOSURE
Authors of these activities are required to disclose activities and relationships that, if known to others, might be viewed as a conflict of interest. Any such author disclosures will be published with each relevant CPD activity.

DO I HAVE TO PAY?
All activities are free to subscribers.

Recommended background reading

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Key words
Oxygen, hyperbaric oxygen, hyperbaric oxygen therapy, hyperoxia, toxicity, central nervous system, MOPS (maintenance of professional standards)

How to answer the questions
Please answer all responses (A to E or F) as True or False. Answers should be posted by e-mail to the nominated CPD coordinator.
For EUBS members for this CPD issue this will be Peter Müller. ***E-mail*:** <peter.mueller@eubs.org>
For ANZCA DHM SIG members, this will be Neil Banham. ***E=mail*:** <neil.banham@health.wa.gov.au>

On submission of your answers, you will receive a brief model answer for each question. A correct response rate of 80% or more is required to successfully undertake the activity. Each task will expire within 24 months of its publication to ensure that additional, more recent data have not superseded the activity.

Question 1. Oxygen toxicity seizures:
A. Are more likely to occur with 'wet' rather than 'dry' diving;
B. Do not occur in scuba divers breathing air;
C. Occur more frequently with increasing partial pressure of oxygen exposure;
D. Were first described by Behnke in 1960;
E. Usually require pharmacological intervention.

Question 2. Oxygen toxicity seizures:
A. Are almost always preceded by prodromal warning symptoms;
B. Have been reported to be more common in patients having their initial hyperbaric treatment for carbon monoxide poisoning;
C. Are usually self-limiting;
D. May be more likely if the patient is on concurrent high-dose corticosteroids;
E. Do not occur with hyperbaric oxygen therapy at 203 kPa (2 Ata).

Question 3. Measures used to prevent oxygen toxicity seizures include:

A. Routine use of anticonvulsants;
B. Reducing the duration of oxygen exposure;
C. Limiting the pressure of oxygen exposure;
D. Limiting patients to a single hyperbaric exposure per day;
E. Removing the oxygen source if prodromal features develop.

Question 4. Well recognised prodromal features include:

A. Visual changes;
B. Auditory hallucinations;
C. Nausea;
D. Twitching;
E. Irritability.

Question 5. With regards to patients who have had an oxygen toxicity seizure:

A. Further hyperbaric oxygen therapy is contra-indicated;
B. They should be investigated to exclude epilepsy;
C. Recurrent oxygen toxicity seizures will be prevented by adding a further air break to the treatment table;
D. The indication for ongoing hyperbaric therapy should be reviewed;
E. Hypoglycaemia should be excluded as a cause.

Book review

Fathomeering: an Amphibian's tale

Ivor Howitt

Soft Cover, 157 pages
ISBN: 0-9758347-0-3
Mountain Ocean and Travel Publications 2007
Obtainable from multiple outlets on the web
RRP: AUD29.95

When I received an e-mail from the Editor informing me that a book was on its way, little did I know what a treat I was in for! *Fathomeering* is the tale of one man's determination to explore the underwater world in a time when diving equipment of any kind was virtually unavailable. Yet, it's more than just that. It's a tale of young adults exploring the world around them: climbing mountains, building makeshift canoes and fabricating their own diving equipment, riding miles on their bicycles in search of adventure.

Ivor Howitt grew up in Aberdeen, Scotland, and was only eleven years old when World War II started; by war's end he was working in an engineering design workshop. Working there clearly honed his mechanical design aptitude which was to stand him in good stead for the adventures to come.

Inspired by the early underwater cinematography of John E Williamson and the writings of William Beebe, Ivor determined not just to explore the underwater world, but also to film it. With diving equipment unavailable, he fashioned a gas mask into a diving mask and developed an air pump from a car tyre hand pump. Later he developed an open helmet by wrapping copper sheet around a dustbin lid and putting in a window. When one became available he purchased a Siebe-Gorman twin-cylinder, twin-hose compressed air breathing apparatus (CABA). Ivor also started fabricating his own camera housings from cooking pots.

In 1951, Ivor immigrated to Australia and brought his CABA with him, probably the first scuba to be imported into the country. He continued his diving adventures in and around Melbourne and further afield to Adelaide and the Great Barrier Reef. For those of us now accustomed to dive trips where we just rock up and everything is provided, the logistics of these early trips are mind boggling. Just getting a supply of compressed air was a mammoth task involving trains and barges. On one of these trips, Ivor took what is possibly the first underwater colour photo taken in Australia.

This is a fascinating book, full of illustrations and photographs from the period. Ivor is a product of a bygone era, a time borne out of war, when self-reliance and self-sufficiency were the norm and a spirit of adventure was able to be fulfilled without today's endless regulation by those who would wrap us all in cotton wool lest we damage ourselves. Although younger, I also grew up in that type of environment, when disappearing on my bicycle for a day did not lead to a police search for a missing teenager.

If you can get hold of a copy, everyone should read this book. Older readers will chuckle and nod in agreement; younger readers will read with incredulity and shake their heads that people could be so reckless.

Steve Goble, Head Diving Supervisor, Hyperbaric Medicine Unit, Royal Adelaide Hospital

Key words
Recreational diving, history, general interest, book reviews

Letter to the Editor

Surgia – inspiring future surgeons and anaesthetists at Griffith University Medical School

The Surgical Interest Association (Surgia) is a newly founded organisation at Griffith University Medical School, Queensland, and it is our pleasure to introduce ourselves to the diving and hyperbaric medicine community. Surgia aims to provide information, resources and potential networking opportunities to Griffith University students, staff and alumni to enhance essential operating room knowledge and skills. This includes holding events and providing opportunities for students in both surgery and anaesthesia.

Surgia has a diverse number of portfolios, including an academic domain that encourages educational endeavours and research opportunities for medical students and graduates who are in the early stages of their career. Uniquely, we look beyond the disciplines that are classically associated with surgery, and, in line with this vision, we were proud to present Surgia's Inaugural Patron's Seminar on hyperbaric medicine earlier this year (sponsored by Hoylands Medical). The keynote speaker for this event was Dr Robert Webb from the Hyperbaric Medicine Service at the Royal Brisbane and Women's Hospital. Dr Webb introduced the theory underpinning hyperbaric medicine, discussed the primary mechanisms of hyperbaric oxygen and elucidated a number of associated treatment applications, including problem wound healing, osteoradionecrosis, decompression illness and cerebral arterial gas embolism. His presentation was well received by an audience of keen medical students.

The evening also included a case study presented by Jane Leadbeater, the hyperbaric oxygen management of a pilonidal sinus. Miss Leadbeater worked on this case with Dr Webb and Professor Errol Maguire (Professor of Surgery, Griffith University and Surgia's Patron). The management of this case included an extended course of hyperbaric oxygen that resulted in the successful healing of a problematic wound that had persisted for over three years.

These presentations showcased the potential applications of hyperbaric medicine in surgical practice, a topic that was of great interest to our members. We were proud to present Surgia's Inaugural Patron's Seminar on hyperbaric medicine, yet another success for our young and ambitious association. This followed on from the Association winning Griffith University's prestigious 2012 Business Innovation Challenge and surpassing a membership base of 300 students and professional members, all less than five months after incorporation. Future plans include the delivery of research-based bursaries and helping to run a medical student surgical conference on acute injury recognition for 600 delegates.

James Nightingale, Daniel Cattanach, Elliot Dolan-Evans.
Medical students, The Surgical Interest Association (Surgia), School of Medicine, Griffith University, Queensland, Australia
***E-mail*:** *<james.n91@gmail.com>*

Key words
Medical society, education, general interest, letters (to the Editor)

The database of randomised controlled trials in hyperbaric medicine maintained by Michael Bennett and his colleagues at the Prince of Wales Hospital Diving and Hyperbaric Medicine Unit, Sydney is now at:

<http://hboevidence.unsw.wikispaces.net/>

Assistance from interested physicians in preparing critical appraisals is welcomed. Contact Associate Professor Michael Bennett: <M.Bennett@unsw.edu.au>

The
Diving and Hyperbaric Medicine
journal website is at
<www.dhmjournal.com>

REUNION 2013

TRICONTINENTAL SCIENTIFIC MEETING ON DIVING AND HYPERBARIC MEDICINE

22–29 September

Preparations continue for the first ever joint scientific meeting of the European Underwater and Baromedical Society, the South Pacific Underwater Medicine Society and the Southern African Underwater and Hyperbaric Medical Association

It promises to be a week full of science, scuba and social interaction on the exotic French island of Réunion in the Indian Ocean. The conference will be hosted by the Association Réunionnaise de Médecine Subaquatique et Hyperbare (ARESUB) in the picturesque coastal village of St Gilles les Bains, where a range of hotel packages are available to suit all styles and budgets. There will be possibilities for diving, whale watching, island excursions; we invite you to extend your stay before or after the meeting and to bring your family.

The meeting format will be a meld from all three societies, including discussion and workshop sessions, keynote lectures, free papers, a scientific poster session/display and industry exhibition.

Programme:

22 September	ECHM Workshop: *Diagnosis and treatment of mild decompression sickness in remote diving destinations*
23 September	ARESUB meeting
23–28 September	Tricontinental Scientific Meeting on Diving and Hyperbaric Medicine
28 September	SPUMS, EUBS, SAUHMA General Assemblies
29 September	International DAN Diver's Day

The Call for Abstracts and Registrations are now closed.
Please enquire about possible remaining places and conditions at: <info@reunion2013.org>.

Language: The official language for the Tricontinental Scientific Meeting, the ECHM Workshop and the International DAN Diver's Day will be English. The language for the ARESUB meeting will be French.

For all practical information (conference, travel, diving, leisure) see the website:

<www.reunion2013.org>

and the regular e-mail alerts sent out by the respective societies to their members.

All enquiries: <info@reunion2013.org>

EUBS SPUMS

Scott Haldane Diving Medicine

European Committee for Hyperbaric Medicine Workshop 2013

Diagnosis and treatment of mild DCS in remote diving destinations

Date: Sunday 22 September 2013
Timing: 1430–1915 h
Venue: Tamarun, St Gilles les Bains, Réunion Island

Organizing Committee:
Alessandro Marroni, Ramiro Cali-Corleo, Jacek Kot

Programme:
- Definition of mild DCS, clinical manifestations, differential diagnosis and threshold between mild and serious DCS
- Natural history of DCS – case histories with special emphasis on delayed versus early treatment and final outcome
- Telemedicine triage and decision making for 'remote locations'
- Immediate care and in-water recompression
- Non-hyperbaric treatment: pros and cons
- Cost-benefit evaluation; liability implications of local non-hyperbaric treatment vs. standard Medevac
- (Panel Discussion and Workshop Conclusions)

Speakers:
Simon Mitchell, New Zealand; Nick Bird, USA; Jordi Desola, Spain; Jack Meintjes, South Africa; Ramiro Cali-Corleo, Malta; Peter Germonpré, Belgium.

Registration is required, but is free.

For further details go to the websites: <www.ECHM.org> or <www.reunion2013.org>

EUBS Annual Scientific Meeting 2014
Preliminary Announcement

Dates: 24–27 September 2014
Venue: Wiesbaden, Germany

The 40th EUBS Annual Scientific Meeting will be held in conjunction with the 2014 Congress of the German Society for Diving and Hyperbaric Medicine (GTUeM) in Wiesbaden, Germany (near Frankfurt/Main).

Dr Peter Müller has been appointed by both societies to serve as the Secretary General for the EUBS ASM 2014.

For further information at this early stage see:
<www.eubs2014.org>

Enquiries e-mail: <peter.mueller@eubs.org>

Réunion2013

Registration for the Tricontinental Conference is now closed. However, those wishing to place their names on a waiting list in case of cancellations should contact the conference information office at:
E-mail: <info@reunion2013.org>

The

website is at
<www.eubs.org>

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

Publication news:
We have an official **Facebook page** that will help you keep instantly updated with news and events related to diving and hyperbaric medicine – please have a look <https://www.facebook.com/pages/European-Underwater-and-Baromedical-Society/283981285037017>
The **Discussion Forum** is accessible to all members of EUBS directly from the homepage: <http://www.eubs.org/members/forum>. Please participate!

Membership news:
Those members who have not renewed their membership by 15 September may experience problems accessing their membership pages. If so, please send us an e-mail, and we will be happy to restore your account!

EUBS European Underwater and Baromedical Society

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SPUMS Notices and news

SPUMS Diploma in Diving and Hyperbaric Medicine (updated March 2013)

Requirements for candidates

In order for the Diploma of Diving and Hyperbaric Medicine to be awarded by the Society, the candidate must comply with the following conditions:

- The candidate must be medically qualified, and be a current financial member of the Society.
- The candidate 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 approved facilities providing two-week courses may be found on the SPUMS website.
- The candidate 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.
- The candidate must submit a written proposal for research in a relevant area of underwater or hyperbaric medicine, in a standard format, for approval *before* commencing their research project.
- The candidate 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 written report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–4 above.

In the absence of documentation otherwise, it will be assumed that the paper is submitted for publication in *Diving and Hyperbaric Medicine*. As such, the structure of the paper needs to broadly comply with the 'Instructions to Authors' – full version, July 2011, 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 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 Education Officer in writing (e-mail is acceptable) to advise of their intended candidacy, and to discuss the proposed subject matter of their research. A written research proposal must be submitted before commencing the research project.

All research reports must clearly test a hypothesis. Original basic or clinical research is acceptable. Case series reports may be acceptable if thoroughly documented, subject to quantitative analysis, and the subject is extensively researched and discussed 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 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 or animals must be accompanied by documented evidence of approval by an appropriate research ethics committee. 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.

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 project is approved prior to commencing research.

The Academic Board reserves the right to modify any of these requirements from time to time. As of October 2012, the SPUMS Academic Board consists of:
Associate Professor David Smart, Education Officer;
Associate Professor Simon Mitchell;
Associate Professor (retired) Mike Davis.

All enquiries and applications should be sent to:
Associate Professor David Smart
GPO Box 463, Hobart, Tasmania 7001
E-mail: *<david.smart@dhhs.tas.gov.au>*

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

Minutes for SPUMS Executive Committee meeting, The Department of Diving and Hyperbaric Medicine, Prince of Wales Hospital, 01–02 December 2012

Opened: 0905 h

Attendance: Mike Bennett (MB), Karen Richardson (KR), Mike Davis (MD), Glen Hawkins (GH), Denise Blake (DB), Simon Mitchell (SM)
By conference call: Peter Smith (PS), Shirley Bowen (SB), David Smart (DS)

Apologies: C Acott (CA), Andrew Fock (AF)

1. Acceptance of previous minutes

1.1 Minutes of Executive Teleconference August 2012 have been circulated by e-mail and were formally accepted into the record.

2. Matters arising from previous minutes

2.1 The SPUMS full medical has been added to the drop-down menu and can be accessed once the user is logged onto the website. Functional printable sections of the medical will be added at a later date.

2.2 The ODEX logo has been placed on the SPUMS website.

2.3 GH has provided full database access for Secretary.

2.4 The SPUMS Executive contact list has been updated but requires some additional editing for correctness.

2.5 MB has informed EUBS of decision to trademark the SPUMS and DHM logos in Australia and New Zealand.

2.6 Nicky McNeish has been given administrator rights to the SPUMS website and will be employed to effect suggested website updates.

2.7 The following actions from the August teleconference have not been completed but should be attended to prior to next Excom meeting:

2.7.1 Trademarking of SPUMS in Australia and New Zealand.

2.7.2 Add the updated Diving and Hyperbaric Medicine Course information to the website as drop-down menu item under Education.

2.7.3 Ensure all membership prices are displayed correctly on website

2.7.4 MB will distribute questions to ExCom members for provision of answers to be posted on the website by GH .

2.7.5 Establish a presence for the Future ASM Steering Committee on the website in forum style with access areas for both members and non-members.

2.7.6 Reciprocate website links between SPUMS and the "*whatsthatfish*" website as per 2012 AGM minutes.

2.7.8 Include Diver Medical Technician course details on website to encourage website use by potential SPUMS associate members. Passed unanimously.

Action: KR to gather information and forward for posting on website.

2.7.9 Multiple further upgrades to website content and appearance were collated and forwarded to GH in e-mail correspondence in June 2012.

2.7.10 GH to provide Secretary with a full list of personal e-mails included in the group mail out for inclusion in the Excom contacts list.

2.8 SPUMS Diploma accredited two-week courses in diving and hyperbaric medicine are the Royal Adelaide Hospital course, the ANZHMG course hosted by Prince of Wales and the Royal Australian Navy Medical Officer Underwater Medicine Course.

Action: GH to ensure these are posted clearly on the website as per the Diploma requirement documents

Action: DS to create journal and website announcement aiming at gathering data on negative outcomes subsequent to Safework legislation changes.

2.9 KR has been granted access to the EUBS members-only webpages.

Action: GH will give reciprocal access to SPUMS members-only webpages to C Balestra with a view to exploring a combined membership category to allow access to each others' websites. GH notes P Germonpré is already a full website member. MB will e-mail CB with request he join the website.

3. ASM

3.1 ASM 2012: Dr C Meehan has provided full accounts which have been formally accepted into record. Final profit was AUD12,415.96. MD notes 48 full society members registered and calculates a refund to the DHM account of AUD268 based on this figure. MB will arrange for a refund to the journal account.

3.2 ASM Reunion 2013: Planning continues for the combined 2013 ASM with aim to have registration open by 20 December 2012. SPUMS Excom agrees there should be no quotas set for society registration numbers.

3.3 ASM Future Meetings Steering Committee: The venue for ASM 2014 will be Bali with SB and Neil Banham as conveners. Timing of future conferences will be decided by the convener in consultation with the Excom, however, other times of year besides April–June can be considered. Suggestions for ASM venues from 2015 include: Heron Island and Fitzroy Island in Australia, Wakatobi, Indonesia, Saipan, Micronesia and Philippines. The Excom notes the success of Cathy Meehan's future steering committee in identifying future venues and offers thanks for same.

3.4 Update to Convenor's Handbook: C Meehan and S Lockley to write update to include Cvent website use as this is proving an effective way to administer ASM organisation.

4. Journal matters

4.1 Editor's Report: MD notes that print run numbers are essentially stable reflecting stable membership. One further addition to the Editorial Board is being sought with an emergency medicine/ICU background.

4.2 Received papers database for 2011/2012: in 2011 55 papers were submitted with 12 rejected/withdrawn, 41 published, two in process. For 2012 to date: 35 papers submitted, four rejected/withdrawn, eight published, 23 in process undergoing revisions or peer review.

4.3 Review of Journal finances for 2012: 2012 final budget will be reconciled once the December issue figures have been obtained.

4.4 Budget proposal for DHM for 2013: MD has provided a draft budget proposal for 2013, noting costs are stable over a 2-year period. One-off costs anticipated for 2013 include new laptop and software, this will be funded from the 2012 budget if funds remain after final reconciliation. Estimated price for provision of Journal is AUD85 (approx. €69). MB in conjunction with SB and PS will communicate this to EUBS Excom.

4.5 Discussion of the issues of workshop proceedings/ abstracts/papers and various scientific meetings: SPUMS will continue to encourage all participants at ASMs to publish full papers in DHM and the Journal Editor will endeavor to negotiate with participants and organisers prior to the event.

4.6 EUBS has requested that the Journal name in the Medline database be updated; MD advises this requires a change to SPUMS' Rules.

4.7 Recommendations for changes to Purposes and Rules, items 39 to 45 in relation to the Journal have been circulated for agreement and will be formally presented for approval at AGM 2013.

4.8 Letter from Editor to President tabled at a previous teleconference has been withdrawn as it is no longer relevant.

4.9 Role of DHM Treasurer: PS as Assistant Treasurer has taken oversight of Journal finances and in conjunction with SB will reconcile budgets for presentation to EUBS.

4.10 The contract between SPUMS, EUBS and the Editor of DHM has been discussed and formalised.

4.11 New editor contract 2013 to 2015 has been formally advertised and one application received from the incumbent Editor.

5. Website update (Glen Hawkins)

5.1 GH notes cleaning of the membership database is absolute priority for SPUMS website.

5.2 Nicky McNeish has been granted full website administrative access, a formal letter will be sent outlining her employment terms.

5.3 **Action:** MB will distribute FAQs page to Excom members for completion and posting on website.

5.4 Significant website updates have not been completed because of technical issues with the site such that any major changes risk compromise of the database and loss of member information and archived history. SPUMS Excom agree sufficient funds exist to hire professional services to fix this issue. Possibility of need for new website platform noted.

6. Education Officer's report/matters (David Smart by telephone)

6.1 International parallels paper is pending; DS encourages further discussion on same at Réunion2013.

6.2 There are no new SPUMS Diplomas completed; however, a further 9 candidates have registered.

6.3 Fellowship of UHMS now exists; DS will investigate process for same and report back to Excom.

6.4 MB notes meeting scheduled for early December on ANZCA Certificate to discuss reduction of training time from 18 months to one year and timing of any candidates for next exam.

7. ANZHMG Representative's report/matters (David Smart by telephone)

7.1 RCC Facility Accreditation progress awaiting review of AS 4774, due in 2013.

7.2 MSAC review process update: SPUMS Excom has funded certain travel and accommodation expenses for DS for his representation during the MSAC process but notes that DS and GH have not received any reimbursement for extensive hours of work. Both individuals are thanked for their significant efforts. Senate inquiry released 12 November 2012 has recommended continuation of funding for non-diabetic wounds until the multicentre RCT hosted by the Wesley is complete; however, this is unlikely to affect any changes to current situation.

7.3 DS was unable to attend a recent Standard Australia meeting because of work commitments. A review of AS2299 scheduled soon will require input from SPUMS Excom with regard to use of the SPUMS diving medical.

8. Treasurer's report/matters (Shirley Bowen by telephone)

8.1 DB has agreed to be added to electronic signatory list.

8.2 **Action:** AF to investigate legalities of publishing SPUMS accounts on website rather than in Journal.

8.3 Mediq Finances have successfully taken over bookkeeping of SPUMS accounts, which maintain a healthy balance. Journal expenses are stable. Significant profits from ASM 2012 and 2011 membership year. Continued problems with St George Bank such that Treasurer will investigate changing banks.

9. Public Officer's report/matters

9.1 KPI achieved relevant documents lodged with authorities before due date.

9.2 **Action:** AF to complete application for moving date of AGM in 2013.

10. Secretary's report/matters

10.1 Assets list information has been supplied to KR by all Excom members.

10.2 KPI report: CA has not attended SPUMS Excom in

over two years; PS has missed two meetings. Concerns expressed re attendance at meetings, particularly lack of quorum at Madang.

11. Membership report/matters

11.1 Membership numbers for period covering 01 November 2011 to 31 October 2012: Full 461, Associate 47, Corporate 6, Retired 14, Student 0; total 528.

11.2 Defining membership categories and benefits: consideration will be given to redefining corporate membership to include logo and link on website, acknowledgement of support of SPUMS, two copies of Journal and advertising in DHM. Consideration will also be given to creating Institutional/Library category with charges as per full membership.

11.3 There are no plans in place for journal access and sharing between SPUMS, EUBS, AHDMA and UHMS as website does not have capability for universal membership.

11.4 Further membership initiatives: significant reduction in Associate Member numbers noted; Sm will promote SPUMS at OzTek 2013. FACEM ASM in Hobart prohibitively expensive. MB will promote SPUMS at ANZCA 2013. ACRRM should be considered. Resources for any SPUMS member wishing to promote their society are available from MB and on website.

11.5 Report from ODEX 2012: SPUMS was successfully represented at the ODEX exhibition in Sydney by Cathy Meehan, Sarah Lockley, KR, GH, Sue Paton and Maria da Costa. SPUMS has been invited to give a dive safety seminar at the same venue in September 2013. Special thanks to Mark Orkney for his assistance.

11.6 Facebook and other initiatives: MB is looking for volunteers to take over the Facebook page.

11.7 SPUMS has become an Associate Member of the Diving Industry Association of Australia and KR will attend her first meeting on 05 December.

12. Other business

12.1 Proposed Safework Legislation and Codes of Practice, ISO Standards: ongoing efforts by DS and MB will be reported in DHM.

12.2 SPUMS relationship with HTNA: HTNA have accepted SPUMS support in the form of a sponsored speaker. SPUMS will provide up to AUD2,000, with acknowledgment of same.

12.3 SPUMS Admin Officer issues: MB awaiting final report on working hours for second half 2012, SG previously billing around 20 hours per week. Aim to have SG attend Réunion2013 pending budget and funding.

12.4 Diving and diabetes developments: CM and MB still working with interested party to develop diabetic diving training modules to assist dive training organisations with education.

12.5 Diving and epilepsy developments: a workshop on this issue has been proposed for Réunion2013.

12.6 Australian repository for SPUMS and DHM journals: MD will send one complete set of SPUMS/DHM journals by secure courier to MB to be stored for safe keeping in a locked environment at the Diving and Hyperbaric Medicine Unit, Prince of Wales Hospital, Sydney.

13. Correspondence

13.1 Karva Libre request re subscriptions categories to be addressed after review of same.

13.2 Letter from Editor MD to President and Excom withdrawn.

14. Next meeting: teleconference February/March.

Closed: 1703 h

Key words
Medical society, meetings

SPUMS website news

As the new Webmaster and a new recruit to website management, I am on a steep learning curve. The management of menus, links, hosts and servers is vastly different to the management of staff and patients! I am very fortunate to have the knowledgeable assistance of Nicky McNeish, our part-time NZ-based webmaster assistant, who is also the DHM Editorial Assistant. This additional assistance is a first for the SPUMS Webmaster and already Nicky has been working through a long list involving minor site restructuring in an effort to continue to make it more user friendly.

Some recent changes include the dissection of the SPUMS Medical document, the merger of 'notices' and 'news', the augmentation of the links page, the addition of society history and improvements within the education menu and course descriptors. There is also the continuous task of general site maintenance and almost all menus and pages have received attention.

The task of trawling through the large society membership database continues in an effort to increase the efficiency and accuracy of the database. This is a complicated task and will take quite some time. In the meantime please be patient and let us know if you are aware of problems with your membership so that we can address your concerns.

We hope you are finding that the menus and links are logical and that navigating the site is getting easier. We appreciate your patience during this period of significant website restructure and welcome your comments and suggestions on ways to continue to improve your society website.

I took over as Webmaster earlier this year, after Glen Hawkins resigned the position after several years. It is important that we acknowledge the tremendous job that Glen did in resuscitating the SPUMS website several years

ago, at a time when the Society was faced with an expensive ultimatum from the original host for rebuilding the site with modern software. Thankfully, Glen took on the arduous rebuild task himself and has maintained the site for several years, despite an ever increasing professional workload. The Society thanks him very sincerely for what he has contributed, and, in the process, for saving the Society a great deal of money and heartache. We wish him all the very best in his endeavours.

Joel Hissink, Webmaster
***E-mail*:** <*Joel.Hissink@spums.org.au*>

SPUMS ASM 2014
Preliminary announcement

Dates: 18–25 May 2014
Venue: Alila Manggis Resort, Bali
Convenor: Dr Neil Banham

Guest Speaker: Peter Wilmshurst, UK

Alila Resort <www.alilahotels.com/manggis> has just 55 seaside rooms surrounding a fabulous pool.

Pre- and post-conference options are extensive!

Further details on the SPUMS website later in the year
For preliminary enquiries:
<neil.banham@health.wa.gov.au>

Fellows of the Undersea and Hyperbaric Medical Society

Congratulations to the following Members of SPUMS and EUBS who have been designated recently as Fellows in Undersea and Hyperbaric Medicine (FUHM) of the Undersea and Hyperbaric Medical Society:

Bakker DJ
Bennett M
Lind FG
Mitchell SJ
Millar IL
Smart DR
Wilkinson D



DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

P O Box 347, Dingley Village
Victoria, 3172, Australia
E-mail:
<deswill@dingley.net>
Website:
<www.classicdiver.org>

The SPUMS Annual General Meeting 2013, Notice of Meeting

The AGM for SPUMS 2013 will be held at La Tamarun Convention Centre, La Saline Les Bains, Réunion Island at 0900 h on Saturday 28 September 2013.

Agenda

1. Apologies
2. Minutes of the previous meeting:
   Minutes of the previous meeting will be posted on the notice board at La Tamarun and were published in *Diving and Hyperbaric Medicine*. (Minutes of the Annual General Meeting of SPUMS held at Madang Resort, Papua New Guinea, at 1500 h, Thursday 24 May 2012. *Diving Hyperb Med*. 2012;42:187-8. Officers' reports are on the SPUMS website <www.spums.org.au>).
3. Matters arising from the minutes
4. Annual reports:
   President's report
   Secretary's report
   Educations Officer's report
   Treasurer's report and annual financial statement
   Journal Editor's report
5. Subscription fees for 2014
6. Election of office bearers:
   Committee member: Nominations for the office of General Committee Member are to be forwarded to the Secretary by 9 September 2013. (A nomination form is enclosed with the June issue of *Diving and Hyperbaric Medicine.*)
7. Appointment of the Auditor 2014:
8. Business of which notice has been given:
   Notice of motions for changes to the Purposes and Rules of the Society are being prepared by the Committee. Once finalised these will be posted on the SPUMS website and notified to members by e-mail.

Karen Richardson, Secretary

Key words
Medical society, meetings

The

SPUMS

website is at
<www.spums.org.au>

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

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

Eligible candidates are invited to present for the examination for the Certificate in Diving and Hyperbaric Medicine of the Australian and New Zealand College of Anaesthetists.

Eligibility criteria are:

1 Fellowship of a Specialist College in Australia or New Zealand. This includes all specialties, and the Royal Australian College of General Practitioners.

2 Completion of training courses in Diving Medicine and in Hyperbaric Medicine of at least four weeks' total duration. For example, one of:

a ANZHMG course at Prince of Wales Hospital Sydney, **and** Royal Adelaide Hospital or HMAS Penguin diving medical officers course **OR**

b Auckland University Postgraduate Diploma in Medical Science: Diving and Hyperbaric Medicine.

3 **EITHER:**

a Completion of the Diploma of the South Pacific Underwater Medicine Society, including six months' fulltime equivalent experience in a hyperbaric unit and successful completion of a thesis or research project approved by the Assessor, SPUMS **AND**

b Completion of a further 6 months' full-time equivalent clinical experience in a hospital-based hyperbaric unit which is approved for training in Diving and Hyperbaric Medicine by the ANZCA.

OR:

c Completion of 12 months' full-time equivalent experience in a hospital-based hyperbaric unit which is approved for training in Diving and Hyperbaric Medicine by the ANZCA **AND**

d Completion of a formal project in accordance with ANZCA Professional Document TE11 "*Formal Project Guidelines*". The formal project must be constructed around a topic which is relevant to the practice of diving and hyperbaric medicine, and must be approved by the ANZCA Assessor prior to commencement.

4 Completion of a workbook documenting the details of clinical exposure attained during the training period.

5 Candidates who do not hold an Australian or New Zealand specialist qualification in Anaesthesia, Intensive Care or Emergency Medicine are required to demonstrate airway skills competency as specified by ANZCA in the document "*Airway skills requirement for training in Diving and Hyperbaric Medicine*".

All details are available on the ANZCA website at:
<http://anzca.edu.au/edutraining/DHM/index.htm>

Dr Suzy Szekely, FANZCA
Chair, ANZCA/ASA Special Interest Group in Diving and Hyperbaric Medicine, Australia
E-mail: *<Suzy.Szekely@health.sa.gov.au>*

Dr Margaret Walker

Margaret Walker, FANZCA, CertDHM(FANZCA), Medical Co-director, Diving and Hyperbaric Medicine, Hobart Hospital, Tasmania retired from hyperbaric medicine practice in March to concentrate on anaesthesia. Margaret has included diving and hyperbaric medicine as part of her professional portfolio for 25 years, and she will be greatly missed by all her colleagues, medical, nursing and technical, in the Hobart unit.

Margaret's contributions to the specialty over a quarter of a century have been considerable, clinically, academically and administratively. She has published a number of papers in the *SPUMS Journal*, and was Chairperson of the Executive Committee of the Diving and Hyperbaric Medicine Special Interest Group of the Australia and New Zealand College of Anaesthetists for several years. During this time, hyperbaric medicine has developed from a novel vocation to a respected and legitimate sub-specialty. The Society wishes her every success in her future endeavours.

David and Cindy Doolette

Dr David Doolette was, for many years, the Education Officer of SPUMS and was responsible for the major upgrade of the academic requirements and standards for the SPUMS Diploma in Diving and Hyperbaric Medicine. David then moved on to a research position at the Navy Experimental Diving Unit, Panama City, Florida, USA, we suspect, at least in part, drawn to the wonderful cave diving in Florida (always a passion!) Now, another passion has been fulfilled and we wish to congratulate Cindy and him on their wedding last October and wish them every happiness in their future together.



Royal Adelaide Hospital Hyperbaric Medicine Unit Courses 2013

July/August
Wk 1: 29 July–02 August
Wk 2: 05–09 August (lecture week)
Wk 3: 12–16 August

Refresher Course – September/October
Wk 1: 23–27 September
Wk 2: 30 September–04 October

Medical Officers' Course
Wk 1: 02–06 December
Wk 2: 09–13 December

All enquiries to:
Lorna Mirabelli
Senior Administrative Asst/Course Administrator
Hyperbaric Medicine Unit
Level 2, Theatre Block
Royal Adelaide Hospital
North Terrace, Adelaide, SA 5000
Phone: +61-(0)8-8222-5116
Fax: +61-(0)8-8232-4207
E-mail: <Lorna.Mirabelli@health.sa.gov.au>

Asian Hyperbaric and Diving Medical Association (AHDMA) IXth Annual Meeting 2013

Dates: 02–06 July 2013
Venue: Singapore

Pre-conference workshop: 02–04 July
Medical support of diving operations
Main conference: 05–06 July

Guest Speaker: Professor Alf Brubakk, Professor of Environmental Physiology, Norwegian University of Science and Technology is the guest speaker and will conduct the workshop.

The event promises rich learning opportunities and a sharing platform with a wide spectrum of physicians from all over the world on all aspects of scientific information on diving and hyperbaric medicine.

For further information:
E-mail: <tarun.sahni@adventhcg.com>
Website: <www.ahdma.org>

Royal Australian Navy Medical Officers' Underwater Medicine Course 2013

Dates: 11–22 November 2013
Venue: HMAS PENGUIN, Sydney

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

Cost: AUD705 without accommodation
(AUD1,600 with accommodation at HMAS Penguin)

For information and application forms contact:
Rajeev Karekar, for Officer in Charge,
Submarine and Underwater Medicine Unit
HMAS PENGUIN
Middle Head Rd, Mosman
NSW 2088, Australia
Phone: +61-(0)2-9647 5572
Fax: +61-(0)2-9960 4435
E-mail: <Rajeev.Karekar@defence.gov.au>

The ANZ Hyperbaric Medicine Group Introductory Course in Diving and Hyperbaric Medicine 2014

Dates: TBA, but late February/early March
Venue: Prince of Wales Hospital, Sydney, Australia

Course content includes:
- History of hyperbaric oxygen
- Physics and physiology of compression
- Accepted indications of hyperbaric oxygen (including necrotising infections, acute CO poisoning, osteoradionecrosis and problem wound healing)
- Wound assessment including transcutaneous oximetry
- Visit to HMAS Penguin
- Visit to the NSW Water Police
- Marine envenomation
- Practical sessions including assessment of fitness to dive

Approved as a CPD Learning Project by ANZCA: Cat 2, Level 2 – 2 credits per hr (approval no. 1191).

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>

Scott Haldane Foundation

The Scott Haldane Foundation is dedicated to education in diving medicine, and has organized more than 100 courses over the past few years, both in the Netherlands and abroad. Below is a list of courses planned for 2013.

The new basic course (Part I plus Part II) fully complies with the current EDTC/ECHM curriculum for Level I (Diving Medical Examiner), and the different advanced courses offer a modular way to achieve Level IIa competence according to the EDTC/ECHM guidelines.

Course details for 2013
09–16 November: Basic course in diving medicine Part 1 (to be decided)
16–23 November: 21st in-depth course in diving medicine (to be decided)
23–30 November: 21st in-depth course in diving medicine (to be decided)

For further information: <www.scotthaldane.nl>

DAN Europe

DAN Europe has a fresh, multilingual selection of recent news, articles and events featuring DAN and its staff.
It can be accessed at: <http://www.daneurope.org/web/guest/>.

Keeping the whole DAN Europe family updated with what is going on...enjoy!

German Society for Diving and Hyperbaric Medicine (GTUeM)

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

ICASM 2013
The 61st International Congress of Aviation and Space Medicine

Dates: 6-10 October 2013
Venue: Inbal Hotel, Jerusalem, Israel

For further information:
Website: <www.icasm2013.org>

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 or computer for later viewing.

We offer video lectures from:
- The 5th Karolinska PG course in clinical hyperbaric oxygen therapy, 07 May 2009
- The European Committee for Hyperbaric Medicine *"Oxygen and infection"* Conference, 08–09 May 2009
- The 17th International Congress on Hyperbaric Medicine, Cape Town, 17–18 March 2011

Also available is the 2011 Stockholm County Council report: *Treatment with hyperbaric oxygen (HBO) at the Karolinska University Hospital*

For further information contact:
Folke Lind, MD PhD
E-mail: <folke.lind@karolinska.se>
Website: <www.hyperbaricoxygen.se>

Belgian Medical Accreditation Committee

It is a pleasure to announce that the Belgian Medical Accreditation Committee has recognised participation in the 2012 EUBS ASM in Belgrade as a CME activity for 9.5 credit points.

This CME is valid for all specialties in Belgium and may be useful for other countries as well. The necessary accreditation information will be posted on the EUBS website.

Advertising in *Diving and Hyperbaric Medicine*

Commercial advertising is now welcomed within the pages of *Diving and Hyperbaric Medicine*. Companies and organisations within the diving, hyperbaric medicine and wound-care communities who might wish to advertise their equipment and services 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: *<editor@dhmjournal.com>*
Fax: *+64-(0)3-329-6810*

Instructions to authors

(Short version, updated June 2013)

Diving and Hyperbaric Medicine (*DHM*) welcomes contributions (including letters to the Editor) on all aspects of diving and hyperbaric medicine. Manuscripts must be offered exclusively to *DHM*, unless clearly authenticated copyright exemption accompanies the manuscript. All manuscripts will be subject to peer review. Accepted contributions will also be subject to editing. An accompanying letter signed by all authors should be sent.

Contributions should be sent to:

E-mail: *<submissions@dhmjournal.com>*

Individual correspondence should be addressed to:

E-mail: *<editor@dhmjournal.com>*

Requirements for manuscripts

Documents should be submitted electronically. The preferred format is Microsoft® Office Word or rich text format (RTF). Paper submissions will not be accepted. All articles should include a title page, giving the title of the paper and the full names and qualifications of the authors, and the positions they held when doing the work being reported. Identify one author as correspondent, with their full postal address, telephone and fax numbers, and e-mail address. The text should generally be subdivided into the following sections: a structured Abstract of no more than 250 words, Introduction, Methods, Results, Discussion, Conclusion(s), Acknowledgements and References. Acknowledgements should be brief. Legends for tables and figures should appear at the end of the text file after the references. Conflicts of interest and funding sources should be identified.

The text should be 1.5 lines spaced, using both upper and lower case. Headings should conform to the current format in *DHM*. All pages should be numbered. Underlining should not be used. SI units are to be used (mmHg is acceptable for blood pressure measurements; bar for cylinder pressures); normal ranges should be shown. Abbreviations may be used after being shown in brackets after the complete expression, e.g., decompression illness (DCI) can thereafter be referred to as DCI.

Preferred length for **Original Articles** is up to 3,000 words. Inclusion of more than five authors requires justification, as does that of more than 30 references. **Review Articles** are welcomed. **Case Reports** should not generally exceed 1,500 words, and a maximum of 15 references. Abstracts are required for all articles. **Letters to the Editor** should not exceed 500 words and a maximum of five references. Legends for figures and tables should generally be shorter than 40 words in length.

Illustrations, figures and tables must NOT be embedded in the word processor document, only their position in the text indicated, and each should be submitted as a separate file.

Tables should be presented either with tab-separated columns (preferred) or in table format. No gridlines, borders or shading are to be used.

Illustrations and figures should be submitted in greyscale TIFF, high resolution JPG or BMP format. If figures are created in Excel, submit the complete Excel file. Give careful thought to fonts being of an adequate size for legibility.

Printed **photographs** should be glossy black-and-white. Colour is available only if essential and will be at the authors' expense. Indicate magnification for photomicrographs.

References

The *DHM* Journal reference style is based closely on the *International Committee of Medical Journal Editors (ICMJE) Uniform Requirements for Manuscripts*. To ensure the correct formatting of all types of citation go to: <http://www.nlm.nih.gov/bsd/uniform_requirements.html> (last updated July 2011). References must appear in the text as superscript numbers at the end of the sentence after the full stop.[1,2] Number them in order of quoting (including in tables). Use Index Medicus abbreviations for journal names: <http://www.nlm.nih.gov/tsd/serials/lji.html>

Examples of the exact format for a standard paper and a book are given below:

1 Freeman P, Edmonds C. Inner ear barotrauma. *Arch Otolaryngol*. 1972;95:556-63.

2 Hunter SE, Farmer JC. Ear and sinus problems in diving. In: Bove AA, editor. *Bove and Davis' diving medicine*, 4th ed. Philadelphia: Saunders; 2003. p. 431-59.

Accuracy of references is the responsibility of the authors.

Manuscripts not complying with the above requirements will be returned to the author(s) before consideration.

Consent and ethics

Studies on human subjects must state that they comply with the Declaration of Helsinki (1964, revised 2008) and those using animals must comply with health and medical research council guidelines or their national equivalent. A statement affirming ethics committee (institutional review board) approval should be included in the text. A copy of that approval (and consent forms) should be provided.

Copyright

Authors must agree to accept the standard conditions of publication. These grant *Diving and Hyperbaric Medicine* a non-exclusive licence to publish the article in printed form in *Diving and Hyperbaric Medicine* and in other media, including electronic form; also granting the right to sub-licence third parties to exercise all or any of these rights. *Diving and Hyperbaric Medicine* agrees that in publishing the article(s) and exercising this non-exclusive publishing sub-licence, the author(s) will always be acknowledged as the copyright owner(s) of the article.

Full instructions to authors (revised July 2011) may be found on the DHM Journal, EUBS and SPUMS websites and must be consulted in preparing a submission.

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
+10-4500-9113 (Korea)
+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 non-fatal 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>

DISCLAIMER

All opinions expressed in this publication are given in good faith and in all cases represent the views of the writer and are not necessarily representative of the policies or views of SPUMS or EUBS or the Editor.

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