Diving and Hyperbaric Medicine

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

SPUMS

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EUBS

Oxygen explosion at a remote dive site

Post-mortem cardiac gas analysis: can it help diagnosis?

Otology 101: diving problems and their management

Decompression illness: no clear consensus in Singapore

HBO and ischaemia-reperfusion injury: a paradox

Transcutaneous oximetry: normal values in healthy adults

Hospital coding of HBOT: not fit for purpose

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PURPOSES OF THE SOCIETIES

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

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DIVING AND HYPERBARIC MEDICINE

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The Presidents' pages

David Smart, President SPUMS

The Annual General Meeting (AGM) this year completes a three-year term in my role as SPUMS President. I have been privileged to lead our society supported by a very motivated Executive committee (ExCom). 2017 will be our first general election since adopting our new purposes and rules in 2014. ExCom positions up for election are: President, Secretary, Treasurer, and five General Committee Members. There are five non-elected executive members: Immediate Past President, Editor of *Diving and Hyperbaric Medicine* (DHM), Education Officer, ANZHMG Subcommittee Chair and Webmaster. The Journal Editor is appointed as a separate joint process by SPUMS and EUBS. The Education Officer, ANZHMG Chair and Webmaster will be appointed, following expressions of interest, after the AGM.

Recruitment of a future Editor commenced December 2016. SPUMS and EUBS are currently working to achieve a smooth transition process. Mike Davis has indicated his intention to retire at the end of 2018. We hope to move to e-journal publication commencing 2018. I offer my personal thanks to Mike for his outstanding contribution to our Society, academically via the Journal, and to diving and hyperbaric medicine in general.

Over the last three years the ExCom has delivered:

- New Purposes and Rules 2014;
- A Journal Governance Committee for DHM;
- Three successful Annual Scientific Meetings;
- Movement of SPUMS banking from St George to ANZ;
- Identifying the cost structure of DHM for accurate budgeting;
- Investigation and reporting of a future e-Journal;
- Complete rebuild of the SPUMS website;
- Subscriptions and banking linkages to website;
- Revision of membership processes;
- Rationalisation of SPUMS membership database;
- Updated Diving Doctors List;
- Linkages to the SPUMS ASM;
- SPUMS history and archives section (in development);
- Processes for SPUMS position statements;
- SPUMS terms and conditions of membership;
- SPUMS governance and other essential policies;
- SPUMS ExCom members (Bennett, Mitchell, Smart and Wilkinson) have helped to complete the rebuilding of the ANZCA DHM training for launch in July 2017 as a Diploma of Advanced Diving and Hyperbaric Medicine.

The SPUMS DHM Diploma is integrated with the ANZCA DipAdvDHM. The new post-fellowship training in DHM will produce world standard graduates.

ExCom has been assisted by Steve Goble, SPUMS Administrator who has weathered the many changes resulting from the new website. Steve has again assisted with and contributed a paper to the 2017 ASM. SPUMS website development has been managed by Nicky Telles, who has been our operational expert and linkage with the IT groups, working with Joel Hissink, Webmaster. Peter Smith, Treasurer, has been intensively involved with most processes. Peter has played a key strategic financial role, producing reports that provide an accurate picture of both the SPUMS and Journal finances.

SPUMS finances are healthy, but we should not be complacent. Costs have risen faster than our income base. Last year produced a significant trading deficit, requiring drawing upon our reserves. More than half of the loss was from Website investment, but moving to a new electronic format also has increased recurrent costs (servers, hosts, financial linkages and security). Journal costs are up significantly, as are our administrative expenses. SPUMS ExCom has a number of strategies in place to reduce costs. We also expect that the investment in the website will reduce costs as manual processes are automated.

We also need to increase our income. There will be a modest increase in subscriptions, and a membership recruitment drive. SPUMS membership numbers have plateaued at around 440. Everyone is called on to assist with recruitment of more members. All members would know a colleague who dives or has some medical involvement with divers. One idea for increasing membership is to "*recruit a friend*". Our initial target is 500 members. A downloadable, one-page flyer about SPUMS is available on the SPUMS website to pass on to potential members.

Following the SPUMS ExCom elections, ExCom General Members will each have specific roles to assist corporate continuity: assistant treasurer, recruitment and marketing, ASM planning, national committee representation, the Tricontinental scientific meeting, and special projects.

I wish to thank SPUMS members for your continued support of SPUMS. Please tell your medical colleagues about the benefits of membership and encourage them to join!

Key words
Medical society; General interest

Front page photo by Dr Martin Sayer shows Dr Neal Pollock holding a rebreather in the type of small dive boat used in Chuuk, Micronesia and on which the rebreather explosion reported in this issue occurred.

Jacek Kot, President, EUBS

Europe is one, but Europeans are many … in most cases, the two Presidents address our messages to our respective Society. This time, I would like to reach SPUMS members, who share the same enthusiasm and dedication in jointly publishing this Journal but have different organisational systems. The paper on clinical indications for hyperbaric oxygen treatment (HBOT), published as the ECHM Consensus Conference Report and endorsed by the EUBS, induced some discussion that clearly showed a misunderstanding amongst our Antipodean colleagues of the European situation concerning the various organisations dealing with diving and/or hyperbaric medicine.[1,2] The myriad entities is confusing even to Europeans, especially to younger members of the diving and hyperbaric community.

The EUBS was founded to advance undersea medicine and related scientific disciplines, including hyperbaric medicine, work in compressed gas and hyperoxia in general. It provides a forum for exchange of scientific and clinical knowledge and for improved safety of all subsea and hyperbaric operations. The two main vehicles for this are the EUBS annual scientific meetings and the journal *Diving and Hyperbaric Medicine*.

The European Committee for Hyperbaric Medicine (ECHM) is an independent group of professionals practising HBOT. It is funded to study and define common indications for HBOT; research and treatment protocols; common standards for therapeutic and technical procedures, equipment and personnel; cost-benefit and cost-effectiveness criteria; to act as a representative body with European health authorities and to promote cooperation among scientific organizations involved in diving and hyperbaric medicine. The ECHM sets standards, guidelines and recommendations for clinical hyperbaric medicine and diving (mainly recreational) medicine, through consensus conferences and workshops.

The European College of Baromedicine (ECB) is a medical speciality organisation that establishes and maintains reciprocal recognition of qualifications in the diving and hyperbaric medicine fields between the academic and training institutions in Europe. It intends to become the accreditation body for baromedicine in the European Union as the executive arm of the ECHM. Its main role is in the accreditation of courses and certification of participants.

The European Diving Technology Committee (EDTC) is an independent society. It was funded to promote good standards for diving, to provide a means of improvement, if appropriate, and to coordinate where possible the different standards that exist around the world. It aims to make European professional diving safer. Its motto is "*securitas per uniatem*". It consists of representatives from medical, industrial, governmental and union backgrounds. From our medical viewpoint, the most important part is the Medical Subcommittee of the EDTC. This subcommittee sets standards of medical care in professional diving as well as education in diving medicine, mostly related to professional diving. An additional role is in the accreditation and certification of courses in this field.

The Diving Medical Advisory Committee (DMAC) is an independent body, comprising of diving medical specialists from across Northern Europe, that seeks to provide advice about medical and some safety aspects of commercial diving in the form of a series of guidance notes. It also accredits courses and certifies participants, mostly in the medical support of commercial diving.

The European Baromedical Association for Nurses, Operators and Technicians (EBAss) is a non-profit organisation whose mission is to encourage integration of baromedical personnel (other than physicians) by working towards standardisation of education throughout Europe while supporting and encouraging a safe approach to daily practices and improving methods of communication. The main outcome for EBAss is definition of training standards, as well as accreditation and certification of courses conducted in different countries.

Most of those organisations cooperate with each other and many members participate in more than one entity. Having so many different organisations in the same branch of medicine is not unique in the world, but perhaps the European situation is more complex than elsewhere.

In future, will we reach a point when the European Union of Entities (EUE) will become the Union of European Entities (UEE) in this field? I do hope so, as otherwise we will be doomed to spread our enthusiasm, emotions and limited time over many organisations. I remember one EUBS conference when I missed almost all the scientific sessions through having to participate in business meetings of different organisations, all interesting and important, but secondary to the main objective of the conference. The biggest challenge was remembering which hat to wear at any given moment! Perhaps we need to be open to considering a less fragmented organisation for diving and hyperbaric medicine in Europe.

In the meantime, I hope you will be participating in the EUBS ASM in Ravenna in September. More information can be found at: <www.eubs2017.org>.

References

1 Mathieu D, Marroni A, Kot J: Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. *Diving Hyperb Med*. 2017;47:24-32.
2 Correction. *Diving Hyperb Med*. 2017;47:132-3.

Key words
Medical society; General interest

Original articles

Understanding scuba diving fatalities: carbon dioxide concentrations in intra-cardiac gas

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Abstract
(Varlet V, Dominguez A, Augsburger M, Lossois M, Egger C, Palmiere C, Vilarino R, Grabherr S. Understanding scuba diving fatalities: carbon dioxide concentrations in intra-cardiac gas. *Diving and Hyperbaric Medicine*. 2017 June;47(2):75-81.)
Introduction: Important developments in the diagnosis of scuba diving fatalities have been made thanks to forensic imaging tool improvements. Multi-detector computed tomography (MDCT) permits reliable interpretation of the overall gaseous distribution in the cadaver. However, due to post-mortem delay, the radiological interpretation is often doubtful because the distinction between gas related to the dive and post-mortem decomposition artifactual gases becomes less obvious.
Methods: We present six cases of fatal scuba diving showing gas in the heart and other vasculature. Carbon dioxide (CO_2) in cardiac gas measured by gas chromatography coupled to thermal conductivity detection were employed to distinguish decomposition from embolism based on the detection of decomposition gases (hydrogen, hydrogen sulfide and methane) and to confirm arterial gas embolism (AGE) or post-mortem offgasing diagnoses. A Radiological Alteration Index (RAI) was calculated from the scan.
Results: Based on the dive history, the intra-cadaveric gas was diagnosed as deriving from decomposition (one case, minimal RAI of 61), post-mortem decompression artifacts (two cases, intermediate RAI between 60 and 85) and barotrauma/AGE (three cases, maximal RAI between 85 and 100), illustrating a large distribution inside the bodies.
Conclusion: MDCT scans should be interpreted simultaneously with compositional analysis of intra-cadaveric gases. Intra-cadaveric gas sampling and analysis may become useful tools for understanding and diagnosing scuba diving fatalities. In cases with short post-mortem delays, the CO_2 concentration of the cardiac gas provides relevant information about the circumstances and cause of death when this parameter is interpreted in combination with the diving profile.

Key words
Gases; Diving deaths; Drowning; Decompression sickness; Air embolism; Arterial gas embolism

Introduction

Decompression stops during scuba diving ascent are recommended to avoid desaturation of the diving gas initially dissolved in the tissue during the dive. If this equilibration time is not respected, dissolved gases are released, causing decompression sickness (DCS). Pulmonary barotrauma may also result in arterial gas embolism (AGE) that could be fatal if the diver is not rapidly placed under hyperbaric conditions. As a result, the intra-cadaveric gas distribution is an important parameter for medical examination of scuba diving fatalities. Gas release can be noticeable in the intravascular system and soft tissues but must be interpreted in regards to the diving profile, macroscopic signs observed during the autopsy and the post-mortem delay.

Indeed, intra-cadaveric gases in scuba diving fatalities can originate from five distinct sources: AGE; DCS, which can also lead to fatal gas embolism according to the magnitude of decompression (even if marginal); post-mortem decompression (off-gassing); resuscitation procedures and decomposition.[1] Barotrauma followed by gas embolism represent the primary cause of scuba diving fatalities where intra-cadaveric gases are present. As loss of consciousness often occurs, signs of drowning are also frequently diagnosed.[2] Severe neurological DCS, which can cause drowsiness and loss of consciousness, can lead to drowning. However, a scuba diving fatality caused by DCS is difficult to diagnose because of post-mortem decompression, decomposition and resuscitation procedures that cause artifactual intra-cadaveric gases. Post-mortem decompression occurs when the diver dies during the dive and begins right after death; the magnitude of the phenomenon

could increase when the body is brought to the surface quickly.[3] This process produces both intravascular and soft-tissue gas and theoretically should be distinguishable from AGE by the presence of gas in the muscles and joints. Resuscitation procedures can also introduce artefactual gases into the body. With an endotracheal tube and positive pressure ventilation, resuscitation gases (air and oxygen) are frequently noticed in the body. Finally, according to the post-mortem delay, microorganisms in the body can generate decomposition gases. Environmental parameters, such as water and ambient temperatures, the diving suit and body storage conditions are important for the interpretation of the distribution and composition of intra-cadaveric gases.

Before the development of forensic imaging, autopsies of divers were performed following specific protocols, such as underwater dissection, to gather evidence about the release of gas.[1] Other sampling tools such as aspirometers were used but were not precise, and they were valid only for significant amounts of gas. Today, forensic imaging tools such as multi-detector computed tomography (MDCT) are helpful for detecting the presence of gas in cadavers.[4] MDCT has been employed to investigate gas distribution after scuba diving fatalities.[5] Reliable distribution patterns have been proposed and should confirm the results of the autopsy.[6] In parallel, other studies have developed the Radiological Alteration Index (RAI) based on the volume and distribution of post-mortem gases in the body to estimate its decomposition state.[7,8] However, with scan images only, it is impossible to attribute definitively the presence of gas to scuba diving accidents or to decomposition due to the post-mortem delay. Moreover, if post-mortem decompression and resuscitation procedures are taken into account, the medicolegal diagnosis becomes even more complex. Consequently, the analysis of the composition of intra-cadaveric gases becomes essential for accurate diagnosis of fatal dives and is required to exclude decomposition as a potential source of gas generation.

We aimed to present a useful protocol for intra-cadaveric gas sampling and analysis and to evaluate the relevance of gaseous intracardiac carbon dioxide (CO_2) concentrations in six fatal dive cases. To our knowledge, intracardiac CO_2 concentrations related to the diving profile for the diagnosis of diving fatalities is reported here for the first time.

Case reports

The bodies of six deceased scuba divers were studied as part of prosecutor investigations. All underwent a full-body CT scan followed by a complete external exam and all but one (Case 1) of them had an autopsy. Table 1 summarises some of the findings and the attributed cause of death.

CASE 1

The body (fresh state) of an experienced, 37-year-old (y.o.) male diver was found at a depth of 28 metres' fresh water (mfw) in a lake. Air was used as the diving gas. The victim was testing new material for a scuba diving drysuit. The maximum depth reached was 33.5 mfw for a bottom time of 15 minutes (min). At the eighteenth minute, at 26 mfw, an alarm indicating a dangerously rapid ascent was registered by the diving computer. One minute later, the victim reached 17 mfw before an immediate descent. After a total diving time of 20 min, the body depth stabilized at 29 mfw. No activity was registered from this moment until being recovered 2 hours (h) 18 min later. No resuscitation was performed. The death was attributed to drowning because of the characteristic foam cone exuding from the mouth. An autopsy was not required by the prosecutor. However, a post-mortem CT examination was carried out and water in the lungs, compatible with drowning, and the presence of gas in all the vessels and organs, including the heart cavity, compatible with a scuba diving fatality, were entered as evidence. The intra-cadaveric gaseous composition was 32.7 $\mu mol \cdot ml^{-1}$ of nitrogen (N_2) and 9.0 $\mu mol \cdot ml^{-1}$ of CO_2 (mean of concentrations measured in left and right ventricles) without the presence of decomposition gases) (Table 2).

CASE 2

The body (fresh state) of a 71 y.o., experienced, male diver was found at 4 mfw in a lake. Air and nitrox49 (49% O_2, 51% N_2) were used as diving gases and no resuscitation was performed. According to his diving computer, a maximum depth of 42 mfw was reached after 23 min, followed by an ascent to 25 mfw, reached after 37 min, followed by a rapid ascent to the surface where the victim showed signs of dizziness, followed by a descent to 14 mfw. The victim was hauled up to 4 mfw by his diving partner, who then finished his decompression stops when the victim was no longer responding. The body was brought to the surface by a police diving team. Autopsy was carried out at our institute. A post-mortem CT examination showed gas present in all the vessels and organs, including the heart cavity, and was entered as evidence. Cause of death was not determined at the autopsy but signs of pulmonary barotrauma, gas embolism and ante-mortem pathologies (moderate obstructive pulmonary disease and mild atherosclerosis of the coronary arteries) were identified. The intra-cadaveric gaseous composition was 30.1 $\mu mol \cdot ml^{-1}$ of N_2 and 11.6 $\mu mol \cdot ml^{-1}$ of CO_2 without the presence of decomposition gases (Table 2).

CASE 3

The body (fresh state) was of a 58 y.o. male diver who died on the beach after scuba diving in a lake. Air was used as the diving gas and a descent of 15 mfw over 20 min was planned. At 9 mfw, the victim felt signs of drowsiness and began an ascent with his partner. Once at the surface, the victim lost consciousness and was hauled out of the water. Basic life support (BLS) was performed without success. An autopsy was carried out at our institute. Natural death with cardiac pathologies (cardiac hypertrophy, atherosclerotic disease of aorta and its branches, coronary atherosclerosis)

Table 1
Case summaries (all male)

Case	Age (y)	Postmortem delay before sampling (h)	Radiological alteration index	Diving/embolism gas	Cardiac sampling site	Cause of death
1	37	< 12	85	Air	R and L ventricles	Drowning
2	71	< 24	100	Air + Nitrox49	R ventricle	Undetermined (barotrauma/ AGE + other pathology); drowning excluded
3	58	40	61	Air	R atrium	Natural death (body stored at + 4°C); + cardiac pathology
4	44	30	60	Nitrox32 + Trimix	R heart	Drowning
5	53	12	100	Air + Nitrox32	R atrium	Drowning + DCS + barotrauma/AGE
6	42	38	85	Nitrox23	Heart	Drowning (body stored at +4°C) + barotrauma/AGE + DCS

was diagnosed as the cause of the death. The intra-cadaveric gaseous composition was 1.2 µmol·ml^{-1} of O_2, 30.6 µmol·ml^{-1} of N_2, 9.2 µmol·ml^{-1} of CO_2 and 0.6 µmol·ml^{-1} of hydrogen (H_2) (Table 2). The presence of H_2 indicated decomposition in conformity with the post-mortem delay of approx. 40 h.

CASE 4

The body (fresh state) of a 44 y.o. male diver was found at 95 mfw in a lake. The diving equipment included a rebreather and cylinders of air, nitrox32 (32% O_2, 68% N_2), trimix (helium, nitrogen and oxygen) and O_2. The diving computer recorded a maximum depth of 80 mfw after 20 min, followed by an ascent to 70 mfw after 5 more min, and then a descent to 90 mfw at approximately 30 min. An ascent to 70 mfw over 5 min was registered, followed by stabilization around 65 mfw and a rapid descent to 95 mfw, the depth recorded after a diving time of 40 min. The O_2 monitoring during the dive showed a hyperoxic period during the last 10 min of the dive, which was hypothesized to be a factor in the loss of consciousness leading to drowning. The post-mortem CT examination and autopsy were carried out at our institute where we diagnosed the absence of barotrauma, but confirmed the presence of water in the lungs and gas in all the vessels and organs, including the heart cavity. The death was attributed to drowning, and the gas presence was attributed to post-mortem decompression. The intra-cadaveric gaseous composition was 29.3 µmol·ml^{-1} of N_2 and 11.7 µmol·ml^{-1} of CO_2 without the presence of decomposition gases despite a post-mortem delay of 36 h (with 20 h at 95 mfw at 6^{o}C) (Table 2).

CASE 5

The body (fresh state) of a 53 y.o. male diver was found 100 m off the beach floating at the surface of a lake. Twin cylinders, one of air and one of nitrox32 and a cylinder of O_2 were used as the breathing mixtures. Nitrox32 was used during the descent between 6 and 40 mfw, followed by air between 40 and 80 mfw. The diving computer recorded an ascent after less than one minute to 65 mfw, followed by a first stop for 4 min between 65 and 68 mfw, a second stop of approximately 1 min at 21 mfw, followed by surfacing. According to the police dive team, 39 min of decompression were needed to avoid a decompression accident. The body was found 75 min after the beginning of the dive and BLS and defibrillation were unsuccessful. The post-mortem CT examination and autopsy were carried out 12 h later at our institute where we diagnosed the absence of massive barotrauma, but confirmed the presence of liquid in the lungs and gas in all the vessels and organs, including the heart cavity. The death was attributed to drowning in the context of barotrauma followed by AGE and DCS. The intracardiac gaseous CO_2 concentration was 16 µmol·ml^{-1} without the presence of decomposition gases (Table 2).

CASE 6

The body (fresh state) of a 42 y.o. male diver was found floating at the surface of a lake. Two cylinders of nitrox23 were used as the diving gas and a descent to 45 mfw for 32 min, followed by a rapid ascent with alarm, were recorded by his diving computer. The body was found 45 min after the beginning of the dive. BLS and defibrillation were unsuccessful. The post-mortem CT examination and the autopsy were carried out at our institute where we diagnosed the absence of massive barotrauma, but confirmed the presence of liquid in the lungs and gas in all the vessels and organs, including the heart cavity. The death was attributed to drowning in the context of barotrauma followed by AGE and DCS. The intra-cadaveric gaseous composition was 1.2 µmol·ml^{-1} of O_2, 30.2 µmol·ml^{-1} of N_2 and 10.2 µmol·ml^{-1} of CO_2 without the presence of decomposition gases (Table 2).

Materials and methods

COLLECTION OF GAS SAMPLES FROM THE BODIES

Gas sampling was performed percutaneously with MDCT following a standardized protocol recently developed at our centre.[8,9] Gas bubbles were detected by MDCT on a native CT scan and the RAI was calculated for each case. By using the biopsy mode, which corresponds to radiological guidance, it was possible to target the gaseous region to be punctured. A three-way tap in the closed position was mounted on a needle and introduced into the gaseous cavity using the three-dimensional coordinates. A second CT scan was performed to check the position of the needle. A Luer-lock PTFE syringe was then mounted on the tap which was slowly opened and gas was sampled. Then, the three-way tap was closed and the system (syringe + tap + needle) removed from the body. Gas volumes were sampled from various anatomical sites of interest (Table 3). The gas samples were individually transferred into a headspace (HS) glass vial of 20 ml, preliminarily filled with stabilized (de-gassed) water heated for 3 h at 60°C, then kept in the fridge (+4°C) until analysis, i.e., not less than 48 h for all cases although the in-vial stability of gases was satisfactory for up to eight weeks. Two needles were inserted through the septum: the system needle (syringe + tap + needle) and another simple needle. The transferred gas displaced the water, which could be evacuated through the second needle. The residual water had to be removed to permit complete airtightness. The vials were stored upside down in the fridge until analysis.

REAGENTS

All the analytical gases used were from Carbagas (Lausanne, Switzerland), including certified CO_2, hydrogen sulphide, carbon monoxide, nitrous oxide and methane. Atmospheric air was used as the source for O_2 and N_2 calibration.

GAS CHROMATOGRAPHY-THERMAL CONDUCTIVITY DETECTION/MASS SPECTROMETRY ANALYSIS (GC-MS/TCD)

An Agilent 6890N GC (Agilent Technologies, Palo Alto, CA) combined with a headspace gas autosampler and equipped with an Agilent Select Permanent Gases column arrangement was used. This column arrangement is specially designed for gas analysis and contains two capillary columns in parallel: a molecular sieve 5 Å PLOT capillary column (10 m x 0.32 mm i.d.) and a Porabond Q (50 m x 0.53 mm i.d.), allowing for the separation of CO_2. A three-way valve was mounted at the end of the capillary column into the gas chromatograph, enabling the gas samples to be directed to a thermal conductivity detector (TCD) or to an Agilent 5973 mass spectrometer (MS) (Agilent Technologies, Palo Alto, CA). The temperature was set to isothermal (45°C) and was held for 8 min and the injector (splitless mode) was set to 100°C. Helium was employed as the carrier gas (8 ml·min^{-1} constant flow). The gas identification was performed by the injection of gas standards and mass spectra. The MS was operating in the electron ionization mode (EI) at 70 eV with an ion source temperature of 230°C. The analyzer temperature was set to 150°C and the interface MS temperature to 250°C. Signals were acquired in full scan mode (2–100 amu). The gas quantification was performed with the TCD at 150°C, calibrated for each gas with standard gases.[9] Thus, intra-cadaveric CO_2 measurements are expressed in µmol·ml^{-1} HS. The other gases, such as methane, oxygen, nitrogen, hydrogen sulfide and hydrogen, are weakly dissolved in water and do not affect the quantification.

RADIOLOGICAL ALTERATION INDEX

The RAI is derived from post-mortem MDCT data from more than 100 non-traumatically deceased people and was validated by 100 additional scanned bodies retrospectively examined by two independent observers.[7] The RAI was developed to document the internal gas presence in cadavers and is based on the amount of gas present in seven defined anatomical sites (the left innominate vein, subcutaneous pectoral tissue, heart, liver, kidneys, abdominal aorta and the third lumbar vertebra).[9] Gas quantity was assessed by a scoring system using four grades ranging from 0 to III: 0 for no gas, I for one to a few bubbles of gas, II for a structure partially filled with gas and III for a structure completely filled with gas. Using the statistical method of linear regression, each anatomical site was weighted using regression coefficients with an adjustment to a maximum of 100. The RAI value, therefore, ranges from no gas (0) to the extensive presence of gas in all tissues (100).

Results

The origin of intra-cadaveric gases in our case series is attributed to decomposition in one case (Case 3), post-mortem decompression artifacts in two cases (Cases 1 and 4) and barotrauma/AGE in three cases (Cases 2, 5 and 6). The RAI of Case 3 was minimal (61), those of Cases 1 and 4 were intermediate (between 60 and 85), whereas the RAI of Cases 2, 5 and 6 were maximal (between 85 and 100), showing a large distribution of gases within the bodies.

The gas compositions measured at intra-cadaveric sampling sites are shown in Tables 2 and 3. For cases with high RAI, CO_2 was also noticeable in various anatomical sites (Table 3). Lower CO_2 concentrations were found in the femoral artery in Case 3 and femoral vein in Case 4. The concentration of gaseous CO_2 in other sites appears related to the RAI; however, this is variable and the CO_2 concentrations seem somewhat randomly distributed through the body. Example CT-scan cardiac images and intra-cardiac gas compositions are shown for three cases in Figure 1.

Discussion

The current challenge in evaluating deceased divers is distinguishing between intravascular/intracardiac gas that

Figure 1
CT-scan images and cardiac gas composition of three of the cases to illustrate the differences seen in divers at post-mortem

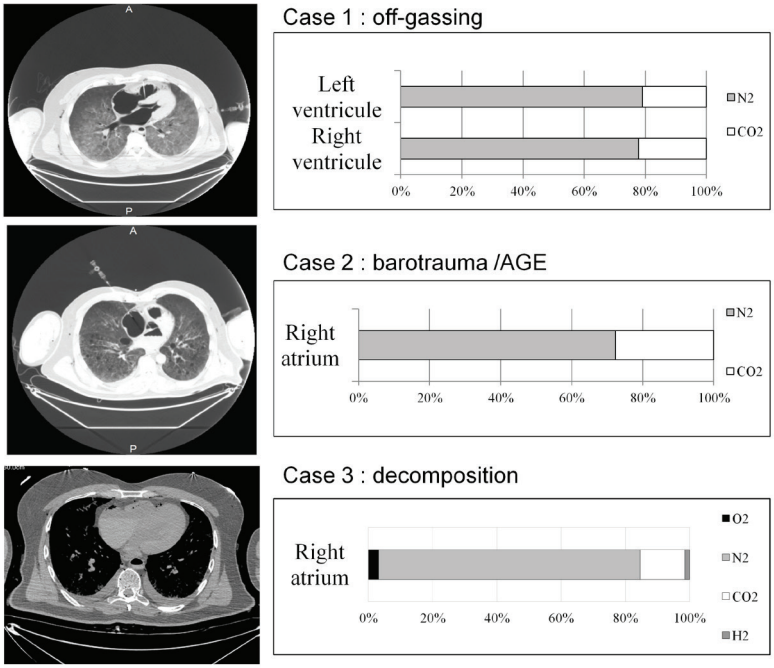

Table 2
Intracardiac gas composition in six divers following fatal diving incidents; gas concentration in μmol·ml^{-1}; * av. of two readings; † sum of oxygen + nitrogen

Diver	Oxygen	Nitrogen	Carbon dioxide	Hydrogen
1	nil	32.7	9.0*	nil
2	nil	30.1	11.6	nil
3	1.2	30.6	9.2	0.6
4	0.6	29.3	11.7	nil
5	25.6*†		16.0	nil
6	1.2	30.2	10.2	nil

is the result of true pulmonary barotrauma/AGE versus post-mortem off-gassing of the inert gas that dissolved in the diver's tissues during the dive. Decomposition gases are another challenge for the forensic radiologist evaluating CT scans and can lead to false interpretations.

DECOMPOSITION

The literature is scarce concerning this topic. Several animal studies have been conducted, while only a few have included human divers.[10–13] One study dealt with the intravascular gas composition occurrence in non-diving and diving autopsies in relation to the resuscitation operations and decomposition processes.[14] Another study focused on the diagnosis of massive gas embolism in the cerebral and spinal arteries using CT and MRI investigations.[15]

The cardiac gas composition and CT scan results for Case 3 are displayed in Figure 1. The cardiac bubble volume was small and the cause of death was diagnosed as natural due to cardiac pathologies (thrombosis). The RAI of 61 is rather moderate in the context of scuba diving, indicating that the intra-cadaveric gas occurrence was not generalized. The presence of H_2, as an indicator of decomposition, indicates that the CT scan cannot be taken into account when studying the relationship between the presence of intra-cadaveric gas and the dive. This result is also supported by a post-mortem delay of 40 h, even though the body was stored at a cold temperature. As the decomposition process can occur very rapidly after death, following the protocol for intra-cadaveric

Table 3
CO_2 concentrations (μmol·ml^{-1}) in gases sampled from cardiac cavities and various veins and arteries in six deceased divers

	R.atrium	R.ventricle	L.ventricle	Heart	Jugular vein	Femoral artery	Femoral vein	Subclavian vein
Case 1		9.2	8.7					
Case 2	11.6				17.1			20.4
Case 3	9.2						5.7	
Case 4				11.7		9.1		7.4
Case 5	16.0					12.0	24.0	
Case 6				10.2		7.2		10.5

gas sampling and analysis, it is easy to distinguish embolism gases from those caused by early decomposition.

BAROTRAUMA/AGE VERSUS OFF-GASSING

The cardiac gas composition and cardiac bubble volumes are important (>10 ml) in ascribing the cause of death in Cases 1 and 4 as drowning. The origin of intra-cadaveric gases in these cases was attributed to off-gassing because the bodies were found at 29 mfw and 95 mfw, respectively. No decomposition gas was detected but the cardiac CO_2 concentrations differed, possibly showing the effect of depth and diving time on the off-gassing magnitude – in long and deep dives, the amount of dissolved gases in the blood is higher relative to shorter, shallower depths. As a result, the CO_2 concentration in the cardiac gas of Case 1 (20 min at 30 mfw max.) is lower than that of Case 4 (40 min at 95 mfw max.) (Table 2). It should be noted that the RAI, initially developed to rank decomposition states of the body, is important but not maximal. As decomposition is excluded, this parameter illustrates the presence and distribution of intra-cadaveric gases. In these off-gassing cases, the fact that the RAI was not maximal shows a heterogeneous distribution relative to decomposition. Indeed, decomposition occurs first in specific areas such as the abdominal cavity.

The origin of intra-cadaveric gases in Cases 5 and 6 was attributed to drowning in the context of barotrauma followed by AGE/DCS since autopsy evidence clearly indicated both aetiologies. The diving profiles showed rapid ascents to the surface. For Case 2, no signs of drowning were noted but signs of pulmonary barotrauma were observed. No decomposition gases were detected. The cardiac CO_2 concentrations in Case 2 (11.6 $\mu mol \cdot ml^{-1}$), Case 5 (16 $\mu mol \cdot ml^{-1}$) and Case 6 (10.2 $\mu mol \cdot ml^{-1}$) may show the effect of depth and the ascent speed on the magnitude of barotrauma/AGE. A rapid ascent from a deep depth will likely result in the release of more gas (and consequent injuries) than would ascent from shallower, even though the greatest proportional pressure/volume changes occur close to the surface. Cases 2 and 6 had ascents from intermediate depths over approximately 2–4 min, whereas Case 5 ascended from 70 msw in 2 min.

However, the RAI scores in these three divers ranged from 85 to 100 (maximum), showing that, in the absence of decomposition, the intra-cadaveric gases were widely distributed inside the body. If we compare the RAI calculated in both categories (barotrauma/AGE and off-gassing groups), the RAI scores are higher for the barotrauma/AGE group. After excluding decomposition as the eventual source of intra-cadaveric gas origin, this parameter may be very useful for differentiating barotrauma/AGE and off-gassing fatalities, especially in the case of deep dives. Indeed, the distribution and volume of intra-cadaveric gas bubbles in deep diving seems to be higher for a rapid ascent leading to barotrauma/AGE compared to cases of off-gassing.

Cardiac gaseous CO_2 cannot constitute a diagnostic parameter by itself because the values are similar for cases of important off-gassing and barotrauma/AGE in shallow to medium depth dives (10 to 12 $\mu mol \cdot ml^{-1}$; Table 2). More cases are needed to improve its predictive power in scuba diving fatalities. Indeed, several sources could explain the CO_2 variation, such as sampling delay and potential diffusion from the tissues after death. However, once the origin of intra-cadaveric gases is determined, the concentration of cardiac CO_2 increases with the depth and duration of the dive.

THE INFLUENCE OF RESUSCITATION

It is of crucial importance to document the conditions and the occurrence of resuscitation.[3] The more active the resuscitation, the higher the risk of actively releasing dissolved gases. However, resuscitation can also cause the elimination of gas released through the lungs and exhaled. Mechanical ventilation with either air or oxygen and the duration of cardiopulmonary resuscitation could also influence the intracardiac gas composition.[16] Moreover, even if no resuscitation occurs, body handling can also generate gas release artifacts. As a result, each scuba diving fatality should be interpreted with regards to the specific resuscitation protocol and diving conditions, such as dive computer information and diving gas.

THE INFLUENCE OF THE SAMPLING SITE

The previously published studies performed on animals were not focused on the cardiac region but took into consideration the whole body or intestinal zones, especially to differentiate gas embolism from putrefaction.[12,13] Among the research using human data, none of the published studies assessed the anatomical precision of gas sampling.[14,15] However, according to the sampling site, the embolism gas composition can differ. The different biochemical properties of the tissues in which the diving gas is dissolved can be responsible for differences in the gas composition (the volume of gas released, elasticity and diameter of vessels and the amount of blood, etc.). In the diving context, the magnitude and nature of the embolic gas, its composition sampled from different intravascular sites varies, as was seen in these cases. However, the CO_2 concentrations seem not to be well correlated to the circumstances of the gas embolism.

THE NATURE OF THE DIVING GAS

The intracardiac gaseous CO_2 concentrations appear to be independent of the nature of the embolism gas. In the cases presented herein, the diving gases were all different: variously nitrox (23, 32, 49% O_2), air and oxygen. As a result, CO_2 concentrations in the intracardiac gas are more closely linked to the desaturation kinetics and the volume of embolism gas than to its nature.[16] However, the analytical methodology used in the gas analysis protocol can also be employed to detect other gases such as argon or helium.[17,18]

Helium is used in trimix whereas argon is used by some divers for thermal insulation in the drysuit. According to the diving gas, the presented approach could be useful for assessing the presence of helium or argon even in cases of noble gas poisoning; another specific sampling protocol focused on pulmonary and gastric gas without CT scan support has been developed. [18] However, alternative sites such as gastric gas should be more easily and precisely sampled under CT scan and laser guidance.

LIMITATIONS AND PERSPECTIVES

Even if other sites could be of potential interest, the cardiac cavity remains the organ of choice for this sampling because it constitutes an airtight organ directly linked to vital functions. According to the post-mortem delay, peripheral sites could be subjected to more redistribution, gas release from body handling and putrefaction. Sampling sites such as the femoral artery/vein or jugular vein could be used for confirmatory samplings of gas embolism but should not be considered as diagnostic sampling. It is preferable to sample gas in areas independent of the endogenous formation of gases such as the stomach or intestines because the origin of CO_2 is made more difficult to identify.

Conclusion

Intra-cadaveric gas sampling and analyses may constitute a useful protocol to help in the investigation of scuba diving fatalities. This should be mandatory from a radiological point of view in order to avoid misinterpretation of the images. Indeed, as diagnoses can be assigned based on CT scans, the forensic radiologist/pathologist must be sure that the intra-cadaveric gas occurrence is not due to decomposition. Moreover, the cardiac gaseous CO_2 concentration and the RAI should be interpreted with the diving profile in order to differentiate between the occurrence of intra-cadaveric gases in barotrauma/AGE/DCS cases and off-gassing. To confirm these findings, additional cases of fatal gas embolism must be analyzed; this confirmatory work is currently in progress.

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Transcutaneous oximetry measurements of the leg: comparing different measuring equipment and establishing values in healthy young adults

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Abstract
(Trinks TP, Blake DF, Young DA, Thistlethwaite K, Vangaveti VN. Transcutaneous oximetry measurements of the leg: comparing different measuring equipment and establishing values in healthy young adults. *Diving and Hyperbaric Medicine.* 2017 June;47(2):82-87.)
Introduction: Transcutaneous oximetry measurement (TCOM) is a non-invasive method of determining oxygen tension at the skin level using heated electrodes.
Aim: To compare TCOM values generated by different machines and to establish lower limb TCOM values in a cohort of healthy individuals younger than 40 years of age.
Method: Sixteen healthy, non-smoking volunteers aged 18 to 39 years were recruited. TCOM was obtained at six locations on the lower leg and foot using three different Radiometer machines. Measurements were taken with subjects lying supine, breathing air.
Results: Except for one sensor site, there were no statistical differences in measurements obtained by the different TCOM machines. There was no statistical difference in measurements comparing left and right legs. Room air TCOM values for the different lower leg sites were (mean (SD) in mmHg): lateral leg 61.5 (9.2); lateral ankle 61.1 (9.7); medial ankle 59.1 (10.8); foot, first and second toe 63.4 (10.6); foot, fifth toe 59.9 (13.2) and plantar foot 74.1 (8.8). The overall mean TCOM value for the lower limb was 61 (10.8; 95% confidence intervals 60.05–62.0) mmHg.
Conclusion: Lower-leg TCOM measurements using different Radiometer TCOM machines were comparable. Hypoxia has been defined as lower-leg TCOM values of less than 40 mmHg in non-diabetic patients and this is supported by our measurements. The majority (96.9%) of the lower leg TCOM values in healthy young adults are above the hypoxic threshold.

Key words
Patient monitoring; Standards; Wounds; Hyperbaric oxygen therapy

Introduction

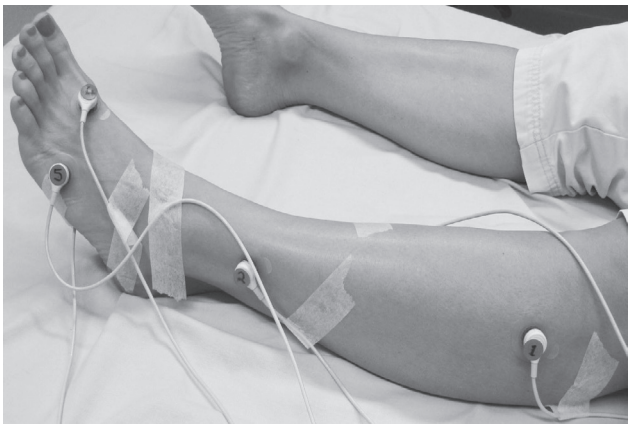
Transcutaneous oximetry measurement (TCOM) is a technique used for recording oxygen (O_2) partial pressure at the skin level ($P_{tc}O_2$). The diffusion of extracellular O_2 into heated electrodes at the skin surface is non-invasively quantified, serving as a surrogate for tissue oxygenation. In hyperbaric medicine, TCOM has become an important assessment tool used to identify peri-wound hypoxia, monitor tissue responsiveness to oxygenation and help distinguish macro- from microvascular disease.[1] Hyperbaric oxygen treatment (HBOT) is likely to be beneficial in patients with chronic wounds who demonstrate hypoxia in the surrounding tissues and who show response to O_2 administration. An algorithm incorporating TCOM has been developed to identify patients who may respond to or are suitable for HBOT and to guide further management.[1]

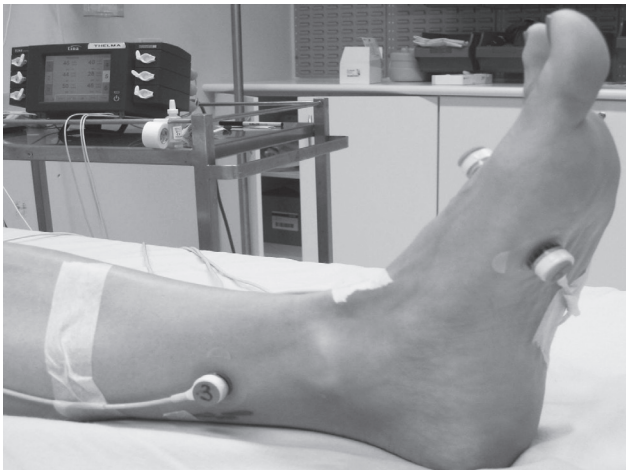
The majority of chronic wounds arise in the lower limbs and the interpretation of TCOM data in this area is based on previous studies defining a normoxic range in a healthy population.[2–5] According to these data, a mean value of 67 (SD 10) mmHg can be considered normoxic. Based on this, hypoxia of the lower limbs was defined as a $PtcO_2$ of less than 40 mmHg in non-diabetic patients.[1,6] A recent study reported TCOM values lower than those previously reported and raised the question as to whether the use of different measurement equipment influences obtained TCOM data. That study has now been retracted after discovering an instrumentation error that renders the measurements from the study unreliable.[7]

This study was undertaken to compare TCOM values generated by three different machines. As a secondary endpoint, we establish TCOM values in a cohort of healthy

Figure 1

TCOM leg sensor placement: sensor 1 – 10 cm distal to the lateral femoral epicondyle; sensor 2 – 5 cm proximal to the anterior aspect of the lateral malleolus; sensor 3 – 5 cm proximal from the centre of the medial malleolus; sensor 4 – dorsum of the foot between the first and second metatarsal heads away from any obvious veins; sensor 5 – dorsum of the foot proximal to the head of the fifth metatarsal; sensor 6 – plantar first metatarsal area (proximal to the fat pad at the base of the great toe)





individuals younger than 40 years of age. This age range was chosen with the aim of selecting a population without age-related physiological changes.[8]

Methods

The Human Research Ethics Committee of the Townsville Hospital and Health Service granted ethics approval for the study (HREC/15/QTHS/111) and the Centre for the Advancement of Clinical Research of the Royal Brisbane and Women's Hospital and Metro North Hospital and Health Service granted site-specific approval.

Sixteen healthy volunteers (eight males, eight females) were recruited to participate in the study. Exclusion criteria included subjects younger than 18 and older than 39 years of age; disorders that could impair diffusion of O_2 through the skin; any significant medical history, especially underlying cardiovascular and respiratory disease; and current or past smoking. All participants were provided with written information at the time of recruitment, questions were answered and informed written consent was obtained. The subjects were de-identified by allocating a study number to ensure confidentiality.

Basic demographic data were collected including age, sex, weight and height. All participants were asked a series of standardized questions to determine their overall health status including medical and surgical history, confirmation of non-smoking status, medication/drug use and allergies. Heart rate and rhythm, blood pressures (on upper arm and lower leg) and O_2 saturation were measured and recorded. Dorsalis pedis (DP) and posterior tibial (PT) pulses were palpated and graded according to quality (palpable/detectable by Doppler/absent). Any abnormalities in these observations or in the detectability of pulses would have led to exclusion from the study. The participants refrained from consuming caffeine, eating a heavy meal and performing heavy exercise for two hours prior to the measurements.

Subjects were placed in a supine position on an examination bed with the head slightly raised on one pillow for the duration of the study. A blanket was offered for comfort and to limit any vasoconstrictive effects from being cold. The room temperature (between 22.5^{O}C and 24.5^{O}C) and humidity (between 52% and 62%) were monitored.

The study compared $P_{tc}O_2$ measurements obtained by five TCOM machines of three types, using the same type of electrodes and membranes:

- 1 x Radiometer TCM400, 6 channels; Software Version 4.2 (v4.2); E5250 tc electrodes
- 1 x Radiometer TCM400, 6 channels; Software Version 5.01 (v5.01); E5250 tc electrodes
- 3 x Radiometer TCM30, 1 channel; E5250 tc electrodes

The TCM400 machines have six electrodes and can record $P_{tc}O_2$ data at all six sensor sites simultaneously. The TCM30 machine only has one electrode, therefore three TCM30 machines were used to allow for simultaneous measurement at three sensor sites. The electrode temperatures were pre-set to 44^{O}C, a temperature that allows maximal vasodilation but limits the risk of burn injury at the sensor site.[9,10] Prior to commencement of the study, new membranes (D826 – $tcpO_2$) were applied to all sensors. The accuracy of the sensors at low and high O_2 values was checked by calibrating the sensors with atmospheric air and by performing a sensor zero-current check with CAL2 standard calibration gas (10% carbon dioxide, 90% nitrogen). The sensors were re-membraned halfway through the study.

Table 1
Demographics and baseline characteristics of 16 healthy subjects (eight male, eight female) < 39 years old; mean (SD) or * median and interquartile range ((IQR))

Variable (n = 16)	Mean or median*	SD or IQR*
Age (years)	33.6	(3.7)
Height (cm)	172.8	(6.8)
Weight (kg)	72.2	(13.1)
BMI ($kg \cdot m^{-2}$)	24.1	(3.6)
Systolic BP (left) (mmHg)	113.2	(11.1)
Diastolic BP (left) (mmHg)*	70	(61.0–71.5)
Heart rate ($beats \cdot min^{-1}$)	67.6	(6.6)
Ankle brachial index (L and R)	1.2	(0.1)
SpO_2 (L and R) (%)*	100	(99.0–100)

For the TCM400 machines, a 'humidity correction factor' was calculated from the saturated water vapour pressure (according to the room temperature) and relative humidity and input into the machine according to the operator's manual.[11] The TCM30 machines do not provide the option of inserting a humidity correction factor. Therefore, a pO_2 calibration value was calculated from the barometric pressure, the relative humidity and the saturated vapour water pressure (according to the room temperature) and programmed into the machines according to the operator's manual.[12] The participants lay quietly for 20 minutes (min) while the TCOM machines were zeroed and calibrated to room air and the sensors were applied (Figure 1).

The sensor sites were prepared by shaving hair, if necessary, wiping clean, rubbing with an alcohol swab and drying with gauze. The order of the TCOM machines for each leg was randomized, right or left leg for TCM30 first then randomized order for the TCM400 machines. Two researchers (TT and DY) placed three sensors of the TCM30 machines to leg 1 (sensor positions 1–3) and six sensors of the first TCM400 machine to leg 2 (sensor positions 1–6). The leads were secured in place by tape to prevent pull on the sensors and an air leak occurring. Subjects were requested to keep talking to a minimum during the study.

After at least 20 min and stabilization of the values, the measurements were recorded and the sensors removed while the fixation rings remained in place. After a 10-min break, the three sensors of the TCM30 were re-attached to leg 1 (sensor positions 4–6) and the sensors of the second TCM400 machine were attached to leg 2. Measurements were again recorded after 20 min. After another 10 min break, the measurement procedure was repeated on the opposite leg: first TCM400 to leg 1 (sensor positions 1–6) and TCM30 to leg 2 (sensor positions 1–3). Then the second TCM400 was applied to leg 1 and TCM30 to leg 2 (sensor positions 4–6).

Table 2
Medial ankle $P_{tc}O_2$ values (mmHG) among the three oximetry devices (n = number of observations); one way ANOVA P = 0.01; post hoc Bonferroni test adjusted for multiple comparisons:
* P = 0.03 for TCM400 (v4.2) vs. TCM30;
† P = 0.04 for TCM400 (v5.01) vs. TCM30

	Transcutaneous oxygen (mmHg)		
Device	Mean	SD	95% CIs
TCOM400 (v4.2)*	57.3	11.4	51.2–63.3
TCM400 (v5.01)†	57.7	5.5	54.7–60.7
TCM30	65.8	8.9	61.1–70.6

At the end of the measurements, the sensors were removed and all sites were inspected for any thermal injury.

DATA ANALYSIS

The primary outcome of this study was to compare the tissue oxygen levels in the lower leg and foot of healthy volunteer participants recorded by the two different models of TCOM machines, TCM400 and TCM30, and different TCOM machines of the same model, TCM400, but using different software versions. Based on the premise that the true difference between the machines is 10 mmHg, our sample size of 16 measurements provided 80% power (with $\alpha = 0.05$) to be able to reject the null hypothesis using a two-sided Student t-test.

Demographic characteristics of the subjects are presented as median and inter-quartile range (IQR) or mean and standard deviation (SD) based on outcome of normality testing. Descriptive statistics are reported for TCOM readings at each of the six sensor sites: mean (standard deviation SD) for normally distributed data; median (IQR) for non-parametric data. Differences between TCOM measurements for each machine were compared using one way ANOVA followed by a Bonferroni post hoc test adjusted for multiple comparisons; P values which can be compared directly to 0.05 have been reported (for an explanation see <http://imaging.mrc-cbu.cam.ac.uk/statswiki/FAQ/SpssBonferroni>). All data were entered into the Statistical Package of Social Sciences version 22 (SPSS, IBM USA, Armonk) for analysis. A P value of < 0.05 was considered statistically significant.

Results

Demographic and baseline data are shown in Table 1. The subjects were all less than 40 years old. There were equal numbers of females and males. All DP and PT pulses were palpable or easily detected by Doppler. Baseline measures of perfusion were clinically unremarkable in all subjects. There were no missing data.

The TCOM readings for all sensor sites were normally distributed. There was no statistical difference between the TCM400 (v4.2) and TCM400 (v5.01) machines at any sensor site or between the right and left leg sensor sites for

Table 3

$P_{tc}O_2$ (mmHg) for each site for the three transcutaneous oximetry devices (n = 16); mean (SD) and range shown; ** One way ANOVA P = 0.01; post-hoc test: Bonferroni adjustment for multiple comparisons: * P = 0.03 for TCM400 (v4.2) vs. TCM30; † P = 0.04 for TCM400 (v5.01) vs. TCM30; ‡ P = 0.05 for TCM400 (v4.2) vs. TCM30; § P = 0.02 for TCM400 (v5.01) vs. TCM30

Anatomical site	**TCM400 (v4.2)**			**TCM400 (v5.01)**			**TCM30**		
Right lateral leg	60.2	(9.1)	40–73	60.4	(9.9)	42–78	61.3	(7.9)	42–72
Right lateral ankle	64.4	(9.0)	43–80	62.6	(11.8)	35–80	58.9	(10.3)	42–74
Right medial ankle**	57.3	(11.4)*	29–77	57.8	(5.6)†	50–66	65.9	(9.0)	46–83
Right foot, 1st/2nd toe	65.6	(11.2)	37–79	61.7	(10.2)	41–75	58.8	(12.7)	34–76
Right foot, 5th toe	60.0	(15.3)	16–80	61.9	(13.8)	27–78	52.7	(14.3)	13–71
Right plantar foot	74.6	(8.2)	54–86	72.9	(9.9)	49–91	73.1	(11.3)	41–90
Left lateral leg	60.4	(12.8)	30–79	64.1	(7.7)	53–78	62.4	(7.8)	52–76
Left lateral ankle	61.3	(7.0)	51–75	61.6	(9.0)	41–78	57.8	(10.1)	37–72
Left medial ankle**	55.1	(13.6)‡	34–92	53.8	(9.5)§	39–67	64.7	(9.3)	43–77
Left foot, 1st/2nd toe	65.5	(12.0)	39–86	64.7	(8.7)	44–86	64.1	(7.8)	49–76
Left foot, 5th toe	59.9	(11.2)	39–78	65.6	(12.3)	40–96	59.6	(10.5)	29–75
Left plantar foot	74.8	(8.1)	61–94	74.9	(8.3)	58–95	74.1	(7.3)	59–85

Table 4

Lower limb transcutaneous oxygen values (mmHg) in 16 healthy subjects < 39 years old

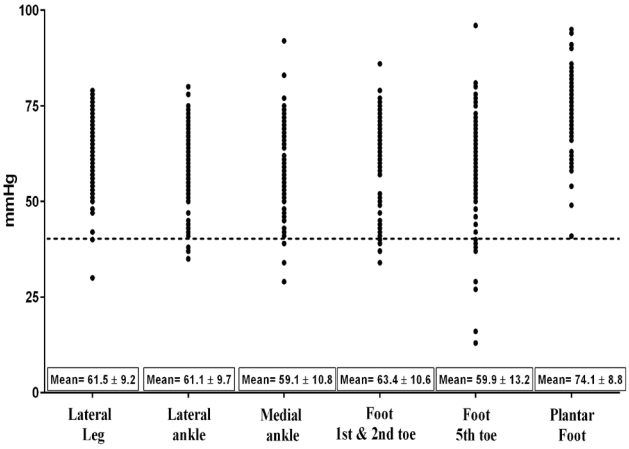
	Transcutaneous oxygen (mmHg)		
Anatomical site	Mean	(SD)	95 % CI
Lateral leg	61.5	(9.2)	59.6–63.3
Lateral ankle	61.1	(9.7)	59.1–63.0
Medial ankle	59.1	(10.8)	56.8–61.2
Foot, 1st/2nd toe	63.4	(10.6)	61.2–65.5
Foot, 5th toe	59.9	(13.2)	61.2–65.5
Plantar foot	74.1	(8.8)	57.2–62.6
Averaged lower leg	61.0	(10.8)	60.1–62.0

each machine. There was a statistical difference between the two TCM400 machines and the TCM30 machine at two out of 12 sensor sites: right medial ankle and left medial ankle (Table 2). Figure 2 displays graphically the combined TCOM readings for all three machines at each site. The majority of measurements show readings above 40 mmHg – by definition non-hypoxic for a healthy population. The means of TCOM values of the lower limbs (mmHg) of a healthy population less than 40 years old are displayed in Table 3 and the combined means are shown in Table 4. The overall mean TCOM value for the lower limb can be calculated as 61.0 (10.8) mmHg; 95% CI 60.05–62.0 (Table 4).

False positives for hypoxia with measurements of less than 40 mmHg were seen in 18 out of 576 measurements (3.1%). These occurred at five out of the six sensor sites: sensor 5 (dorsum of the foot proximal to the head of the fifth metatarsal) 7/18; sensor 3 (5 cm proximal from the centre of the medial malleolus) 4/18; sensor 2 (5 cm proximal to the anterior aspect of the lateral malleolus) 3/18; sensor 4 (dorsum of foot between first and second metatarsal heads) 3/18; sensor 1 (10 cm distal to the lateral femoral epicondyle) 1/18. Hypoxic readings were found with all machines:

Figure 2

Combined TCOM readings for all three models of oximetry devices at each monitoring site on the lower leg of 16 healthy subjects < 39 years old; dotted line = 40 mmHg



TCM400 (v4.2): 7/192 (3.65%); TCM400 (v5.01): 4/192 (2%); TCM30: 7/192 (3.65%).

Discussion

Transcutaneous oximetry measures tissue O_2 tension noninvasively and is a useful tool in determining patient who are unlikely to respond to HBOT. Hypoxic wounds that improve with a 100% O_2 challenge are potentially amenable to HBOT whilst non-responding and normoxic wounds are usually excluded from treatment. To define hypoxic TCOM readings in lower limbs, it is important to establish the normoxic range in a young population without underlying medical disease or age-related vascular changes. Even though there have been studies to determine TCOM readings in a normal population,[2–4] there have not been any that define lower limb TCOM readings in healthy, non-smoking subjects younger than 40 years of age by using a standardized measurement method.

Two earlier studies reported TCOM values for both the upper and lower limbs of healthy subjects, but an instrumentation error was identified that rendered these measurements unreliable and the papers have been retracted. The present study was undertaken in part to redress this problem.

Most of the studies that laid the foundation of defining hypoxia and normoxia in a healthy population are from the 1980s and 1990s. The equipment used was of older technology and presumably less sophisticated compared to newer generation TCOM machines. Despite technological advances, we could not find a statistical difference comparing an older generation machine (TCM30) with newer generation machines (TCM400) for 10 out of 12 sensor sites. This result is expected considering that the measuring sensors of the different generation TCOM Machines are all based on Clark electrodes and are similar in construction. The differences at the left and right medial ankle sensor sites between the TCM30 and both the TCM400 (v4.2) and TCM400 (v5.01) models were statistically significant. The causes for the consistently higher reading with TCM30 at the medial ankle sites are unknown. Our measurements confirm the reproducibility of results, despite the technological advances with the passage of time.

Hypoxia is defined as a $P_{tc}O_2 < 40$ mmHg in patients without underlying diabetes mellitus and as a $P_{tc}O_2 < 50$ mmHg in patients with diabetes mellitus and in those with renal failure.[1,13–15] The majority of the readings were non-hypoxic by definition and consistent with current guidelines. Only 3.1% of the readings were < 40 mmHg, i.e., the hypoxic range. Hypoxic readings were found with all the machines and were not specific to any measuring site.* Isolated low readings in a healthy population are to be expected and can be explained by underlying low-perfused structures (e.g., tendons, bones). It is often difficult to place fixation rings in peri-wound areas but away from these low-perfused structures especially near the base of the fifth toe. The decision to treat should not be influenced by an isolated, single low reading.

There were no statistical differences between the right and left lower limb sensor sites of the same patient, measured by the same TCOM machine. Historically, the contralateral limb was used to determine an individual patient's baseline values. Some hyperbaric units still use this technique and apply sensor/sensors to the contralateral (non-diseased) leg and use it as a reference point in the context of wound assessments. Given our data this may be an acceptable practice.

The plantar foot site has traditionally not been used for TCOM measurements due to a presumed thicker stratum corneum with a subsequent increased diffusion distance. Contrary to expectations, we measured consistently high values at this site. The mean difference between the plantar foot site and the other sensor sites was 10.7 mmHg to 15 mmHg (Table 3). The sole has adapted to deal with high local compression forces by developing a system of pressure chambers, composed of fibro-fatty tissue covered by external collagen. The internal walls of these chambers are permeated by numerous blood vessels, making the sole of the foot one of the most vascularised regions of the human body.

LIMITATIONS

The five TCOM machines of three model types used in the study were all manufactured by Radiometer Medical, Denmark, using the same type of electrodes and membranes. Comparing the reproducibility of data obtained by TCOM machines from different manufacturers, and also with different electrodes and membranes, would be an area of further research. All the subjects in the study were younger than 40 years old without any significant medical problems and without age-related changes. The obtained data might not be generalizable to a different population.

Conclusions

Lower limb TCOM measurements obtained using Radiometer TCM30 machines and same generation Radiometer TCM400 machines using different software versions were comparable except for the medial ankle site. Only 18 out of 576 observations (3.1%) were below the hypoxic threshold. This appeared to be random rather than related to a specific measuring site. The overall mean $P_{tc}O_2$ value for the lower limb was 61 mmHg (SD 10.8; 95% confidence intervals 60.05–62.0).

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* **Footnote:** Separate data plots for each machine at each anatomical monitoring site are available from the authors or the journal office <editorialassist@dhmjournal.com>.

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Identifying and acting on potentially inappropriate care? Inadequacy of current hospital coding for this task

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Abstract
(Cooper PD, Smart DR. Identifying and acting on potentially inappropriate care? Inadequacy of current hospital coding for this task. *Diving and Hyperbaric Medicine*. 2017 June;47(2):88-96.)
Introduction: Recent Australian attempts to facilitate disinvestment in healthcare, by identifying instances of 'inappropriate' care from large Government datasets, are subject to significant methodological flaws. Amongst other criticisms has been the fact that the Government datasets utilized for this purpose correlate poorly with datasets collected by relevant professional bodies. Government data derive from official hospital coding, collected retrospectively by clerical personnel, whilst professional body data derive from unit-specific databases, collected contemporaneously with care by clinical personnel.
Aim: Assessment of accuracy of official hospital coding data for hyperbaric services in a tertiary referral hospital.
Methods: All official hyperbaric-relevant coding data submitted to the relevant Australian Government agencies by the Royal Hobart Hospital, Tasmania, Australia for financial year 2010–2011 were reviewed and compared against actual hyperbaric unit activity as determined by reference to original source documents.
Results: Hospital coding data contained one or more errors in diagnoses and/or procedures in 70% of patients treated with hyperbaric oxygen that year. Multiple discrete error types were identified, including (but not limited to): missing patients; missing treatments; 'additional' treatments; 'additional' patients; incorrect procedure codes and incorrect diagnostic codes. Incidental observations of errors in surgical, anaesthetic and intensive care coding within this cohort suggest that the problems are not restricted to the specialty of hyperbaric medicine alone. Publications from other centres indicate that these problems are not unique to this institution or State.
Conclusions: Current Government datasets are irretrievably compromised and not fit for purpose. Attempting to inform the healthcare policy debate by reference to these datasets is inappropriate. Urgent clinical engagement with hospital coding departments is warranted.

Key words
Clinical coding; Data; Economics; Evidence; Health; Hyperbaric oxygen therapy; Policy

Introduction

In August 2015, a paper was published in the *Medical Journal of Australia* (*MJA*) that attempted to develop a model to measure potentially inappropriate care in Australian hospitals.[1] Written from an economic perspective, this paper was based on a report prepared by the Grattan Institute, a self-proclaimed "*independent think tank focused on Australian public policy*".[2] Utilizing computerized hospital discharge data from all Australian hospitals for the 2010–2011 financial year (FY2010–11), the authors attempted to identify the hospital-specific incidence of selected diagnosis/procedure pairs that had previously been identified as 'inappropriate' in other literature.[1] The authors targeted five hospital procedures as having the potential for disinvestment on these grounds, and went so far as to recommend punitive measures against healthcare providers whose use of these procedures they deemed as "*outliers*".[2]

Amongst the 'do-not-do' procedures included in the Grattan study was "*(h)yperbaric oxygen therapy for a range of conditions including osteomyelitis, cancer, non-diabetic wounds and ulcers, skin graft survival, Crohn's disease, tinnitus, Bell's palsy, soft tissue radionecrosis, cerebrovascular disease, sudden deafness and acoustic trauma, and carbon monoxide poisoning*".[1] Hyperbaric oxygen treatment (HBOT) was by far the largest contributor to this study's results, comprising some 79% (4,659/5,888) of the procedures identified as potentially inappropriate. These results were problematic to the majority of Australian hyperbaric physicians since, in FY2010–11, both soft tissue radionecrosis and hypoxic non-diabetic wounds/ulcers were approved indications for HBOT under the Australian *Medicare Benefits Schedule* (*MBS*)[3,4] – and soft tissue radionecrosis remains so to the present day.[5] This *MBS* approval followed rigorous review of the available evidence by the Government's own Medical Services Advisory Committee.[6] Numerous other methodological flaws and factual errors have also been identified in the Grattan study, invalidating its conclusions and leading to calls for a formal retraction.[7,8]

A state-by-state breakdown of Australian HBOT use in the Grattan report clearly identified Tasmania as an outlier, with a rate of 'do-not-do' treatment approximately ten times higher than any other state.[2] This figure was not consistent with our understanding of local hyperbaric medicine practice and required explanation. The Royal Hobart Hospital (RHH) operates the only medical hyperbaric chamber in Tasmania and, as its co-directors, we had a responsibility to answer the charges levelled against this institution.[8]

During analysis of the Grattan paper, it became apparent that, amongst other problems, their primary data source may have been compromised. De-identified patient-level data about all public and private hospital separations (discharges, deaths and transfers) for the year in question had been obtained from the Australian Institute of Health and Welfare (AIHW) – the Government agency responsible for providing "*reliable, regular and relevant information and statistics on Australia's health and welfare*".[9] Diagnosis and procedural data submitted to the AIHW database were extracted retrospectively from individual patients' medical records by clinical coders at each hospital, utilizing the *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Australian Modification* (*ICD-10-AM*) for diagnosis coding and the *Australian Classification of Health Interventions* (*ACHI*) for procedure coding. Review of the HBOT data ("*Therapeutic Intervention 1888*") in the 2010–11 Procedure Data Cube on the AIHW website, however, demonstrated no apparent correlation with the Australian hyperbaric unit activity data published annually by the relevant independent professional society, the Hyperbaric Technicians and Nurses Association (HTNA).[10,11] Given that HTNA data derive directly from individual hyperbaric unit databases (collected contemporaneously with treatment by personnel responsible for providing the front-line healthcare services in question), it appeared reasonable to assume that it should be at least as accurate as the 'official' data collected retrospectively by the hospital coders. This current project arose from the necessity to explain the discrepancy between these two datasets.

Aim

To review hyperbaric-relevant coding data submitted to the AIHW by RHH for FY2010–11, and compare this against actual hyperbaric unit activity as determined by reference to original source documents.

Methods

All patients treated with HBOT at RHH between 01 July 2010 and 30 June 2011 were identified from the hyperbaric unit database. All coding data for every hospital presentation (hyperbaric-related or not) of these patients between those dates was requested from the hospital's clinical coding department. A separate list of patient medical record numbers for all individuals whom the hospital had coded as receiving HBOT (*ACHI* procedure codes 13025-00, 13020-00 and 96191-00 (Table 1A)) between these same dates was also requested to ensure that there were no patients coded as having received HBOT who were missing from the hyperbaric unit database. The official hospital diagnosis and procedure data codes were then compared against the hyperbaric unit database to identify any discrepancies in patient numbers, treatment numbers, treatment durations, dates and/or diagnoses. Any procedure code discrepancies between hospital- and unit-based data were resolved by reference to the original, hand-written dive log (which provides the definitive statement of who was in the chamber on the day in question and what treatment was administered). Diagnosis code discrepancies were resolved by reference to the patient's medical record and associated correspondence.

Table 1

Comparison of constraints on HBOT coding in the Australian Classification of Health Interventions (ACHI) and Medicare Benefits Schedule (MBS) systems; A. ACHI hyperbaric code numbers for fiscal year 2010–2011; B. MBS hyperbaric item numbers FY2010–2011

A.	***ACHI* code number**	**HBOT duration**		
	13020-00	> 90 min, ≤ 3 h		
	13025-00	> 3 h		
	96191-00	≤ 90 min		
B.	***MBS* item number**	**HBOT duration**	**2010–2011 MBS-funded diagnoses**	**Doctor role**
	13015	90 min to 3 h	Soft tissue radionecrosis	External
			Chronic/recurring hypoxic wounds	
	13020	90 min to 3 h	Decompression illness	External
			Air or gas embolism	
			Diabetic wounds	
			Gas gangrene	
			Necrotising soft tissue infections	
			Prevention of osteoradionecrosis	
			Treatment of osteoradionecrosis	
	13025	> 3 h	Decompression illness	External
			Air or gas embolism	
	13030	N/A	Continuous life-saving emergency treatment	In-chamber

Table 2

Treatments administered vs. treatments coded for the decompression illness/arterial gas embolism diagnostic category; bold numbers highlight where coding and treatment match correctly; RN – Royal Navy, USN – United States Navy; 18:60:30 and 14:90:20 in depth [msw]: duration (min): decompression (min) format; ToP – trial of pressure; all times measured from start of pressurisation to completion of decompression

	ACHI hyperbaric code numbers				
Treatment table	13025-00 (>3 h)	13020-00 (>90 min, ≤3 h)	96191-00 (≤90 min)	Missed (not coded)	Number correct
RN62/USN TT6 (270 min)	**5**	4	1	2	5/12
RN61/USN TT5 (135 min)	1	**0**	0	1	0/2
18:60:30 (95 min)	1	**7**	1	3	7/12
14:90:20 (115 min)	2	**6**	1	2	6/11
Aborted/ToP/custom (≤90 min)	0	0	**0**	1	0/1
Non-existent (did not occur)	0	0	0	**N/A**	N/A
Number correct	5/9	13/17	0/3	0/9	18/38

Once the cases had been matched between datasets and assigned to the appropriate diagnostic groups, a random study number was assigned to each case and all personal identifiers removed from the study dataset. Errors were then tabulated and compared within each of the following broad diagnostic categories: (a) decompression illness (DCI) and arterial air/gas embolism (AGE); (b) gas gangrene and necrotizing soft tissue infections, including necrotizing fasciitis or Fournier's gangrene; (c) diabetic wounds including diabetic gangrene and diabetic foot ulcers; (d) refractory non-diabetic hypoxic wounds (NDHW); (e) refractory soft tissue radiation injury (STRI); (f) osteoradionecrosis (ORN) prevention; (g) treatment of established ORN; (h) carbon monoxide (CO) poisoning; and (i) miscellaneous indications – looking for specific patterns of miscoding in each group. This study was approved by the relevant institutional Human Research Ethics Committee (UTas HREC Nº: H0015606).

Results

One hundred patients underwent a total of 1,734 hyperbaric treatments at RHH in FY2010–11. One or more diagnosis and/or procedure coding errors were detected in the hospital data for 70% of patients (70/100). The proportion of patients whose coding was affected by errors varied by diagnostic category. One 'additional' patient who had not received HBOT that year was also identified as having been coded as receiving HBOT.

PROCEDURE CODING ERRORS

Of all the patients who underwent HBOT, 6% (6/100) were not coded as having received any HBOT that year, and 8% (138/1,734) of the individual treatments administered were missing from the coding data. Seven 'false' HBOT episodes (which had not occurred) had been coded, including one hyperbaric treatment for the 'additional' patient described above.

The hyperbaric treatments actually provided by the unit were tabulated against the hyperbaric procedure codes available to clinical coders for each of the broad diagnostic categories described above. Table 2 shows the example for the DCI/AGE diagnostic grouping. These results were then combined to provide an overview of total hyperbaric unit activity and how it was coded (Table 3).

Of the 1,734 hyperbaric treatments actually provided to patients that year 1,344 were correctly coded (77%), with the remaining 23% being either miscoded as the wrong duration (15%; 252/1,734) or missed entirely (8%; 138/1,734). Accuracy of coding for a specific hyperbaric treatment table approximated the frequency with which that table was used, being most reliable (80%; 1,326/1,660) for the most commonly used treatment (14:90:20 table; 243kPa pressure (14 metres' sea water (msw) equivalent depth): 90 minutes duration at pressure: 20 minutes decompression).

Of the 1,603 hyperbaric treatments that were coded as occurring that year 1,344 were correctly coded (84%), with the remaining 16% being either miscoded as the wrong duration (15.6%; 252/1,603) or never actually having occurred (0.4%; 7/1,603).

DIAGNOSIS CODING ERRORS

With many hundreds of diagnosis codes available in the *ICD-10-AM* coding manual, and no upper limit to the number that may be included in a single episode of care

Table 3

Treatments administered vs. treatments coded across all diagnostic categories; bold numbers highlight where coding and treatment match correctly; RN – Royal Navy, USN – United States Navy; 18:60:30 and 14:90:20 in depth [msw]: duration (min): decompression (min) format; ToP – trial of pressure; all times measured from start of pressurisation to completion of decompression

	ACHI hyperbaric code numbers				
Treatment table	13025-00 (>3 h)	13020-00 (>90 min, ≤3 h)	96191-00 (≤90 min)	Missed (not coded)	Number correct (%)
RN62/USN TT6 (270min)	**5**	4	1	2	5/12
RN61/USN TT5 (135 min)	1	**0**	0	1	0/2
18:60:30 (95 min)	5	**12**	1	22	12/40
14:90:20 (115 min)	24	**1,326**	204	106	1,326/1,660 (80%)
Aborted/ToP/custom (≤90 min)	0	12	**1**	7	1/20
Non-existent (did not occur)	0	5	2	**N/A**	0/ 7 (N/A)
Number correct (% correct)	5/35	1,338/1,359 (98%)	1/209 (0.5%)	0/138 (0%)	1,344/1,741 (77%)

when active co-morbidities are included (up to 31 used in this patient series), there are an almost limitless number of combinations and permutations possible.[12] This was reflected in the diversity of codes used within each broad diagnostic category.

Decompression illness/arterial gas embolism

The primary diagnosis was appropriate in 14 of the 16 treated divers (T70.3 "*Other effects of decompression and barotrauma*"); however, only eight were coded as having sustained their injuries whilst diving. This reflects an idiosyncrasy in the coding manual: classifying recreational injuries by activity (U54.2 "*Scuba diving*"), but occupational injuries by industry (U73.00 "*Agriculture, forestry and fishing*") and location (Y92.82 "*Other specified place of occurrence, large area of water*"). Of the remaining two divers, one had a prior diving-related diagnosis from some years previously (dysbaric osteonecrosis of the hip, M87.95 "*Unspecified osteonecrosis, pelvic region*") transcribed forward for a presentation with DCI of the shoulder (condition and site both incorrect), and the other was missing from the coding. Of the two nosocomial AGE patients treated that year, both were appropriately coded.

Gas gangrene and necrotizing soft tissue infections

Two clinically almost indistinguishable necrotizing fasciitis patients were treated in FY2010–11. Each was coded differently; one as M72.65 "*Necrotising fasciitis, pelvic region and thigh*" + K61.3 "*Ischiorectal abscess*", and the other as N49.8 "*Inflammatory disorders of other specified male genital organs*" + K61.0 "*Anal abscess*".

Diabetic wounds including diabetic gangrene and diabetic foot ulcers

Over 46% (80/173) of coded HBOT episodes in this group had no mention of diabetes linked to that episode, being mainly (78/80) coded as L97 "*Ulcer of lower limb, not elsewhere classified*". Discussions with our coding department revealed that the guidelines for coding diabetes had evolved through several iterations over the past decade (Spurr B, personal communication, 2016) and that it had not always been standard practice to code for diabetes unless it was seen as an active problem in that particular presentation. However, this does not explain why these individuals could not be coded as being treated for established complications of diabetes like the remainder of this group (e.g., E11.69 "*Type 2 diabetes mellitus with other specified complication, ulcer (lower extremity)*" or E11.73 "*Type 2 diabetes mellitus with foot ulcer due to multiple causes*").

Treatment of established ORN

This was the most consistently coded Medicare-funded diagnostic category. All patients were correctly coded as having K10.2 "*Inflammatory conditions of jaws*" as their primary diagnosis; with Y84.2 "*Other medical procedures as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure; Radiological procedures and radiotherapy*" as secondary diagnosis for all but one treatment. Cancer was listed amongst the causes of the current episode in one of four patients (30/115 treatments). Since none of the patients were known to have active cancer at the time of HBOT this was inappropriate. The most appropriate cancer-related diagnosis, Z85.8 "*Personal history of malignant neoplasms*", was not used in any case.

ORN prevention

Various primary codes were used in this diagnostic category, reflecting the difficulty in knowing how to classify prophylactic treatments, as ORN does not actually exist at the time of HBOT. The likely most appropriate code, Z51.4 "*Preparatory care for subsequent treatment*" was used in only 10/130 treatments (one of seven patients). Inappropriate codes included: (a) C02.9 "*Malignant neoplasm of tongue, unspecified*" in 29/130 treatments (one patient), as the individual was cancer-free at that stage and, with no mention of radiation elsewhere in the coding, it appeared we were treating cancer with HBOT. (b) K10.2 "*Inflammatory conditions of jaws*" in 33/130 treatments (two patients), despite the absence of ORN at that time; (c) T66 "*Unspecified effects of radiation, radiation sickness*" in 29/130 treatments (two patients) was likewise inappropriate because it refers to radiation sickness – a specific acute syndrome not present in this type of patient; and (d) Z29.8 "*Other specified prophylactic measures*" in 29/130 treatments (one patient), which appeared initially to be potentially appropriate until it was realised that this code refers to fluoridation for dental health purposes.

There was no mention of malignancy (active or historical) amongst the diagnoses in 90/130 treatments (69%). Likewise, radiation was not mentioned in 57/130 treatments (44%). The most appropriate diagnoses (Z85.8 "*Personal history of malignant neoplasms*" + Z92.3 "*Personal history of irradiation*") were used in only the Z51.4 individual (10/130 treatments), but the simultaneous use of C00.9 "*Malignant neoplasm of lip, unspecified*" (despite the patient being cured some time previously) potentially confused the link between diagnoses and procedures.

Carbon monoxide poisoning

All patients (four) in this non-Medicare-funded diagnostic category were coded accurately as T58 "*Toxic effects of carbon monoxide, from all sources*".

Miscellaneous indications

The diversity of other 'off-label' indications for HBOT (nine patients, 112 treatments) precludes comment generally. However, a patient primarily coded as C20 "*Malignant neoplasm of rectum*", who incidentally developed central retinal artery occlusion (CRAO) secondary to atrial fibrillation during hospitalization, would appear in the coding data to have received HBOT for cancer since CRAO is not currently a Medicare-funded indication.

Assessment of the appropriateness of the *ICD-10-AM* diagnosis coding for refractory non-diabetic hypoxic wounds and refractory STRI (both approved for Medicare funding from 2004 under a new *MBS* item number, 13015)[3,4,6] was problematic because of the wide range of primary diagnoses that could lead to presentation. Confounding the issue further was confusion arising from the subtly different rules governing the *MBS* and *ACHI* procedure coding systems (Tables 1A and 1B). The greatest error rates in procedure coding were encountered in these two groups, reflecting this confusion. Eighty-one percent (499/614) of NDHW treatments were coded as 13020-00 and 11% (66/614) as 96191-00, whilst 67% (333/499) of STRI treatments were coded as 13020-00 and 25% (125/499) as 96191-00 (see below: GENERAL CODING ERRORS).

Refractory non-diabetic hypoxic wounds

No non-healing wound/ulcer was mentioned amongst diagnosis codes in 78/584 (13%) of coded treatments. It therefore appeared that HBOT was utilized to treat T88.8 "*Other specified complications of surgical and medical care, not elsewhere classified*", which excludes wounds (classified elsewhere) (15/78); M86.96 "*Unspecified osteomyelitis, lower leg*" (31/78), and T81.41 "*Wound infection following a procedure*" (32/78). This last case used the original hospital diagnosis (infected left total hip replacement) throughout multiple hyperbaric day-case admissions for a separate problem (a non-infected, demonstrably hypoxic, non-healing split-skin graft donor site).

Refractory soft-tissue radiation injury

No radiation-specific diagnoses were recorded in 72/475 (15%) of coded treatments. Wide variation was encountered in primary diagnosis coding, reflecting both the ability of cancer to occur anywhere throughout the body and the potential for radiotherapy to cause a range of injuries to both involved and neighbouring structures. Persistent use of the primary (cancer) diagnosis, even after the cancer was cured, with no mention of radiotherapy or its complications, led to 9/475 (2%) of HBOT in this group appearing to have been administered for cancer. Eleven percent of HBOT sessions (50/475, one patient) appeared to have been given to treat delayed complications of HBOT itself. This unusual circumstance appears to have arisen from an initial inappropriate code (Y84.8 "*Other medical procedures as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure, Hyperbaric oxygen therapy*", used instead of Y84.2 "*Other medical procedures as the cause of abnormal …, Radiological procedure and radiotherapy*") being perpetuated through multiple presentations, with no mention of radiation anywhere in the coding. Six percent (27/475) of treatments were inappropriately coded as being administered for T66 "*Unspecified effects of radiation, radiation sickness*". Radiation sickness is a potentially lethal acute syndrome of radiation poisoning not applicable to refractory STRI patients. Furthermore, the *ICD-10-AM* manual specifically excludes this patient's condition (L55-L59 "*Radiation-related disorders of the skin and subcutaneous tissue*") from inclusion under code T66.

GENERAL CODING ERRORS

A number of other issues, unrelated to the difficulties encountered allocating appropriate diagnosis and procedure codes described so far, were also identified.

Default coding

Thirteen per cent of coded treatments (209/1,603) were coded as < 90 min duration, only one of which (0.5%) was correct (Table 3). Discussions with our coding department revealed that, if clinical coders were unable to determine the duration of a given hyperbaric treatment, the shortest duration code (96191-00) was utilized as the default (Reynolds K, personal communication, 2016).

Cut-and-paste

A large proportion of the diagnosis and procedure codes entered for each patient were identical, or nearly so, across multiple admissions for that individual. This was to be expected given that they were receiving multiple HBOT sessions for one specific condition. However the presence of identical typographical errors carried through free-text fields in multiple episodes of care for several patients (e.g., "*RENALF AILURE*" appearing 12 times across three patients) appeared to indicate that a 'cut-and-paste' technique was sometimes adopted. Whilst understandable, given the repetitive nature of coding these individuals, this would permit initial coding errors to be carried forward, multiplying their detrimental effect on data quality.

Random assignment

Despite the potential cut-and-paste approach described above, not all patients were coded consistently throughout their course of treatment. The coding of identical hyperbaric treatments sometimes changed part-way through a course. Eight patients (249 treatments) had their HBOT variably coded as being > or ≤ 90 min (118/249 as 13020-00; 131/249 as 96191-00), whilst two patients (51 treatments) had their HBOT variably coded as > or ≤ 3 h (21/51 as 13025-00; 30/51 as 13020-00). All these episodes were routine, 115 min, 243 kPa HBOT exposures (14:90:20 table), documented in a consistent manner throughout the medical record. The apparently random assignment of treatment duration codes within an individual appeared due to a change in the coder responsible, and reflected their variable familiarity with hyperbaric treatment tables.

Missing patients

Six patients were entirely missing from the official hospital HBOT coding. One CO poisoning was missing all three treatments as an inpatient, together with all intensive care (ICU) procedure codes, and was simply coded as receiving 95550-03 "*Allied health intervention, physiotherapy*". One STRI who aborted after 76 min on his first dive (oxygen toxicity seizure at 243 kPa), and did not return for further HBOT, was missed. One DCI (two day-case treatments) had no coding record of any episodes of hospital care that year. One AGE patient who aborted treatment after 10 min (unable to clear ears) was missed. Two NDHW patients were also missed: one missing all 19 treatments whilst an inpatient and one following a single treatment aborted after 10 min (claustrophobia from oxygen hood).

Missing treatments

Thirty-three patients had incomplete coding of their HBOT course, the majority of which were related to inpatient admission. Twenty-six patients underwent 28 hospital admissions during which they received HBOT. Only 21/28 of those admissions coded any HBOT as happening and, of those 21 admissions, none coded more than a single HBOT episode. Inpatient treatments made up 8% (136/1,734) of HBOT treatments but only 15% (21/136) of those were coded. Of the missing day-case treatments, one dialysis-dependent patient who combined hospital visits for dialysis and HBOT had only one procedure coded (haemodialysis), when both were provided, on five occasions. Non-standard HBOT exposures (e.g., trial-of-pressure and aborted treatments) accounted for the majority of the remainder.

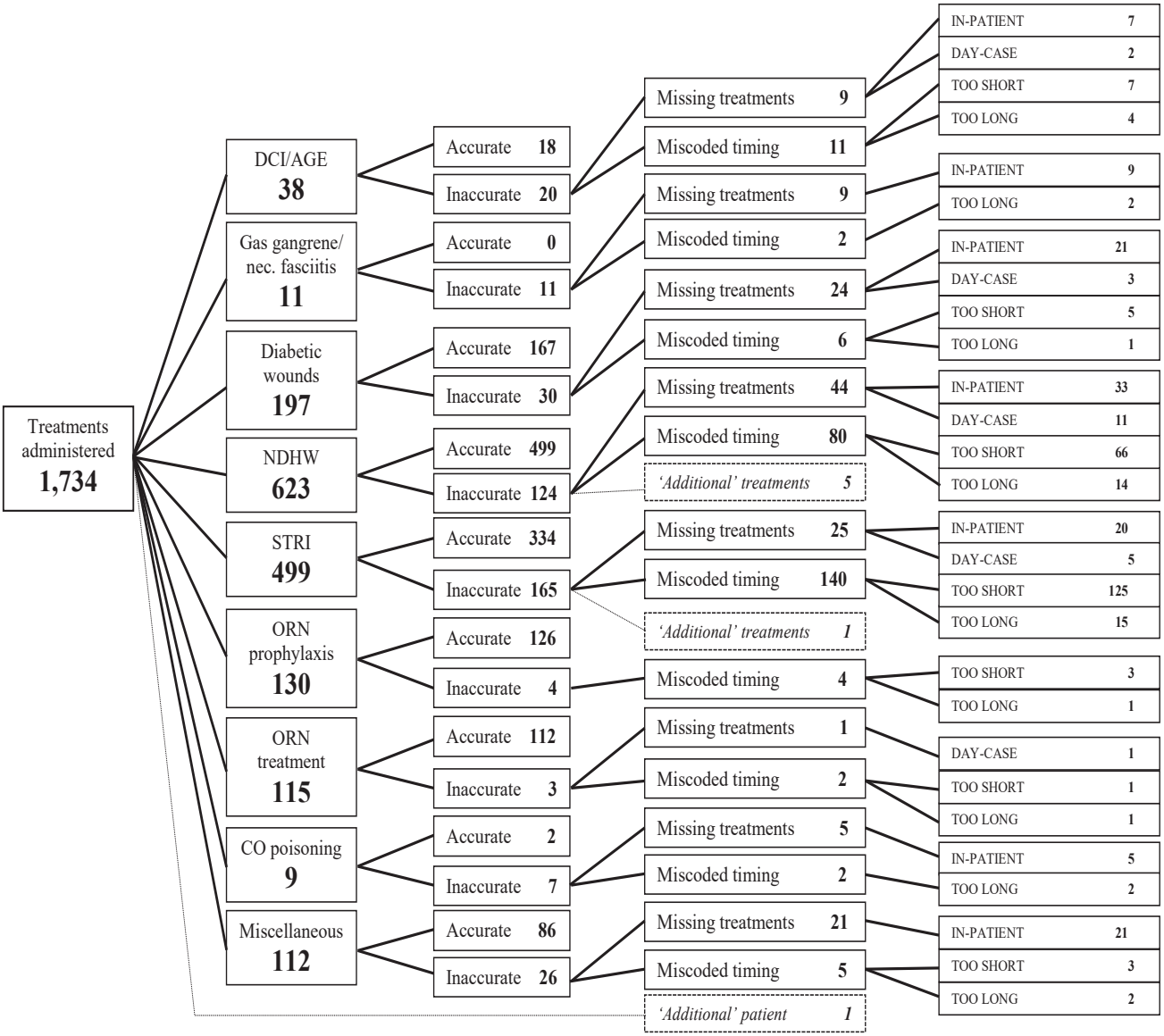
Extra treatments

Six 'additional' treatments were identified amongst patients receiving HBOT. No reason was apparent in two cases, one of which coded an 'additional' treatment day and the other coded two treatments with different procedure codes (13020-00 and 96191-00) during the same day-admission. One patient presented for a scheduled treatment but HBOT did not proceed as they were unwell on the day. Another had a separate admission for non-HBOT reasons part way through their course, which was coded as including HBOT when it did not. One patient with a subsequent overnight admission (for a medically unrelated condition), after having received HBOT as a day-case earlier that day, had the same treatment coded twice. The sixth case arose from confusion between two patients with similar names, as the random appearance of one patient (five months after discharge) coincided with a 'missing' treatment for the other in the middle of their HBOT course. In light of their different hospital record numbers this remains difficult to explain.

Extra patient

One 'additional' patient was coded as receiving HBOT. This individual received HBOT the next financial (but same calendar) year for head-and-neck STRI. On the date they were incorrectly coded as receiving HBOT, however, they actually underwent excision biopsy of a tonsillar lesion, and had yet to be referred for HBOT. Of note was the complete absence of coding for the surgical procedure (41849-00)

Figure 1
Procedure coding errors by diagnostic category



or associated anaesthetic (92514-29), despite the patient being recorded as admitted to the peri-operative unit under an otolaryngologist that day.

Inpatient coding uncertainty

The rules governing inpatient hyperbaric coding nationally were only clarified on 15 March 2016.[13] Prior to this it was unclear whether inpatient HBOT should be coded as a cumulative intervention (cf. 95550-00 "*Allied health intervention, physiotherapy*" – a single entry irrespective of the number of attendances) or as multiple discrete episodes during a single admission (cf. 44338-00 "*Amputation of toe*" – which was coded five times in a single admission for one diabetic patient). Although the system software would permit multiple sessions to be coded on the same day (as demonstrated by the presence of 'additional' treatments in two patients described above), no inpatient admission had more than a single HBOT session coded. A 'cumulative' approach to inpatient coding would, therefore, have been expected. Despite this, in all the 18 inpatient admissions where more than one HBOT session of > 90 min duration was administered, only seven admissions (24 treatments) coded HBOT as occurring for a total duration > 3 h (13025-00). Eight admissions (52 treatments) coded between 90 min and ≤ 3 h of HBOT (13020-00) and 3 admissions (29 treatments) coded ≤ 90 min of HBOT (96191-00).

Non-HBOT coding problems

Incidental observations of non-hyperbaric coding in this group of patients suggest that problems are not confined to hyperbaric medicine. Of five patients whose inpatient stay included mechanical ventilation in ICU, one was missing all procedure coding (ICU and HBOT) except 95550-00 "*Allied health intervention, physiotherapy*", despite a four

day ICU stay involving 49 h of mechanical ventilation and three HBOT sessions. Of the other four patients, one had the duration of ventilation miscoded (110 h coded as 13882-01 "*Management of continuous ventilatory support, > 24 and < 96 hours*"). The omission of all surgical and anaesthetic codes for the 'additional' patient described above also suggests that coding inconsistencies may be widespread.

Discussion

In Australia, all medical procedures approved for government funding are assigned an 'item number' and listed (together with explanatory notes and constraints upon their use) in the Commonwealth's *Medicare Benefits Schedule Book*, updated annually.[3–5] Specific *MBS*-funded hyperbaric item numbers are constrained by patient diagnosis, HBOT duration, and the presence or absence of a doctor in-chamber (Table 1B). For hospital coding purposes, however, a different system is used – the *Australian Classification of Health Interventions* (*ACHI*). Although the *ACHI* classification is based upon the *MBS*, a two-digit suffix has been attached to each *MBS* item number to represent individual procedural concepts (e.g., 13020-00), and interventions which are not represented in the *MBS* are allocated a code number in the 90000 series.[12] Several other (sometimes subtle) differences are also present in the rules governing the application of these codes. Thus, whilst *MBS* hyperbaric items are constrained by duration/diagnosis/doctor-involvement, application of the comparable *ACHI* codes is dependent solely on duration and is irrespective of the condition being treated (Tables 1A and 1B).[13] For example, *MBS* Item 13020 specifically precludes the provision of HBOT under that item number for NDHW and STRI (covered separately by item number 13015) (Table 1B),[6,14] however, the *ACHI* provides no option but to code these treatments as 13020-00 if they are of the requisite duration (1 h 30 min to 3 h).[12] Failure to appreciate these differences may lead to difficulty interpreting the respective datasets, and cause all patients with these two conditions to appear as being treated or coded inappropriately.

Miscoding of procedure duration and omission of inpatient HBOT sessions were the most common problems across all diagnostic groups (Figure 1). The high coding error rates for the NDHW and STRI groups reflect the confusion described above. This issue could potentially be resolved by amending the two-digit suffix on the *ACHI* 13020-00 procedure code to reflect provision of 90 min to 3 h duration HBOT for non-*MBS*-13020-approved diagnoses (e.g., those covered under *MBS* item 13015). Individual procedural concepts of this nature are what the suffix is designed to account for but, despite *MBS* Item 13015 having been in use since 2004 and the *ACHI* claiming to represent "*the latest in contemporary thinking of clinicians, classification experts, epidemiologists and statisticians from both public and private sectors*", no such modification has yet been forthcoming.[12]

Issues such as these are unlikely to be unique to this institution. The same coding standards apply nationally, and Tasmanian coders are trained to a standard comparable to that of their interstate counterparts. A review of HBOT coding at a major interstate facility revealed a 25% error rate at that institution in that same year.[7] Whilst this paper illustrates that current hospital coding data are not fit for purpose, other reasons for the discrepancy in HBOT use between Tasmania and elsewhere must be sought.[8,15] Regional variation in HBOT provision has been discussed previously and several potential contributory factors have been identified.[15] Although beyond the scope of this paper, disease prevalence, chamber logistics, health service administrative systems, local geography and population distribution relative to the regional hyperbaric facility have all been implicated. It has been suggested that, rather than demonstrating inappropriate over-utilization in high treatment-rate locations, this variation is potentially indicative of unmet need in lower treatment-rate regions.[15]

IMPLICATIONS FOR THE GRATTAN REPORT

The appearance that HBOT was provided for 'do-not-do' indications in the Grattan Report could arise from either (a) incorrect inclusions or omissions in the Grattan Institute's 'do-not-do' or 'potentially legitimate' diagnosis or procedure lists, or (b) incorrect inclusions or omissions in the diagnosis or procedure codes submitted to AIHW by the hospital.

The erroneous inclusion of NDHW and STRI amongst the Grattan authors' 'do-not-do' indications for HBOT would have resulted in 45 patients (1,059 coded treatments, six of which did not actually occur) treated at this institution in FY2010–11 being misclassified as 'inappropriate'. A major methodological flaw in the Grattan Report (inability to derive data on a per-patient basis) would, however, multiply this error and lead those authors to conclude that 1,059 separate patients received HBOT here inappropriately.[1,2]

Irrespective of this, and the numerous other methodological deficiencies identified in the Grattan Report,[8] coding errors have clearly compromised their primary data-source (AIHW) beyond repair. The omission of diabetes-related codes in three diabetic wound patients (80 treatments) added a further 80 'inappropriate' 'patients' to our tally using Grattan methodology, whilst one STRI patient (three treatments) with no mention of their intercurrent diabetes (an alternative, 'potentially appropriate' diagnosis) in their coding, added another three 'patients'. Finally, the inclusion of malignancy amongst the active diagnosis codes (even after clinical cure), in the absence of a radiation-related or other appropriate *MBS*-funded diagnosis code, led to three patients (39 treatments) appearing erroneously to be treated for cancer, adding yet another 39 'patients'.

Conclusions

The AIHW dataset appears to be irretrievably compromised and not fit for purpose. The presence of coding errors in 70%

of our cohort invalidates any conclusions drawn from such data. Attempting to inform the healthcare policy debate by reference to such datasets is inappropriate and will inevitably lead to poorer outcomes for patients. A more rigorous approach to the validation of such databases is required if they are to serve any genuinely useful function.

Most clinicians would be unaware that *Australian Coding Standards* categorically state that "*(t)he responsibility for recording accurate diagnoses and procedures, in particular principal diagnosis, lies with the clinician, not the clinical coder*".[12] Therefore, we are held accountable for work performed by people over whom we have no authority or routine oversight. Engagement by clinicians with their hospital's coding department is, therefore, essential to develop strategies to facilitate extraction of accurate data from future patients' medical records.

It is ironic that clinicians who wish to introduce new therapies to the *MBS,* or even retain funding for existing interventions, are obliged to support their case with the highest-quality Level 1 clinical evidence, whilst non-clinicians pursuing a purely economic agenda can promote disinvestment in healthcare on the basis of contaminated data such as this. The medical profession has an obligation to challenge this blatant double standard.

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Declaration of interests

PDC and DRS are medical co-directors of the Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, Tasmania. DRS is also the current president of the South Pacific Underwater Medicine Society and has previously participated in the Commonwealth's MSAC reviews 1054 (2003) and 1054.1 (2011).

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Review articles

Scuba diving and otology: a systematic review with recommendations on diagnosis, treatment and post-operative care

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Abstract

(Livingstone DM, Smith KA, Lange B. Scuba diving and otology: a systematic review with recommendations on diagnosis, treatment and post-operative care. *Diving and Hyperbaric Medicine*. 2017 June;47(2):97-109.)
Scuba diving is a popular recreational and professional activity with inherent risks. Complications related to barotrauma and decompression illness can pose significant morbidity to a diver's hearing and balance systems. The majority of dive-related injuries affect the head and neck, particularly the outer, middle and inner ear. Given the high incidence of otologic complications from diving, an evidence-based approach to the diagnosis and treatment of otic pathology is a necessity. We performed a systematic and comprehensive literature review including the pathophysiology, diagnosis, and treatment of otologic pathology related to diving. This included inner, middle, and outer ear anatomic subsites, as well as facial nerve complications, *mal de debarquement* syndrome, sea sickness and fitness to dive recommendations following otologic surgery. Sixty-two papers on diving and otologic pathology were included in the final analysis. We created a set of succinct evidence-based recommendations on each topic that should inform clinical decisions by otolaryngologists, dive medicine specialists and primary care providers when faced with diving-related patient pathology.

Key words
Head and neck; ENT; Injuries; Medical conditions and problems; Barotrauma; Decompression sickness; Review article

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Introduction

Over the past half century there has been a dramatic increase in the number of recreational scuba divers, with over nine million certified in the United States in 2015 and approximately 100,000 new divers per year.[1] While scuba diving is commonly viewed as a safe recreational activity, it exposes the participant to real risks of injury or even death. More than 80% of all diving complications occur in the head and neck.[2] Of these, approximately 65% are outer, middle or inner ear disorders.[3] It is essential that clinicians understand the physiology and physics of scuba diving as well as the diagnosis, treatment and prevention of diving-related complications. However, there are currently few evidence-based recommendations or systematic reviews on this topic. The purpose of this report is to systematically review the current literature evaluating scuba diving physiology and complications pertinent to otology, and to provide a comprehensive resource with evidence-based recommendations where possible.

Two important scuba diving injuries are barotrauma and decompression sickness (DCS). To understand their pathophysiology, clinicians must understand the physics laws governing these injuries: Boyle's Law and Henry's Law.

BAROTRAUMA AND BOYLE'S LAW

Barotrauma is a pressure-mediated injury to tissue governed by Boyle's law. As a diver descends and the pressure increases, the volume of the gas compresses. This can result in a relative negative pressure in rigid- or semi-rigid-walled air-containing spaces in the body such as the middle ear or paranasal sinuses. Negative pressure can cause mucosal oedema, haemorrhage and even perforation if the space cannot equalize. On ascent, the volume of gas increases as the ambient pressure decreases. If an air-containing space cannot equalize with the surrounding pressure, the expanding volume of the gas may result in a variety of head and neck pathologies, including middle ear perforation or pneumocephalus from sinus barotrauma.[4]

DECOMPRESSION SICKNESS AND HENRY'S LAW

As a diver descends and ambient pressure increases, progressively higher pressure gas is delivered to the lung and more inert gas dissolves in the blood stream. The amount of inert gas that dissolves in a given tissue is proportional to the maximum depth and bottom time, as well as the perfusion and diffusion characteristics of that tissue. As a diver ascends, the additional inert gas load comes out of

solution at the level of the alveolus and is exhaled. If the rate of ascent exceeds the rate of alveolar gas exchange, inert gas will dissolute inside the diver, forming bubbles within the circulation and in tissues. The severity and nature of the DCS injury vary from mild systemic, musculoskeletal and cutaneous manifestations to severe, life-threatening central nervous and cardiorespiratory symptoms.

Literature search

A systematic search of the literature was performed using the following databases: Ovid/Medline, PubMed, EMBASE, UpToDate, Rubicon Repository and Cochrane Review Database up to January 2017. A screening literature search was used to identify all literature discussing scuba diving and any otolaryngology topics. Search terms included: "*scuba*" and/or "*diving*", and "*head and neck*", "*otolaryngolog**", "*otolog**" "*rhinolog**", "*sinus surgery*" or "*laryngolog**". Reference lists of identified publications were reviewed to ensure no relevant studies in this field were missed. Grey literature, including the Diver's Alert Network online resources, was also queried for completeness. Inclusion criteria included any paper discussing scuba diving and otology at any level of evidence (LOE). Exclusion criteria included papers that were not available in English or in an English translation. Given the limited amount of literature available, all studies meeting these inclusion criteria were included for completeness.

The combined search resulted in identification of 398 abstracts to be reviewed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[5] Screening resulted in 285 abstracts being excluded owing to duplications, leaving 113 abstracts to be reviewed. In assessing eligibility, 19 abstracts were excluded as they were not available in full text or in English, two because the topic did not include scuba diving, 20 as they did not discuss otology as it relates to diving and 23 as they solely discussed rhinology and oromaxillofacial topics. This left a total of 49 articles that met the criteria of including both scuba diving and otology topics. The works cited section of these articles were reviewed and 13 additional studies were also identified for review.

Included studies were evaluated and their LOE was noted based on a reported research methodology utilized by the Oxford Centre for Evidence Based Medicine (CEBM).[6] After quality evaluation for each study, a summary was produced that included the aggregate grade of evidence and relevant recommendations. When there was only a single study available, an aggregate grade of evidence was not provided as grades are derived from the findings of multiple studies. Two authors (DML and KAS) reviewed the literature and produced the initial manuscript. A subsequent author (BL) was asked to review and critically appraise the recommendations based on the literature. Recommendations incorporate both the quality of evidence and the balance of benefit versus harm.

After additional review and synthesis of all information, a total of 74 articles were included in the study. There were no systematic reviews or meta-analyses found. The highest levels of evidence came from randomized controlled trials (Level 1b). The Appendix contains a summary of the 44 relevant papers that constituted primary literature related to otology and scuba diving. Eighteen papers were relevant but were either reviews, grey literature or individual case reports, and thus not included in the Appendix. The references section also contains 12 papers that did not specifically mention diving, but were relevant to the method used or contextualizing the relevant literature.

External ear

OTITIS EXTERNA

Otitis externa (OE) is the most common otologic disorder among divers, afflicting nearly half of all active divers on at least one occasion.[7] *Pseudomonas aeruginosa* is the most common micro-organism responsible.[8] Treatment is no different among divers versus non-divers and should consist of dry ear precautions, topical antimicrobial therapy (e.g., Ciprodex: three drops to affected ear BID x 7 days) and serial debridement of the external auditory canal. Divers should be counselled on the prevalence of this condition and may consider bringing antimicrobial drops on remote diving trips. Ethanol or acetic acid otic drops may be useful to prevent OE by drying the canal post-dive, and can be considered in divers prone to this condition.[4]

Recommendations (LOE)

- Divers should be counselled on the high prevalence of OE (5);
- Suggest bringing topical therapy on remote trips (5);
- Treatment similar to non-diving related OE (5).

EXOSTOSES

Exostoses are bony outgrowths of the external auditory canal (EAC) that typically occur bilaterally in scuba divers.[9] They are very common, with a prevalence of up to 40% among professional divers,[8] in comparison to about 6% among the general population living in coastal regions.[10] Exostoses can lead to recurrent otitis externa, recurrent otorrhoea, cerumen impaction and conductive hearing loss from canal obstruction.[8–10] If the canal is completely occluded, an asymmetrical caloric stimulus with vertigo can occur upon submersion.[4] Divers with symptomatic exostoses should seek evaluation by an experienced otolaryngologist for consideration of canalplasty.[9] Surgical indications for removal are identical to non-divers, with the caveat that they are very likely to experience progression of their exostoses due to further water exposure, and are at higher risk of OE.[7,9] Exostoses should not affect fitness to dive unless they are occluding the canal or causing recurrent infections.[11]

Recommendations (LOE)

- Exostoses can lead to recurrent otitis externa, recurrent otorrhoea, cerumen impaction and conductive hearing loss (4);
- Divers with symptomatic exostoses should seek evaluation by an experienced otolaryngologist for consideration of canalplasty (5);
- Exostoses should not affect fitness to dive unless they are symptomatic (5).

EXTERNAL AUDITORY CANAL BAROTRAUMA

External auditory canal barotrauma can also occur in the setting of occlusion due to cerumen impaction, foreign body, or a tight fitting wetsuit or drysuit hood. Severe exostoses can also cause cerumen impaction and lead to an isolated air space within the external auditory canal. Regardless of the aetiology of the predisposing canal occlusion, a relative vacuum is created on descent causing oedema and haemorrhagic vesiculation of the canal.[12] Treatment of EAC barotrauma consists of a short course of topical analgesic or steroid ear drops, and is similar to the treatment of OE.[13] The aetiology of canal barotrauma should be understood by the clinician and diver to prevent the occurrence of subsequent episodes.

Recommendations (LOE)

- Treat with debridement and a short course of topical steroid/antibiotic (5);
- Refrain from diving until resolved (5);
- Treatment similar to OE (5);
- Identify and mitigate inciting aetiology of EAC barotrauma (5).

Middle ear

MIDDLE EAR BAROTRAUMA AND IMPAIRED EQUALIZATION

Middle ear barotrauma (MEBt) occurs when there is dysequilibrium between the middle ear and ambient pressure, and accounts for up to 46% of patient presentations for diving-related head and neck pathology.[14] During descent, middle ear pressure becomes progressively less than ambient pressure and the Eustachian tube (ET) must open to equilibrate these pressures. If the diver is unable to equalize and continues to descend beyond 1.4 metres depth, a pressure differential of greater than 90 mmHg is created, irreversibly blocking the ET.[12] The persistent negative pressure in the middle ear space can lead to extravasation of fluid and haemorrhage into the middle ear and tympanic membrane (TM) perforation. The resulting middle ear transudation and tubal oedema can impair middle ear ventilation on ascent, leading to a progression of barotrauma.[15] MEBt with TM rupture can also occur during uncontrolled ascent, and is associated with pulmonary barotrauma if a diver ascends with a closed glottis.[16]

MEBt is not always associated with inner ear sequelae. In a cohort of 67 professional divers, recurrent MEBt was not associated with sensorineural hearing loss.[17] Risk factors for MEBt include poor ET function and poor mastoid pneumatization.[18,19] In patients with tubal tonsillar hypertrophy and inability to equalize on descent, there may be a role for tuboplasty operations, including laser tuboplasty. In a series of nine divers, improved middle ear equalization was demonstrated postoperatively with seven being able to return to diving long-term.[20]

Equalization of the middle ear space through the ET is active on descent, and passive on ascent. Importantly, equalization manoeuvre effectiveness is impacted by the diver's head position relative to their body. Clearing capacity is maximized in head-up positioning.[21] Head-down position impairs passive equalization and should be avoided during descent.[22] Multiple manoeuvres exist to assist pressure equalization of the middle ear space, including Valsalva, Frenzel, Toynbee, Lowry, Edmonds and voluntary tubal opening (French: *béance tubaire volontaire* – BTV) techniques. A forced Valsalva can be injurious to the inner ear, and the BTV manoeuvre is considered the least traumatic method.[12] A patient who can perform BTV is able to voluntarily contract their tensor veli palatine muscle and can often maintain ET patency on command. The Fédération Française d'Études et de Sports Sous-Marins has created a series of exercises to facilitate learning BTV. Divers with difficulty with equalization should descend at a slow rate and attempt to equalize pressure with every breath.

Importantly, diving at shallow depth is not useful to prevent MEBt as the greatest change in volume occurs near the water's surface; TM implosion can occur at depths as shallow as 1.2 m.[12] Rupture of the TM can lead to caloric stimulation of the vestibular apparatus, vertigo and disorientation underwater. This can be a highly dangerous scenario if it leads to a diver panicking.

Recommendations (LOE)

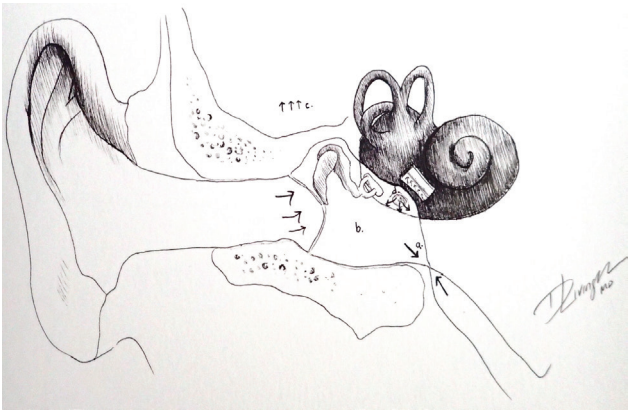
- Avoid head down position on ascent/descent (3b);
- Do not descend if unable to equalize, do not utilise the forced Valsalva (5);
- Ideally, utilize the BTV technique for equalisation (5);
- Optimise ET function and equalization technique (2b);
- Formal testing of ET function can be considered (5);
- Tuboplasty techniques may be helpful in specific ET dysfunction cases (4).

ALTERNOBARIC VERTIGO

Alternobaric vertigo (AV) is thought to arise from asymmetrical equalization of middle ear pressure transmitted

Figure 1
Implosive mechanism of inner ear barotrauma and perilymphatic fistula: a successful forced Valsalva manoeuvre (a) communicates excessive pressure to the middle ear space, distending the tympanic membrane, causing implosion of the round window (b) and subluxation of the stapes footplate (c)

Figure 2
Explosive mechanism of inner ear barotrauma and perilymphatic fistula; a failed forced Valsalva manoeuvre due to a blocked Eustachian tube (a) in the setting of a relative vacuum within the middle ear space (b) causes elevation of CSF pressure (c); this increased pressure is communicated to the inner ear, resulting in round window rupture (d) and intracochlear hemorrhage.



via the oval and round window membranes. AV is the most common cause of transient vertigo while diving,[17] typically during ascent.[4] Vertigo can last for several minutes and is often accompanied by nausea, vomiting and disorientation.[23] Caloric effects on the vestibular system can also cause transient vertigo and are pathophysiologically distinct from the dysequilibrium associated with nitrogen narcosis. ET dysfunction is a significant risk factor for the development of AV, and is considered an independent risk factor for experiencing an adverse event or accident while diving.[24] However, divers with AV were not at increased risk of experiencing a life-threatening or critical event while diving among a cohort of 63 recreational divers or 64 professional divers.[23,24]

Risk factors for AV other than ET dysfunction include previous barotrauma, noise exposure during diving, cold water diving, a history of otitis media, a history of previous episodes of AV and female gender.[23,25,26] AV is approximately four times more prevalent in females than in males.[23] Patients should be counselled on the aetiology and nature of AV as well as the potential risks of this condition, including aspiration and death. If a diver can tolerate the transient vertigo and pause their controlled ascent or descent until their vertigo resolves, the risk to the diver is minimized. Transient vertigo of any aetiology during technical or commercial diving portends a significantly higher risk of disorientation, accidental regulator dislodgement, scuba apparatus damage and asphyxiation.

Recommendations (LOE)

- Divers must understand the risks of disorientation, accidental regulator dislodgment, scuba apparatus damage and asphyxiation due to attacks of AV (2b);
- Recommend ET function optimization to minimize AV symptoms (5).

Inner ear

INNER EAR BAROTRAUMA

Inner ear barotrauma (IEBt) occurs when pressure changes within the middle ear are transmitted to the cochlea through the round and oval windows, and can occur through either implosive or explosive mechanisms (Figures 1 and 2). The oval window is somewhat more protected from pressure changes compared to the round window due to the added stability of the stapes footplate and associated ligamentous attachments. The stapes footplate can, however, be forcefully displaced by divers that employ forced Valsalva methods for middle ear equalization during descent. High pressure air is forced into the middle ear space, causing rapid outward displacement of the stapes and inward displacement and implosion of the delicate round window membrane (Figure 1). The pressure wave generated by this manoeuvre can cause cochlear haemorrhage with disruption of Reissner's membrane and the basilar membrane. Perilymphatic fistula (PLF) can also occur due to tearing of the round window membrane via an explosive mechanism of IEBt. Rapid fluctuations in the CSF pressure can be communicated to the perilymphatic space via the cochlear aqueduct or the lamina cribosa. A failed Valsalva attempt in the setting of ET dysfunction may elevate CSF pressure causing round window membrane rupture (Figure 2). Early studies and grey literature on diving noted an association between hearing loss and diving, even in the absence of IEBt. Importantly, high frequency sensorineural hearing loss is common among commercial divers, but is likely a noise-induced phenomenon from the use of underwater machinery.[27] High activity sport

divers do not experience any increased risk of SNHL.[28,29]

Certain anatomic risk factors may predispose divers to IEBt. Patients may have an enlarged cochlear aqueduct orifice that can more readily transmit elevated CSF pressures to the delicate structures of the membranous labyrinth.[30] This may also be a consideration among paediatric divers who have a shorter cochlear aqueduct that can more easily transmit pressure fluctuations within the subarachnoid space.[31] The approximate length of the cochlear aqueduct in a newborn is 3.5 mm and undergoes postnatal lengthening to 10 mm in an adult.[32] The additional pressure may also cause rupture of Reissner's or the basilar membrane, leading to admixture of perilymph and endolymph.[33] Other anatomic risk factors for PLF are the potential communication between the inner and middle ear through the *fissula ante fenestrum* and enlarged vestibular aqueducts.[30,34]

Diagnosis of IEBt can be difficult, with vague and variable symptom onset. Vestibular dysfunction and/or hearing impairment as a consequence of IEBt can occur on descent owing to impaired equalization, on ascent from expanding pneumolabyrinth, or even on non-diving days while straining or lifting.[35] The symptomatology and severity are dependent on the specific anatomical subsite affected; isolated basilar membrane tears can present with sensineural hearing loss (SNHL) as the only presenting complaint.[36] Typically, patients present with a combination of vestibular and hearing deficits, and may complain of aural fullness, tinnitus and hyperacusis.[33] IEBt must be distinguished from inner-ear DCS, though these diagnoses are not mutually exclusive. A dangerous or atypical dive profile, diving using mixed gases or other symptoms of DCS elevates the likelihood of inner-ear DCS. Importantly, IEBt can occur in the absence of otoscopic findings of barotrauma, with a normal tympanic membrane and EAC.[37,38] Clinical suspicion must remain high in these circumstances; delay between dive and symptom onset does not exclude the diagnosis of IEBt.[37] The dive profile must be thoughtfully interpreted and can be used to inform clinical suspicion of IEBt and other otologic pathologies.[37, 39]

Treatment recommendations for IEBt include high-dose steroids (250 mg prednisolone for three days) with a taper for a total duration of therapy of 18 days, a recommendation based on expert opinion.[2] Surgical exploration is recommended when clinical suspicion of perilymphatic fistula is high, or the patient's hearing deteriorates despite appropriate conservative therapy. If a tympanotomy is undertaken, both the oval and round windows should be patched with fascia and absorbable surgical packing such as Surgifoam, even in the absence of active intraoperative perilymphatic leakage.[33] Intraoperative identification of a PLF can be facilitated using Trendelenburg positioning, or elevation of intrathoracic pressure in an intubated patient.[35] Conservative therapy for PLF should include bed rest, elevation of the head of the bed to 45^{o}, the use of stool softeners and avoidance of straining manoeuvres.[13] A high-resolution CT scan of the temporal bone should also be performed in all patients that experience IEBt to rule out any anatomic factors that may predispose the patient to future episodes.[30]

Patients should be counselled on the presence of anatomic risk factors that may influence their fitness to dive. Divers who suffer IEBt are often counselled to avoid diving. This recommendation may, however, be unnecessarily restrictive. A cohort of 21 patients who suffered IEBt and continued to dive against medical advice were counselled on middle-ear equalization techniques and methods to improve ET function. No further deterioration of inner-ear function was noted among these divers over a 1–12 year follow-up.[40] A recent comprehensive review identified five criteria for returning to diving following IEBt including stable hearing loss in a narrow frequency band, absence of vertigo/dysequilibrium, mitigation of risk factors for MEBt, no further anatomical risk factors present and no further surgical intervention required.[35]

Recommendations (LOE)

- Patients with IEBt should undergo initial observation and medical therapy (3b) including corticosteroids (5);
- Exploratory tympanotomy and round/oval window patching should be performed if there is clinical deterioration, or high suspicion for a PLF (3b);
- A high-resolution CT scan of the temporal bones should be done to rule out anatomic risk factors (4);
- ET dysfunction and risk factors for MEBt should be mitigated (5);
- A fitness-to-dive assessment and consultation should be performed by an otolaryngologist or dive medicine specialist before more diving is undertaken (5).

INNER EAR DECOMPRESSION SICKNESS

Inner-ear DCS occurs according to the principles outlined earlier with regard to Henry's Law. The vestibular portion of the labyrinth appears to be more prone to damage than the cochlea, a phenomenon that is likely related to tissue perfusion and washout of inert gas. The vestibular apparatus has a higher tissue volume to blood supply ratio in comparison to the cochlea, leading to higher rates of local supersaturation and arterial microbubble load.[41] Inner-ear DCS manifests with vertigo occurring within about two hours (h) of surfacing, with up to 40% of patients also experiencing some degree of hearing loss.[41] Haemorrhage and protein deposition in the membranous labyrinth can eventually develop into fibro-osseous labyrinthitis.[42] Inner-ear DCS can occur in isolation, or in combination with other CNS manifestations of DCS. Deep technical diving using He-O_2 and trimix breathing gases appears to confer a higher risk for inner-ear DCS.[33]

Treatment of inner-ear DCS includes recompression with hyperbaric oxygen treatment (HBOT) as soon as possible; if the latency to HBOT for inner-ear DCS exceeds 5 h, approximately 90% of divers can expect some degree of permanent inner ear damage.[43] An animal model study has shown that precipitated material within the perilymph can appear as early as 1.5 h in squirrel monkeys with experimentally induced inner-ear DCS.[42] Unfortunately the median time to treatment is often well in excess of these critical windows.[2] While waiting for HBOT, 100% oxygen should be administered during transport.[44] Adjunctive medical therapy can include steroids to reduce inflammatory oedema and low molecular weight dextran to improve microcirculation.[44] Doppler sonography should also be performed in these patients to rule out a cardiac or pulmonary right-to-left (R/L) shunt. Prevalence of a R/L shunt can be as high as 82% among inner-ear DCS patients compared with 25% in the normal population.[45] Patients with isolated R/L shunts may dive in accordance with 'low bubble diving' recommendations established by the Swiss Undersea Medical Society.[46] If the patient has suffered concurrent IEBt, emergent bilateral middle ear paracentesis or tympanostomy tube insertion followed by HBOT is recommended to prevent a worsening of symptoms.[2,47]

Recommendations (LOE)

- Patients with inner-ear DCS should receive emergent HBOT as soon as possible (3b);
- Medical adjuncts including corticosteroids can be considered (5);
- If there is concern regarding concurrent IEBt, bilateral myringotomies with equalization tubes should be performed (4);
- Once the inner-ear DCS is adequately treated, Doppler ultrasonography to rule out a R/L shunt should be performed (3b);
- The aetiology of the DCS should be considered and the patient must be counselled on preventative measures (5).

Facial nerve pathology

Facial nerve paralysis as a complication of scuba diving is a rare condition that is hypothesized to be a consequence of reduced axonal capillary blood flow in the setting of a defect in the bony covering of the tympanic segment of the facial nerve. Initially this process is caused by negative middle ear pressure due to the relative vacuum created by inadequate equalization.[48] Secondary post-ischaemic intraneural swelling from transudate or blood may perpetuate axonal compression and ischaemia.[15] Direct compression of the nerve can also occur due to trapped haemotympanum.[48] A bony defect of the tegmen, the bony separation between the cranial cavity and middle ear, can also result in pneumocephalus and associated intracranial complications.[49] Compressive neuropraxia may occur during ascent from expanding trapped gas within the middle ear space. Air can also enter a normal facial nerve canal and cause compression by tracking along the chorda tympani nerve.[50] The degree of facial nerve injury should be documented and followed closely for recovery. Oral corticosteroid therapy may be useful to minimize further neuropraxia secondary to intraneural swelling. Facial nerve decompression is generally not indicated although, similar to surgical decompression following temporal bone trauma, there is great institutional variability whether or not this procedure is performed. A simple myringotomy can be performed to evacuate any haemotympanum and relieve the middle ear over-pressure and consequent facial nerve compression.[48]

Recommendations (LOE)

- Corticosteroid therapy is recommended to minimize neuropraxia secondary to direct nerve compression (5);
- There is no consensus on the role of facial nerve decompression (5);
- Perform myringotomy to relieve middle ear over pressurization (4).

Sea sickness

Sea sickness, a type of motion sickness, occurs when there is a mismatch between vestibular, proprioceptive and visual inputs.[4] In diving, this typically occurs on a boat heading to a dive site, while a diver is attached to a shot line during decompression, or during a prolonged stay on a liveaboard diving vessel.[4,51] Divers are typically less susceptible to sea sickness once underwater, which can promote hasty and poorly executed water entries among those affected.[4] Almost everyone is susceptible to sea sickness, but tolerance can develop from episodic exposure and after two to three days of continuous open-ocean exposure.[4] Symptoms include a non-vertiginous sense of dysequilibrium, nausea, increased salivation, flushing, diaphoresis and general malaise.[52] Risk factors include female gender,[53] altered vestibular or visual sensory cues,[54] history of migraine[55] and hormonal effects of pregnancy and oral contraception.[52,56] Psychosocial factors also play a role; naval cadets were at lower risk of developing sea sickness when told they were unlikely to experience it.[57] Specific environmental modifications are useful for treatment and prevention of sea sickness. Lying supine while inside a ship may decrease susceptibility to motion sickness.[51] Standing on deck and staring at the horizon will lessen the degree of vestibular-visual mismatch and improves symptoms of sea sickness. Medications for treatment and prevention of sea sickness are typically antihistamines or anticholinergics. Ondansetron, a 5-HT antagonist, and droperidol, a dopamine antagonist, are typically less effective for motion sickness.[4] Scopolamine, an anticholinergic medication given trans-dermally every 72 h, has been the subject of three randomized, prospective double blind studies on motion sickness. It has been shown to be more effective in preventing motion sickness than

promethazine, meclizine, and lorazepam and has shown superiority over cinnarizine for sea sickness prevention in naval crew.[58,59] Caffeine may also be of benefit when combined with other anti-nauseants for motion sickness; caffeine plus promethazine was shown to be superior to scopolamine in preventing air sickness among helicopter passengers.[60] Importantly, scopolamine has not been shown to affect cognitive performance or manual dexterity in hyperbaric chamber dives.[61] Dimenhydrinate, however, has been shown to have significant cognitive side effects at therapeutic doses necessary to treat experimental motion sickness, and thus is likely unsuitable for diving.[62] In animal studies neither scopolamine nor cinnarizine increased the risk of CNS oxygen toxicity.[63,64]

Recommendations (LOE)

- Environmental modifications such as lying supine or visual fixation on the horizon should improve symptoms of sea sickness (4);
- Transdermal scopolamine q.72 h is superior to cinnarizine for prevention of sea sickness (1b), and superior to other anti-nauseant medications for motion sickness prevention (1b);
- Caffeine may be a useful adjunct for motion sickness medications; promethazine plus caffeine is more effective than scopolamine alone (1b);
- Caution should be exercised when diving while under the influence of any of these medications, and sedating medications should be avoided (5);
- Divers should not dive while nauseated due to the risk of vomiting underwater and subsequent asphyxiation (5).

Mal de debarquement

Mal de debarquement (MdDS) is the sensation of swaying or rocking movement with dysequilibrium that occurs in individuals upon returning to land after an extended period of time in a boat. Most patients have resolution of symptoms within minutes to days. Of 236 sailors, 73% experienced MdDS symptoms for up to 24 h (mean 2.6 h).[65] In some people, symptoms are persistent for months to years and are associated with significant fatigue, anxiety and cognitive impairment. Risk factors include female gender and previous history of seasickness.[47] Human and primate studies have implicated central maladaptation of the vestibulo-ocular reflex as a primary cause of MdDS.[66,67] Treatment for MdDS is generally considered to be ineffective, though recent work focusing on readaptation of the vestibulo-ocular reflex (VOR) has shown some promise. In one study, 24 subjects with persistent MdDS (mean duration 19.1 months) were treated by rolling the head side-to-side while being exposed to a full-field optokinetic stimulus in an attempt to readapt the VOR. Head roll frequency was matched with the subjective oscillations felt by the subjects, with direction of optic kinetic rotatory stimulus based on the Fukada stepping test or a patient's subjective sense of rotation. Seventeen subjects showed cure or substantial improvement at one-year follow-up. Other proposed therapies include vestibular rehabilitation, and use of long-acting benzodiazepines and tricyclic antidepressants.[68]

Recommendations (LOE)

- Novel techniques to alter a maladapted VOR in MdDS may prove to be useful (2b);
- Recommend trial of medical therapy, and vestibular physiotherapy as adjuncts to refractory cases (5).

Post-operative recommendations

TYMPANOSTOMY TUBES

When diving with tympanostomy tubes at sufficient depth or pressure, the surface tension of water at the tube orifice will be exceeded and water will enter the middle ear space. This can generate an asymmetrical caloric effect, leading to transient vertigo and dysequilibrium. There is also an increased risk of otitis media from water freely entering the middle ear leading to middle-ear sequelae and early tube extrusion. Patients should be counselled on these serious risks if they are considering diving with tympanostomy tubes, and may be considered unfit to dive. Some authors advocate use of one-way membrane (Castelli-type) tympanostomy tubes to prevent these sequelae.[12] A scuba diving mask that keeps water out of both ears, such as the ProEar 2000, may also be useful in this patient population.[12] The ProEar mask is built with a tube connecting the ear covers to the facial portion of the mask. This ensures that the air space within the EAC remains equal to ambient pressure, preventing EAC barotrauma.

TYMPANOPLASTY

The integrity of the TM while diving is closely related to its compliance. Sclerotic, immobile membranes may impair middle ear equalization, while a monomeric, hypermobile TM may be at higher risk for rupture during a forced Valsalva. Patients who have previously undergone tympanoplasty may also have impaired ET function at baseline and be at higher risk for associated barotrauma. Safety to return to diving should be considered on a case-by-case basis, and a trial of diving at depth in a controlled environment such as a swimming pool should be considered.[69]

STAPEDECTOMY

Stapes surgery was thought to increase the risk of IEBt, owing to an iatrogenic predisposition for perilymphatic fistula formation. However, no increased risk of otologic insult was found among large cohorts of divers who had undergone stapedectomy.[70,71] Postoperative recommendations include dry-ear precautions for the first three weeks, and allow diving one month postoperatively, assuming normal ET function.

Appendix

Primary literature on otology and scuba diving; AV – alternobaric vertigo; CRS – Chronic rhinous sinusitis; ENG – electronystagmography; ETD – ET dysfunction; ET – Eustacian tube; HBOT – hyperbaric oxygen treatment; IEBt – inner ear barotrauma; IEDCS – inner-ear decompression sickness; MEBt – middle ear barotrauma; NIHL – noise-induced hearing loss; OM – otitis media; PLF – perilymphatic fistula; PTA – pure tone audiometry; RCT – randomised controlled trial; SCC – semicircular canal; SHA – sinusoidal harmonic acceleration testing; SNHL – sensorneural hearing loss; TMJ – temporo-madibular joint; VOR – vestibulo-ocular reflex

First Author	LOE	*n*	Study design	Methods	Results	Conclusions/comment
External ear						
DiBartolomeo[10]	4	70	Retrospective cohort review	Chart review for exostoses	Incidence 6.36/1,000	Epidemiology and risk factors for exostoses identified
Middle ear						
Antonelli[72]	5	11	Retrospective post-mortem	18 temporal bones from 11 divers: 8 rapid ascent; 3 drowning, no rapid ascent	Middle ear haemorrhage in all rapid ascent bones; 5/11 rapid ascent TMs perforated	General commentary on histology of temporal bone injury due to rapid ascent
Ivarsson[21]	4	3	Case series	ET clearance in various head positions	Supine positioning impaired equalization on ascent and descent	Assuming an upright body posture during exposures to pressure changes is ideal
Jumah[20]	4	9	Prospective, non-consecutive case series	Divers with ET laser tuboplasty; pre- and post-op ET function/opening pressure	All subjects restored ability for pressure equalization; 7/9 able to resume diving	Divers with ETD may benefit from minimally invasive laser tuboplasty
Money[16]	4	3	Case series	Postmortem histology of temporal bones from recently deceased divers	MEBt found in pulmonary barotrauma patient; IEDCS case had neo-ossification in SCCs	Breath holding causes MEBt; maladaptive neo-ossification occurs following IEDCS
Ornhagen[22]	3b	7	Case control series	Dry and wet pressure chambers; measured passive ET opening vs head position	Horizontal position and prone position equivalent; head-down position worse	Avoid head down position on ascent
Roydhouse[3]	3b	650	Retrospective cohort study	Review of patients with diving-related ENT pathology	64.6% ear, 23.9% teeth/TMJ, 3.1% nose, 6.6% paranasal sinuses	Most common preventable cause of diving pathology is reversible nasal congestion
Uzun[18]	2b	24	Prospective cohort study	Survey, CT scan temporal bones of mastoid pneumatization	MEBt occurred in 15 ears of 11 divers; pneumatization related to risk of MEBt	Inverse relationship between degree of pneumatization and risk of barotrauma
Uzun[19]	3b	31	Retrospective cohort study	History, mastoid pneumatization, ET function	MEBt in 19 ears of 14 divers; ETD higher in divers	ETD measured by 9-step test and small mastoid are risk factors for MEBt
Vertigo						
Caruso[73]	4	14	Retrospective, consecutive case series	Audiometry, vestibular testing and DCS questionnaire	11/14 abnormal otologic, neuro-otologic findings	Expanded classification for vertigo related to diving
Kitajima[74]	3b	64	Non-consecutive cohort study	Sonotubometry and impedance tests	Diving incident group had significantly worse ETD	Divers with ETD prone to AV; check ET function pre dive
Klingmann[23]	2b	63	Retrospective cohort	Questionnaire, otoscopy, audiometry, caloric testing, ABR and MRI, etc	Higher prevalence of AV and ETD in females	Female divers 4x more likely to suffer AV; no increased risk for death if you experience AV
Molvaer[25]	3b	194	Retrospective cohort	Audiometry, interview of professional divers	39% had vertigo; 33% from AV; risk factors: previous barotrauma, noise exposure, cold water diving	Manage risk factors for AV while diving; AV did not cause any critical situations; theoretical risk remains

Appendix (cont.)

First Author	LOE	*n*	Study design	Methods	Results	Conclusions/comment
Uzun[26]	4	29	Retrospective case series	Survey, otoscopy, 9-step inflation/deflation tympanometry, ET function	Previous OM present in ¾ of AV divers; 14% of divers experienced AV	Risk factors for AV include previous history of OM and impaired ET function
Inner ear						
Cantais[45]	4	101	Case control, DCS/ non-DCS divers	Transcranial Doppler	R/L shunt associated with increased incidence of cerebral DCI	Paradoxical emboli may be potential mechanism of cochleovestibular symptoms/ cerebral DCI
Edmonds[37]	4	50	Consecutive case series IEBt	Clinical manifestations, audiometry and treatment	17/50 Teed grade 0	Absence of TM haemorrhage does not exclude diagnosis of IEBt
Harill[71]	5	231	Survey	Survey of otologists re: activity restrictions post stapes surgery	>50% recommend no diving; 32% had experience with postop Bt	No correlation between frequency of barotrauma reported and activity restriction
House[70]	5	22	Survey	22 divers post stapedectomy	3 otalgia on descent; 1 tinnitus; 1 transient vertigo; 1 PLF; no complaints related to labyrinthine injury	Stapedectomy does not increase the risk of IEBt in divers; dry ear precautions for 3/52, diving after 1/12 postop; ensure no ETD
Klingmann[2]	4	46	Retrospective case series	Review of divers treated for inner ear DCS/ barotrauma	Median latency to HBOT 10 hrs; 83% DCS patients had a R/L shunt	Divers with inner ear DCS associated with R/L shunting must undergo sonography
Klingmann[41]	3b	34	Retrospective non-consecutive cohort	Divers with IEDCS were analysed re: symptomatology	All had vertigo; 40% had hearing loss; symptoms within 120 min of ascent; 73% had a R/L shunt	Vestibular symptoms predominate in IEDCS, likely due to the decreased tissue washout relative to the cochlea
Parell[40]	3b	20	Retrospective cohort, previous IEBt	Serial audiometry	No divers suffered a secondary bout of IEBt despite regular diving	Divers who suffer IEBt may continue to dive
Shupak[33]	3b	9	Retrospective case series	Cases of IEDCS/IEBt reviewed over 2 years	IEBt 5/9 divers; exploratory tympanotomy in 2/5; IEDCS 4/9, 7 underwent recompression	Consider IEDCS even when diving within no-stop limits; initial observation in IEBt, surgery if deterioration
Shupak[30]	4	2	Retrospective case series	Cases of IEBt were reviewed	PLF repair was successful; patients had anatomic risk factors on CT scan	CT temporal bone scans should be performed in IEBt to rule out anatomic risk factors
Shupak[33]	3b	25	Case-control series	PTA, ENG and VOR and SHA	PTA hearing threshold higher and decreased VOR phase values in divers	Slightly lower VOR values may represent adaptive underwater opticokinetic changes
Shupak[43]	4	11	Retrospective consecutive case series	Audiometry, ENG, posturography, rotatory chair	10 IEDCS and 4 IEBt had cochleovestibular deficits	IEDCS has high risk for inner-ear sequelae even with HBOT; deficits common even if asymptomatic
Tal[47]	4	3	Retrospective case series	Review of IEDCS cases	Patients with IEDCS require HBOT	If doubt over diagnosis of IEDCS, recompression should still be undertaken
Wong[39]	4	8	Non-consecutive case series	Report on complaints and management of inner-ear symptoms in divers	See individual aetiologies highlighted in case series	Careful history and physical examination will help distinguish between IEBt and IEDCS

Appendix (cont.)

First Author	LOE	*n*	Study design	Methods	Results	Conclusions/comment
General articles						
Klingmann[14]	2b	306	Retrospective cohort analysis	Chart review of anatomical sub-site/symptoms	8% external ear; 46% middle ear; 18% inner ear; 17% nose, paranasal sinuses; 8% DCS	Female divers significantly more affected by ETD; CRS associated with higher number of dives
Beckett[7]	5	770	Internet survey of divers	Risk behaviours and safety practices	DCS symptoms in 53%; OE in approx. 50% divers	Injury more common in non-certified divers
Hearing						
Goplen[17]	4	67	Prospective cohort study	Audiometry, ENG, posturography; 3/6 year follow up	Occupational SNHL in commercial divers; no change in ENG or posturography	No contribution of diving frequency to high frequency hearing loss; no evidence of permanent vestibular loss
Klingmann[29]	3b	123	Cross-sectional control comparison	PTA, tympanometry and otoscopy of sport. vs professional divers	No differences detected	No hearing loss among rec divers; professional divers risk occupational NIHL
Molvaer[27]	2b	116	Prospective cohort	Audiometry of professional divers over 6 years	Diver's hearing deteriorated faster than non-divers at comparable age	Noise exposure during commercial diving likely cause of hearing loss
Taylor[28]	3b	16	Retrospective cohort	Audiometry	No significant differences in audiological testing	Recreational divers not at increased risk of hearing loss
Sea sickness						
Cooper[53]	2b	1350	Prospective cohort on ocean liner	Epidemiologic study of sea sickness	Odds ratio for seasickness: female sex 2.95; young age 0.99; non crew 19.87	Sea sickness more common in women, may share common pathophysiology with migraine
Eden[57]	1b	25	RCT of naval cadets	Experimental group given positive self-efficacy/'verbal placebo' during 5-day cruise	Experimental cadets reported less seasickness; rated as better performers	Seasickness may be a self-fulfilling prophecy, and may be reduced with 'verbal placebo'
Gahlinger[51]	2b	260	Prospective cohort on cruise	Epidemiologic data and cabin location in ship recorded	Risk of motion sickness associated with age and sex	Location of cabin not associated with likelihood of motion sickness
Gil[59]	1b	76	RCT with crossover	Navy crew given transdermal scopolamine and cinnarizine, follow up questionnaires	Scopolamine more effective, less drowsiness, preferred agent, 41 vs 12%	Scopolamine patch should be considered drug of choice for treatment of seasickness
Williams[61]	1b	24	RCT	Dexterity, arithmetic, sentence comprehension tested, varying depth and scopolamine dose	Dexterity and comprehension impaired at depth; no effects from scopolamine	Transdermal scopolamine during dive operations may be suitable; perform field testing
MdDS						
Dai[66]	5	5	Prospective	Videonystagmography and roll chair	Adaptation of the angular VOR generated through velocity storage	Central maladaptation of the VOR implicated in MdDS
Gordon[65]	2b	234	Retrospective cohort	Survey of MdDS among healthy crew members	73% had MdDS symptoms; <6 h in 93%	Transient MdDS common and expected among crew members

Appendix (cont.)

First Author	LOE	*n*	Study design	Methods	Results	Conclusions/comment
Animal studies						
Antonelli[15]	5	16	Prospective case control animal model	Guinea pig stapedectomy model; consecutive hyperbaric dives, electrocochleography and hair cell counts	Middle ear barotrauma in 8 stapedectomy ears vs. 5 controls; no difference in hair cell counts	No predisposition to cochlear sequelae post stapedectomy in guinea pig model of barotrauma
Arieli[64]	5	26	Prospective case control animal model	Rats given cinnarizine/control O_2; exposure protocols to explore CNS toxicity	Latency to first electrical discharge on EEG increased at high O_2 pressures	Cinnarizine does not increase risk of CNS O^2 toxicity
Bitterman[63]	5	36	Prospective case control animal model	EEGs and HR measured to test interaction of scopolamine with HBO	No difference in latent period between control and scopolamine rats	Scopolamine does not alter hyperoxic seizures
Landolt[42]	5	100	Case control animal model	Histology of squirrel monkey temporal bones	Histologic vestibular apparatus deficits post decompression exposure	Neo-ossification within otic fluid spaces post DCS could cause permanent deficit to diver

Conclusions

Scuba diving has a significant potential for complications in the external, middle and inner ear. Otolaryngologists and clinicians with an interest in dive medicine should have a keen understanding of the pathophysiology, treatment and fitness-to-dive implications of diving-related disorders of the head and neck. The recommendations within this review are intended to supplement good clinical judgment, and should be applied within the context of each individual patient's circumstance. Overall, there is a need for more high-quality research on diving-related head and neck pathology. Research in this area can lend insight into the pathophysiology of barotrauma and DCS while improving patient care and decreasing dive-related morbidity.

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Ischaemia-reperfusion injury and hyperbaric oxygen pathways: a review of cellular mechanisms

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Abstract

(Francis A, Baynosa R. Ischaemia-reperfusion injury and hyperbaric oxygen pathways: a review of cellular mechanisms. *Diving and Hyperbaric Medicine*. 2017 June;47(2):110-117.)
Ischaemia-induced tissue injury has wide-ranging clinical implications including myocardial infarction, stroke, compartment syndrome, ischaemic renal failure and replantation and revascularization. However, the restoration of blood flow produces a 'second hit' phenomenon, the effect of which is greater than the initial ischaemic event and characterizes ischaemia-reperfusion (IR) injury. Some examples of potential settings of IR injury include: following thrombolytic therapy for stroke, invasive cardiovascular procedures, solid organ transplantation, and major trauma resuscitation. Pathophysiological events of IR injury are the result of reactive oxygen species (ROS) production, microvascular vasoconstriction, and ultimately endothelial cell-neutrophil adhesion with subsequent neutrophil infiltration of the affected tissue. Initially thought to increase the amount of free radical oxygen in the system, hyperbaric oxygen (HBO) has demonstrated a protective effect on tissues by influencing the same mechanisms responsible for IR injury. Consequently, HBO has tremendous therapeutic value. We review the biochemical mechanisms of ischaemia-reperfusion injury and the effects of HBO following ischaemia-reperfusion.

Key words
Hypoxia; Hyperoxia; Reperfusion injury; Free radicals; Nitric oxide; Ischaemic preconditioning; Review article

Introduction

Tissue ischaemia represents the final common pathway of various disease states that include myocardial infarction, stroke, amputations, compartment syndromes and failing tissue flaps and grafts. In these scenarios, emergent interventions are undertaken to restore blood flow to the affected areas, which in some cases may be life- and limb-saving on a global scale. However, this reperfusion is not without consequence; despite restoration of flow, further tissue and microcirculation injury still occur, even to a greater extent than the initial ischaemic insult. Tissue necrosis and microcirculatory collapse that occur because of reperfusion following prolonged ischaemia is referred to as ischaemia-reperfusion (IR) injury. Examples of IR injury can be seen in many settings: thrombolytic therapy for stroke, any cardiovascular invasive procedure (e.g., angioplasty of the popliteal artery to coronary artery bypass with assisted circulation), organ transplantation, and major trauma resuscitation. Reactive oxygen species (ROS) have been shown to be the principal mediators of this phenomenon. During IR injury, the blood-endothelial cell interface shows increased microcirculatory neutrophil adhesion that incites tissue necrosis and starts a feedback loop that results in further ROS production and injury. Given the potentially devastating clinical outcomes of IR injury, much investigation has been undertaken to better understand the molecular signals and changes that occur in the microcirculation. As our understanding of the mechanisms of IR injury has evolved, so too has interest in therapeutic interventions to reverse or prevent it, particularly with hyperbaric oxygen (HBO). The purpose of this article is to discuss the biochemical mechanisms of ischaemia-reperfusion injury and review the effects of HBO treatment.

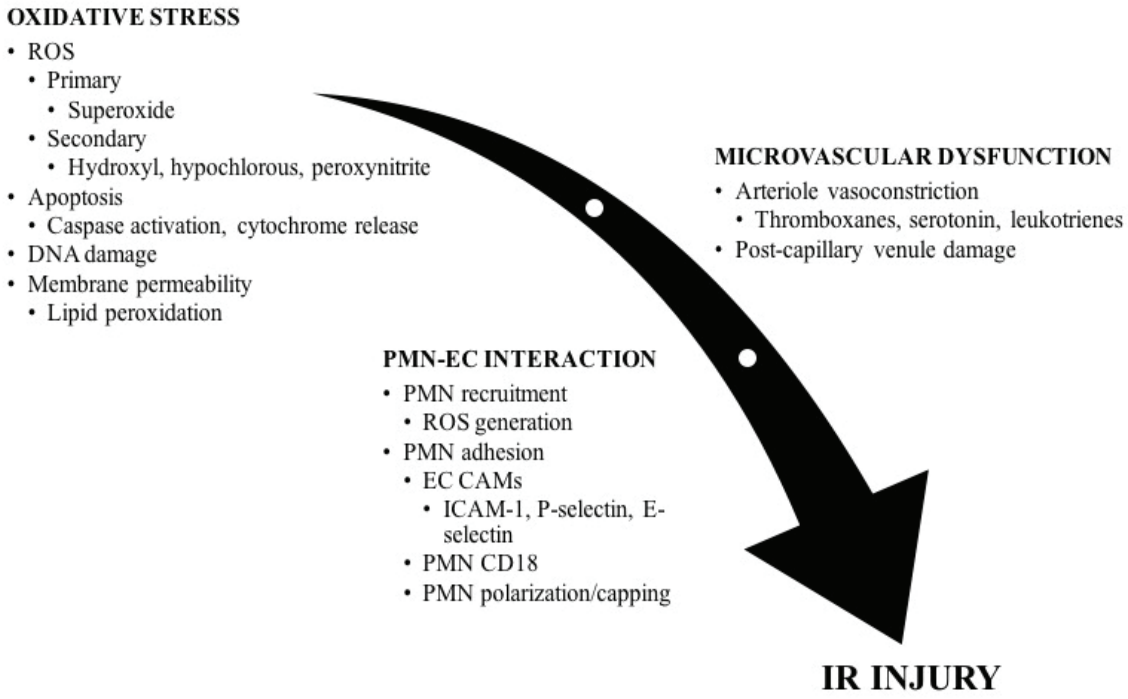
Ischaemia-reperfusion injury (Figure 1)

OXIDATIVE STRESS

ROS, chiefly oxygen free radicals, serve a cell-signalling role and are formed during cellular metabolism.[1] While their role in normal homeostasis continues to be investigated, their involvement in mediating oxidative damage seen during IR injury has been documented extensively.[2] The predominant ROS in the cell are superoxide and hydroxyl radicals. Their cellular toxicity results from lipid peroxidation and its associated membrane damage, direct DNA damage, and production of other free radical and reactive species.[3] Due to the instability of free radical species, free radical scavengers have been utilized to indirectly prove the detrimental effects of ROS in IR injury. Using a mouse hind limb model, improvement in inflammatory cell infiltration in skeletal muscle after IR was shown when pretreating with edavarone, a synthetic free radical scavenger.[4]

Figure 1

Mediators of ischaemia-reperfusion injury; oxidative stress, microvascular dysfunction, and the neutrophil-endothelial cell interaction produce changes in cellular physiology that increase cell damage and tissue death; CAM – cellular adhesion molecule; EC – endothelial cell; PMN – polymorphonuclear neutrophil; ROS – reactive oxygen species



In the normal physiologic state, multiple antioxidant mechanisms exist to counteract the effect of these ROS: superoxide dismutase (SOD), glutathione, and catalase.[5] Once these systems are overwhelmed, as occurs during IR injury, excess ROS is produced and incites tissue damage. These antioxidant systems have also been utilized as physiologic free radical scavengers that provide improvements in skeletal muscle function after undergoing IR injury. As a model for limb replantation, rabbit tibialis anterior muscle was subjected to IR at five-and eight-hour intervals and muscle function was examined after administration of the hydroxyl free radical scavenger dimethylsulfoxide (DMSO) and superoxide free radical scavenger SOD prior to reperfusion.[6] Muscle treated with SOD had normal strength after five hours of ischaemia but no protective effective after eight hours; conversely, DMSO had improved function after eight hours but no effect after five hours compared to untreated controls.[6]

During IR injury, two sources for ROS generation are xanthine oxidase and neutrophils. Xanthine oxidase, the conversion product of oxidative damage to xanthine dehydrogenase found in skeletal muscle endothelial cells, produces superoxide and hydrogen peroxide (H_2O_2) during purine metabolism.[3] These ROS recruit neutrophils to the blood-endothelial cell interface, thereby initiating migration into the surrounding tissues. Neutrophils then produce a greater amount of ROS, further precipitating the effects of IR injury. Consequently, much research into IR injury has focused on the interaction between neutrophils at the blood-endothelial cell interface. Neutrophils generate a large amount of extracellular superoxide owing to the presence of membrane-bound nicotinamide adenine dinucleotide phosphate (NADPH) oxidase. Following dismutation to H_2O_2, subsequent reactions result in the formation of other toxic molecules: hydroxyl radical (reaction with ferritin) and hypochlorous acid (reaction with chloride via neutrophil myeloperoxidase). It appears that, in IR injury, xanthine oxidase may produce the initial liberation of ROS species, with further propagation coming from neutrophils, finally culminating in tissue injury.[7,8]

Programmed cell death (apoptosis) has also been implicated in IR injury although the mechanisms remain unclear. ROS accumulation has been shown to induce apoptosis.[9] More recently, nitric oxide (NO) has been suggested as a mediator of IR injury. NO is produced by nitric oxide synthase (NOS), which has three isoforms: neuronal NOS (nNOS), endothelial NOS (eNOS), and inducible NOS (iNOS).[10] The former two isoforms are expressed constitutively, whereas the latter requires protein synthesis. It should be noted that NO competes with oxygen in binding to terminal cytochrome *c* oxidase, which has a higher affinity for NO than for oxygen. At higher oxygen concentrations, NO is consumed by cytochrome *c* oxidase and thus simulates a hypoxic environment. Conversely in lower oxygen tension, NO is not consumed and is available to mediate its physiologic effects.[11]

High levels of NO produced by iNOS may interact with superoxide to produce peroxynitrite, resulting in

mitochondrial cytochrome *c* release and caspase activation, and ultimately apoptosis.[12,13] Rat intestinal mucosa subjected to IR injury demonstrated iNOS, NO, and apoptosis.[14] The data regarding NO and apoptosis is conflicting as other studies have demonstrated a protective role for NO against apoptosis.[15,16] Further investigation is required to clarify this relationship. Therefore, it appears that the secondary products of superoxide radical interactions (i.e., hydroxyl radical, hypochlorous acid, peroxynitrite) are the primary mediators of the toxic effects of IR injury rather than superoxide itself. Moreover, there is a growing body of evidence demonstrating a cellular signalling role for superoxide and other oxidative species.[17]

MICROCIRCULATION DYNAMICS

In studies investigating reperfusion following myocardial infarction in dogs, reperfusion results in improved flow through the large vessels. However, the microcirculation demonstrates obstruction, circulatory collapse, and myocardial function still suffers.[18] These findings suggest that IR injury involves changes in the microcirculation. An early study found significant increases in vasoconstricting thromboxanes compared to vasodilating prostaglandins in a rat hind-limb model of the no-reflow state, a phenomenon describing complete microcirculatory failure, compared to ischaemic limbs with reflow.[19] This study also found decreased venous outflow with absent vascular thrombosis, suggesting a mechanism of excess thromboxane release producing microcirculatory vasoconstriction in the impending no-reflow state.[19] Similar findings regarding vasoconstriction in IR injury were observed in a rat skeletal muscle utilizing intravital microscopy to examine arteriolar and venule diameters.[20] It was found that reperfusion resulted in initial vasodilation followed by severe vasoconstriction after one hour. Distant arteriolars were spared from this effect, suggesting an influence of the local environment damaged by neutrophils.[20]

Another study demonstrated that vasoactive substances exert a greater effect on arteriolar smooth muscle than on the endothelium in the microcirculation.[21] It was concluded that there is a barrier to diffusion of water-soluble vasoactive substances between the smooth muscle and endothelium. During IR injury, the post-capillary venule endothelial cells are damaged by neutrophils. This might provide a putative explanation as to why the vasoconstrictive effect of IR injury is confined to the immediately adjacent microarterioles. Other vasoactive substances have been implicated in modulating microarteriolar vasoconstriction, including serotonin and leukotrienes.[22,23] While much of the focus has been on neutrophil-induced injury following reperfusion, other cell lines may be involved. Skeletal muscle IR injury results in adenosine-regulated mast cell degranulation that initiates arteriolar vasoconstriction.[24] Therefore, it is likely that the dynamic microvascular changes occurring during IR injury reflect the complex interplay between multiple cell lines and vasoactive molecules. Additional research is necessary to better understand these interactions.

NEUTROPHIL-ENDOTHELIAL CELL ADHESION

It is interesting to note that tissue damage from ischaemia differs microscopically from that from IR injury. With ischaemia, tissue architecture is preserved and there is a relative acellularity. In contrast, IR injury is characterized by tissue necrosis and leukocyte infiltration, especially neutrophils. Neutrophils are recruited to the ischaemic site following reperfusion and, prior to extravasation, adhere to the endothelium. Given the role of neutrophils in mediating IR injury and ROS production, investigation of the neutrophil-endothelial cell interface has increased for its potential therapeutic targetting.

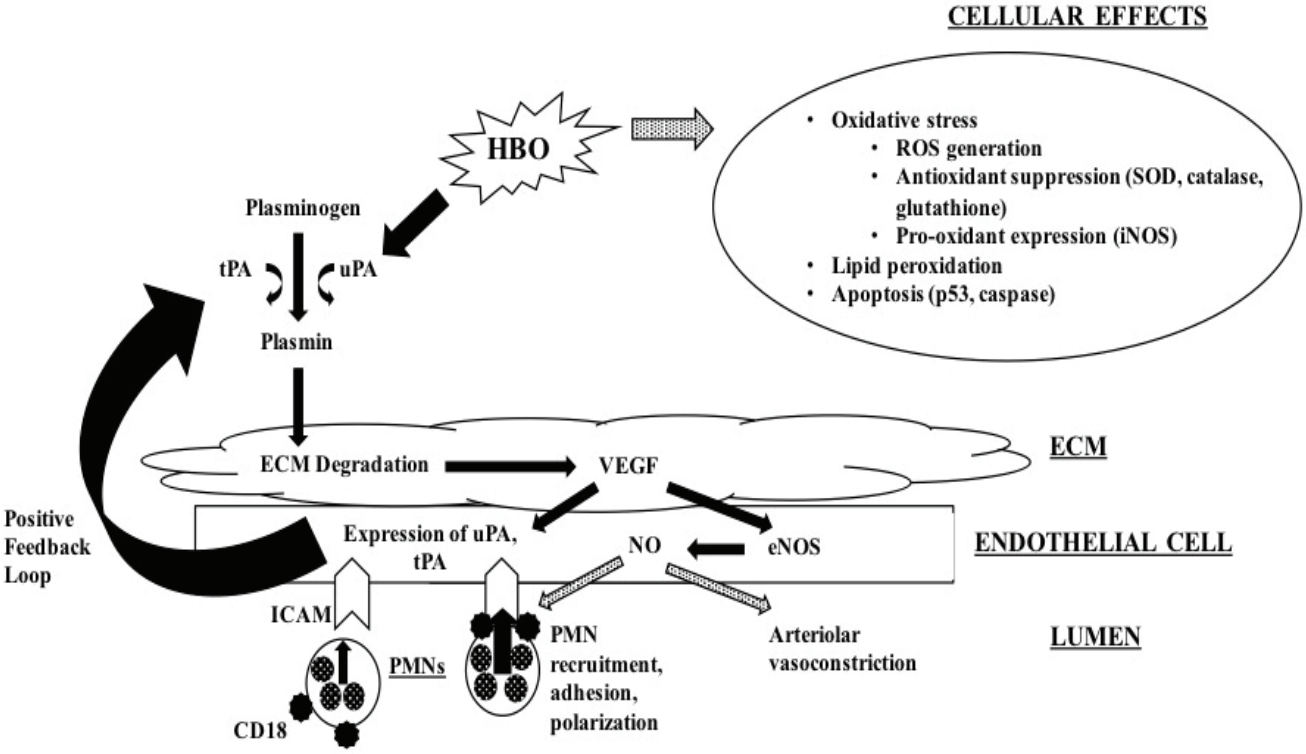
Neutrophil adhesion to the microvascular endothelium is dependent on interactions between receptors and ligands on the surface of the neutrophil and endothelium called cell adhesion molecules (CAMs). Examples include P-selectin, E-selectin, and ICAM-1. Expression of these molecules varies depending on the local tissue conditions and on cytokine release. P-selectin is expressed on the surface of endothelial cells within 15 minutes of middle cerebral artery occlusion, where it can bind to its respective neutrophil ligand (P-selectin glycoprotein ligand-1).[25] P-selectin is contained within Weibel-Palade bodies and is secreted onto the endothelial cell surface after these storage granules are exocytosed.[26]

Whereas P-selectin expression occurs acutely following IR injury, other CAM molecules (e.g., E-selectin and ICAM-1) expression occurs in a delayed fashion, likely because of increased CAM molecule expression via transcription and translation.[27] E-selectin and ICAM-1 then bind to neutrophil ligands to produce the neutrophil-endothelial cell adhesion. Using monoclonal antibody against CD18 to block neutrophil-endothelial cell adherence, a study of rat skeletal muscle showed that ICAM-1 interacts with neutrophil cell-surface CD18 molecules during IR injury.[28] Microarteriolar vasoconstriction was also blocked, suggesting that neutrophil CD18 plays a key role in altering the microcirculation during IR injury. Using phorbol-12 myristate 13-acetate (PMA) to simulate endothelial cell injury, it has been shown that ischaemia-reperfusion also upregulates neutrophil CD18.[29] In another *in vitro* study of neutrophil adherence, confocal microscopy demonstrated neutrophil capping, which refers to the change in polarity of surface CD18 molecules by concentrating them in one area, thereby increasing the likelihood of adhesion to endothelial ICAM-1 after IR injury.[30]

Protection against IR injury has been shown by blocking neutrophil-endothelial cell adhesion *in vivo*. Use of anti-CD18 monoclonal antibody in baboons decreased cerebral infarction.[31] Additionally, a knock-out mice model

Figure 2

Physiologic effects following hyperbaric oxygen therapy for ischaemia-reperfusion; hyperbaric oxygen results in interference with neutrophil-endothelial cell interactions, promotes arteriolar vasodilation, and ameliorates cellular damage; solid arrows represent stimulatory pathways; dotted arrows represent inhibitory pathways; ECM – extracellular matrix; eNOS – endothelial nitric oxide synthase; HBO – hyperbaric oxygen; ICAM – intercellular adhesion molecule; iNOS – inducible nitric oxide synthase; NO – nitric oxide; PMN – polymorphonuclear neutrophil; ROS – reactive oxygen species; SOD – superoxide dismutase; tPA – tissue plasminogen activator; uPA – urinokinase-like plasminogen activator; VEGF– vascular endothelial growth factor



for ICAM-1 exhibited a six-fold decrease in infarction size compared to wild-type.[32] Interestingly, neutrophil recruitment was similar between the groups, suggesting that the extent of inflammatory cell response is less crucial than the interaction between neutrophils and the endothelium.[32]

Hyperbaric oxygen (Figure 2)

HALLMARK STUDIES

The initial ischaemic insult deprives tissues of oxygen and results in cellular injury, so it follows that restoration of oxygenation through the microcirculation would halt or perhaps reverse the tissue necrosis. IR therefore represents a paradoxical process because reperfusion produces a greater degree of tissue damage, dependent on ROS. In addition, it was thought that a hyperoxic tissue environment provided by administration of HBO following IR injury would increase ROS production and worsen the extent of tissue necrosis.

Unexpectedly, after subjecting an axial skin flap model to eight hours of ischaemia to determine the effects of HBO during reperfusion, skin-flap survival was significantly improved following HBO.[33] It had been anticipated that HBO would increase free radical liberation, worsen IR injury and decrease skin-flap survival. Subsequent findings of increased perfusion of ischaemic skin flaps treated with HBO using laser Doppler analysis confirmed these results.[34] Similarly, HBO provided a three- to six-fold improvement in free skin-flap survival in rats after microvascular anastomosis.[35] The authors posited that 24 hours was the threshold for irreversible ischaemic damage.[35] Consequently, we now understand that HBO ameliorates the detrimental effects of IR injury by improving tissue microcirculation.

IMPROVEMENT IN OXIDATIVE DAMAGE AND CELL DEATH

Since ROS are a key mediator in IR injury, studies have investigated the effects of HBO on the generation of these toxic molecules. Carbon monoxide (CO) simulates ischaemic conditions, a concept that was utilized in a rat model of brain injury.[36] Lipid peroxidation mediated by CO was inhibited by preventing xanthine oxidase formation, presumably decreasing superoxide radical and hydrogen peroxide levels.[36] Free radical scavenging systems, specifically SOD, may also be upregulated following HBO treatment.[35] HBO has also been shown to upregulate

antioxidant gene expression in human endothelial cells which may protect against oxidative damage seen in IR injury.[37] As a result, HBO appears to produce its beneficial effects on ischaemic tissue by both decreasing production of ROS and increasing their degradation. Rat studies of renal IR injury treated with HBO prior to ischaemia demonstrated decreased oxygen radical-induced lipid peroxidation.[38] A more recent study demonstrated HBO-induced inhibition of apoptosis and improvement in cellular proliferation following renal IR injury.[39]

Additionally, utilizing a validated ischaemic flap model in rats, it was demonstrated that HBO improves ischaemic wound healing compared to untreated and N-acetylcysteine-treated (a non-specific free radical scavenger) groups. The mechanisms for this appeared to be by down-regulation of hypoxia-inducible factor-1 alpha (HIF-1 alpha) and p53- and caspase-3-mediated apoptosis.[40] In addition, the inflammatory response, as demonstrated by VEGF, cyclooxygenase-2, and neutrophil counts, were reduced in the HBO group.[40] Subsequently it was demonstrated that HBO increased antioxidant enzyme expression (SOD, catalase, and glutathione peroxidase) and decreased pro-oxidant enzyme expression (iNOS and gp91-phox) in ischaemic wounds.[41] These findings show that HBO does not exacerbate ROS-mediated tissue injury.

INTERFERENCE WITH NEUTROPHIL-ENDOTHELIAL CELL ADHESION

The potential mechanisms of HBO on neutrophil adhesion have also been of great interest. In a rat gracilis model investigating neutrophil adherence following HBO, adherence was significantly decreased during and after four hours of ischaemia. When HBO was initiated one hour after reperfusion, however, leukocyte adhesion was reduced to a lesser degree.[20] In the absence of ischaemia, HBO had no observable effect on the neutrophil-endothelial cell interaction. The same study also reviewed the effects on microvascular vasoconstriction. Vasoconstriction was inhibited when HBO was initiated during ischaemia, immediately after reperfusion, and one hour after reperfusion, with maximal effect during ischaemia.[20] These findings suggest that the maximal beneficial response to HBO occurs during the ischaemic phase and may be time-dependent. A rodent model of renal IR injury demonstrated decreased neutrophil infiltration following HBO and associated improvements in blood urea nitrogen and creatinine levels.[42]

A study at 284 and 304 kPa reported on the inhibition of human neutrophil adherence to injured endothelium via beta-2-integrin (CD18) function.[43] CD18-mediated neutrophil adhesion was inhibited but expression was not affected. Moreover, this study demonstrated that this function is cyclic GMP (cGMP)-regulated. HBO inhibited the function of guanylate cyclase and neutrophil adhesion was restored directly by cGMP incubation and also by increasing guanylate cyclase activity with N-formyl-Met-Leu-Phe (FMLP).[43] cGMP production was altered by inhibition of the membrane-bound guanylate cyclase, but free intracellular guanylate cyclase was unaffected. Therefore, it appears that HBO inhibits CD18 activity via impaired cGMP production. The finding that CD18 expression is not decreased by HBO treatment has been confirmed by others in a skeletal muscle rat model.[29] Neutrophil capping and CD18 surface polarization were inhibited by HBO, providing another plausible mechanism for the reversal of IR injury.[44]

The role of the endothelial cell cannot be overlooked in IR injury and other investigators have sought to focus on endothelial cell CAM (E-selectin and ICAM-1) expression after HBO. Ischaemia-reperfusion was simulated with hypoxia and hypoglycaemia exposure and demonstrated increased adhesion of neutrophils to endothelium.[45] HBO significantly reduced ICAM-1 expression and neutrophil adhesion.[45] Similar results were noted in *in vivo* experiments of rat skeletal muscle flaps.[46] HBO was administered at 253 kPa for 90 minutes and down regulated ICAM-1 expression with a resultant improvement in flap survival.

THE ROLE OF NITRIC OXIDE

NO has been shown to regulate many processes in IR injury including the microcirculation through its vasodilatory properties and reversal of leukocyte adhesion. Loss of the protective effect of NO resulted in increased CAM expression.[47] Indirect evidence has been found for increased survival and decreased neutrophil-endothelial adhesion after infusion of L-Arginine, a NO precursor, into ischaemic muscle.[48] eNOS inhibition promotes neutrophil adherence in the endothelium. In a previously mentioned study, HBO induced expression of eNOS; additionally, inhibition of NOS attenuated inhibition of ICAM-1 after HBO.[45] Another study of isolated rat neutrophils showed that NO inhibited CD18 activity by decreasing guanylate cyclase activity, corroborating the finding that NO decreases neutrophil adhesion.[49] Rat studies have demonstrated a favorable effect of HBO following IR injury on intestinal mucosa and hepatic cell apoptosis which may be mediated through decreased iNOS activity with a resultant decrease in peroxynitrite.[50,51]

The NO-dependent effect of HBO on CD18 polarization also has been examined.[52] Following administration of a NO scavenger, CD18 polarization and adherent neutrophils increased significantly compared to untreated controls. Furthermore, NOS inhibitors given before HBO restored neutrophil adhesion and capping via CD18. Together these findings represent a NO-regulated mechanism underlying the beneficial effects of HBO after IR injury and its associated CD18 polarization.[52] More recently, two important findings on the effect of HBO on NOS activity and expression in IR injury in rats have been demonstrated. First, eNOS was increased in pulmonary tissues, which supports the theory that the beneficial effects of HBO therapy occur systemically, not locally. Additionally, a temporal relationship of HBO-mediated NOS effects exists with an early phase increase

in eNOS enzymatic activity and a subsequent late-phase increase in protein expression, the delay accounted for by transcription and translation.[53] Unpublished data from our laboratory suggests that the NO-dependent effect of HBO on CD18 polarization occurs through the plasmin-mediated release of membrane-bound vascular endothelial growth factor (VEGF).

The role of VEGF has recently been an area of investigative focus. HBO improves wound angiogenesis by increasing VEGF transcription and protein production.[54] In contrast to the acute changes seen after HBO following IR injury, the effects on VEGF represent long-term effects. VEGF can be bound to the extracellular matrix and released by the activity of various proteases, including plasmin.[55] Plasminogen is activated to yield plasmin by tissue or urokinase-like (tPA or uPA) plasminogen activators, the expression of which is increased with HBO.[56] The enhanced plasmin activation results in release of VEGF from the extracellular matrix and increased NO production.[57] IR injury increases alpha2-antiplasmin, thereby decreasing the amount of plasmin available to release stored VEGF.[58] Part of the beneficial effect of HBO after IR injury may be to increase levels of tPA and uPA, increasing plasmin beyond the inactivating capability of alpha2-antiplasmin present from the initial ischaemic event.

HYPERBARIC OXYGEN PRECONDITIONING

Preconditioning refers to the administration of HBO to limit the effects of subsequent ischaemia. The putative mechanism appears to be from the induction of antioxidant intracellular systems including catalase and SOD.[59,60] It has been suggested that the cardio-protective effects of HBO therapy in a rat model were NOS-regulated.[61] Much of the recent literature regarding HBO and IR injury has focused on this phenomenon. There is evidence that preconditioning rat skin flaps with HBO prior to IR injury resulted in improved survival and microcirculatory perfusion.[62] This beneficial response was the result of increased expression of anti-apoptotic factor B-cell lymphoma-2 (Bcl-2) and inhibition of apoptotic factors phosphorylated apoptosis signal-regulating kinase 1 (pASK-1), phosphorylated c-Jun N-terminal kinase (pJNK) and Bcl2-associated K protein (Bax). A diminution of the inflammatory cytokine cascade has also been advocated.[63]

The preconditioning effect of HBO was confirmed in an hepatic IR study in rats. HBO not only resulted in improvements in serum alanine aminotransferase and aspartate aminotransferase levels, but also demonstrated improvements in mitochondrial respiration and swelling.[64] The relationship between mitochondrial injury, cytochrome *c* release, and apoptosis suggests that the improvement in mitochondrial function revealed by this study may result in inhibition of apoptosis. HBO preconditioning provides systemic and local tissue benefits; however, the response appears to be dependent on the timing of HBO exposure with the exact window remaining unknown.[65] HBO preconditioning may be useful for limiting the well-documented neurological complications following elective cardiac surgery and carotid endarterectomy. It may also prove useful in complex reconstructive procedures requiring composite tissue allotransplantation, such as face and hand transplants, where ischaemia times can be extremely prolonged and multiple tissue types are involved including muscle and bone.

Limitations

The studies mentioned above, and others, have provided a great deal of clarity in this challenging area. However, it should be noted that much of our understanding of IR injury and HBO derives from experimental studies in animal models or cell culture. While these experimental findings are promising, it is unclear whether the physiologic outcomes correlate to clinically relevant findings. The clinical data regarding this topic are mostly from retrospective studies and are insufficiently powered with small sample sizes, and thus, the clinical impact remains debatable.

Conclusions

Studies of the microcirculation, neutrophil adhesion, and ROS reflect the complex interactions between various cell signalling molecules, intracellular pathways, and cell types in IR injury. HBO can ameliorate the cytotoxic effects of reperfusion injury in a dose-dependent manner. However, the critical issue at the centre of IR injury is the duration of ischaemia as the primary factor in determining the outcome from injury. The adage ‘time is muscle/nerve’ emphasizes the well-established fact that irreversible damage is observed in ischaemia-sensitive tissues such as muscle and nerve tissue after six hours of ischaemia. The window of reversible changes presents a valuable opportunity not only for promptly initiating the appropriate interventions to reverse the ischaemic aetiology, but also to institute adjunctive therapies such as HBO to limit the extent of tissue damage after IR injury.

Our understanding of IR and the protective effects of HBO continues to evolve. The evidence from rat skeletal muscle and skin flap studies provides insight into the potential for HBO in the treatment of IR injury following crush injuries, and failing grafts and flaps. Other studies of animal heart, brain, kidney, intestine and liver demonstrate the positive effects of HBO in the context of myocardial infarction, stroke, ischaemic renal failure and solid organ transplantation. HBO preconditioning has promising therapeutic value and its applications are under investigation. Additionally, standardized protocols for HBO have not been defined. It is apparent that questions remain for these processes and therefore more basic-science and clinical research is required to elucidate them.

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The world as it is

Treatment preferences for decompression illness amongst Singapore dive physicians

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Abstract
(Tan VH, Chin K, Kumar AA, Chng J, Soh CR. Treatment preferences for decompression illness amongst Singapore dive physicians. *Diving and Hyperbaric Medicine*. 2017 June;47(2):118-122.)
Introduction: Owing to the scarcity of randomized controlled trials to guide treatment for decompression illness (DCI), there are many unanswered questions about its management. Apart from reviews and expert opinion, surveys that report practice patterns provide information about useful management strategies. Hence, this study aimed to identify current treatment preferences for DCI amongst diving physicians in Singapore.
Methods: An anonymous web-based questionnaire was sent to known diving physicians in Singapore. The demographics of the respondents were captured. Respondents were asked about their preferred management for five different DCI scenarios.
Results: The response rate was 74% (17 of 23 responses). All respondents chose to recompress patients described in the five scenarios. Regarding the number of recompression sessions, "*one additional session after no further improvement in signs and symptoms*" was the most common end point of treatment across all the scenarios (47 of 85 responses). Analgesics would be used by five physicians, three would use lidocaine and two steroids as adjuvant therapies.
Conclusions: Apart from the general agreement that recompression is indicated for DCI, there was no strong consensus regarding other aspects of management. This survey reinforces the need for robust RCTs to validate the existing recommendations for DCI treatment.

Key words
Decompression sickness; Cerebral arterial gas embolism (CAGE); Hyperbaric medicine; Hyperbaric oxygen therapy; Recompression; Survey

Introduction

Singapore is geographically located in the popular tropical recreational diving region of South East Asia and treats an average of 20 patients with decompression illness (DCI) annually.[1] There are many published guidelines on DCI management such as those of the Undersea and Hyperbaric Medical Society (UHMS) 2011 and the US Navy Diving Manual 2008 (USN).[2,3] However, due to the scarcity of rigorous data from randomized controlled trials (RCTs),[4] these guidelines are often based on retrospective reviews and expert opinion. This study aimed to identify current treatment preferences of Singapore's diving physicians for DCI to determine if the lack of robust data was associated with variations in practice patterns.

Method

Ethics approval was obtained from the Singapore General Hospital Institutional Review Board (2015/2212). An anonymous web-based questionnaire was sent to individual emails of known practicing diving physicians in Singapore. The questionnaire captured the respondents' demographic data and elicited their management preferences for five different scenarios (Table 1). Two mild decompression sickness (DCS) scenarios included were early presentation of DCS with joint pain only and late presentation of joint-pain DCS. Three more severe DCS scenarios included were cutaneous DCS (*cutis marmorata*), late presentation of mild neurological (sensory only) DCS and severe DCI manifesting as paraplegia or cerebral arterial gas embolism (CAGE). There were also questions on the use of adjunctive therapies. Responses were collated over one month from

Table 1
Brief summary of the five scenarios presented to Singapore diving physicians (the full questionnaire is available either from the corresponding author or the DHM office <editorialassist@dhmjournal.com>)

Scenario 1: A diver presenting at 4 h with joint pains (pain score 5/10) after diving

Scenario 2: A diver presenting at 48 h with joint pains (pain score 5/10) after diving

Scenario 3: A diver presenting with cutaneous DCS (*cutis marmorata*) only

Scenario 4: A diver presenting with mild sensory deficits at 48 h after diving

Scenario 5: A diver presenting with paraplegia or cerebral arterial gas embolism

For each scenario, the physician was asked five questions:

1. What initial treatment would they recommend (recompression/normobaric oxygen/none)?

2. What table would they use as first treatment? (five options presented)

3. If symptoms were unchanged post treatment, what would they recommend? (six options presented)

4. If there was a good response to the first treatment, what would they recommend for follow up? (six options presented)

5. When would they cease treatment? (six options presented)

February 2015 to March 2015, and a second round of data collection was performed from January 2016 to February 2016. Data were logged in a Microsoft Excel© spreadsheet from which, because of the small sample size, we only report simple descriptive results.

Results

The response rate was 17 out of 23 (74%). Five physicians had practiced for one to five years, six for six to 10 years and six had more than 11 years of practice. Nine physicians had received training in diving medicine units in the USA, three in Australia, two in both Australia and Canada, one in both Australia and the USA, and two locally in Singapore.

DIVE TABLES

All 17 respondents recommended recompression for each of the five scenarios. Treatment preferences are shown in Figures 1 and 2. The majority opted for a US Navy Treatment Table 6 (USN TT6) as the first recompression table for both mild (21 of 34 responses) and severe DCS (39 of 51 responses). The deeper USN TT6A was advocated by about a third of the responders, predominantly for severe DCI.

With respect to the number of recompression sessions, "*one additional session after no further improvement in signs and symptoms*" was the most common option for the end point of treatment across all scenarios (47 of 85 responses), followed by "*till no further improvement*" (25 of the 85 responses). In only eight responses was continued HBOT recommended until "*complete resolution*".

ADJUVANTS

Ten of the 17 respondents would not use analgesia for DCS; two recommended paracetamol, two non-steroidal anti-inflammatories (NSAIDs) and one both paracetamol and NSAIDs. Two responses were void. Thirteen would not use steroids. One would use intravenous dexamethasone in severe neurological cases on the basis of potential reduction of oedema and inflammation arising from significant injury.

Thirteen out of 17 would not use lidocaine. Of those who would, one would use it for high pain scores and another only as per resuscitation guidelines, or in arterial gas embolism for its anti-arrhythmia properties. Only one would use aspirin. One respondent would consider gabapentin and pregablin for neuropathic pain, but acknowledged that this was not evidenced-based.

Discussion

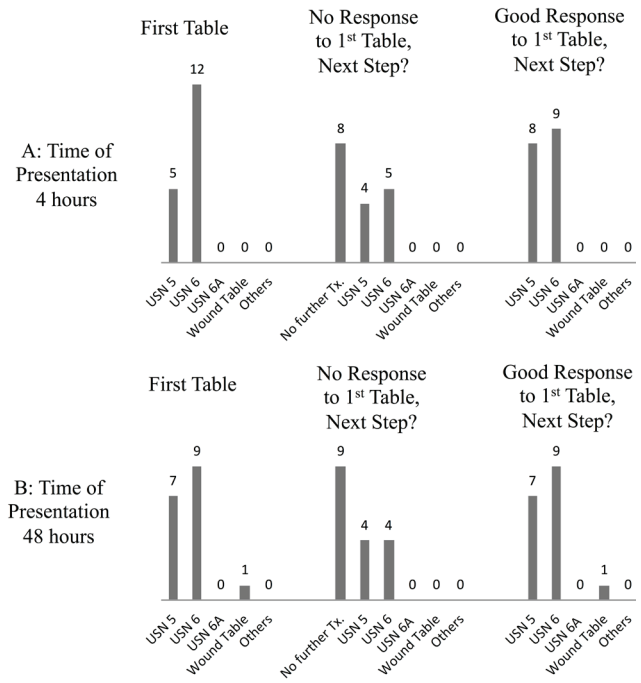
So far, there has been only one RCT on treatment for DCI.[5] Guidelines are largely based on case reports, case series and animal studies, and these have changed over the last 60 years, especially with respect to first aid and adjuvant treatment.[4]

INDICATIONS TO TREAT

All the respondents decided to recompress the cases described in the five scenarios. This is a more aggressive approach to treatment than that from a Swiss study in which for a pain-only DCI scenario with a delay-to-treatment of more than 24 hours post dive, only half the respondents chose recompression over normobaric oxygen.[6]

Mild DCI can be managed without HBOT, as after a finite period of time, stable mild symptoms rarely progress.[7] An international symposium in 2005 on the management of mild or marginal DCI in remote locations concluded that delays in the treatment were unlikely to adversely affect outcome.[8] Some physicians choose not to recompress patients with pain-only DCI. Using the American Heart Association classification, the use of HBOT for DCI is level C evidence with a Level I recommendation.[9] A Cochrane review also

Figure 1
Hyperbaric treatment preferences of 17 physicians for decompression sickness presenting with joint pain only; A – presenting within 4 h; B – presenting at 48 h



concluded that there was insufficient RCT data to support or refute the effectiveness of recompression.[4]

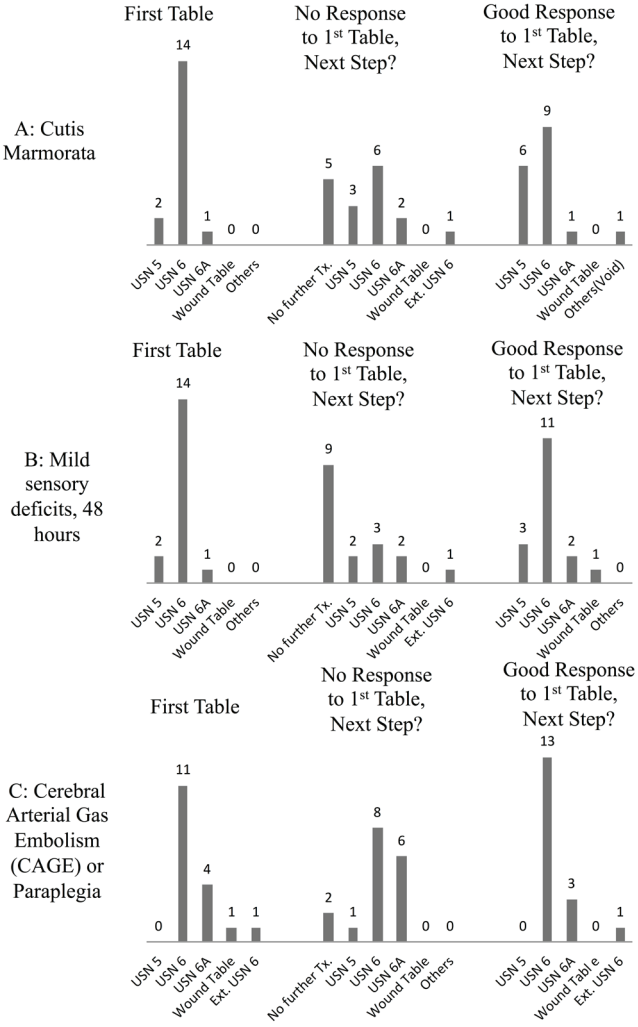
Alternatively, when oxygen treatment tables are used with an initial treatment pressure of 284 kPa and the delay to treatment is not excessive, most DCI symptoms tend to resolve with a high degree of success.[7] The Cochrane review also recommended HBOT as a universally accepted therapy for DCI and for ethical reasons mentioned it is not likely to be compared with placebo.

HBOT TREATMENT PREFERENCES

Recompression typically involves pressurization between 203 and 608 kPa for periods ranging from 2 hours (h) to several days.[3] The optimal treatment strategy for different clinical presentations has not been determined. One of the most common recompression profiles is USN TT6, with a 284 kPa maximum pressure while breathing 100% oxygen and lasting 4 h 45 min with the option for extensions. This profile has a low risk of cerebral and pulmonary oxygen-associated toxic effects.[3]

Twenty-one out of the 34 responses for the pain-only scenarios opted to start treatment with USN TT6. This could be because, although patients may present with pain-only symptoms initially, especially in an acute presentation with a post-accident time of 4 h or less, mild DCS may progress in severity after the initial assessment.[11] The preference for

Figure 2
Hyperbaric treatment preferences of 17 physicians for decompression illness; A - cutis marmorata; B –mild sensory symptoms at 48 h; C – cerebral air embolism or paraplegia



USN TT6 is supported by others who emphasize that shorter tables such as a USN TT5 are not recommended for initial treatment owing to higher rates of recurrence and post-treatment deterioration relative to USN TT6.[12] Although presentation with pain-only DCS at 48 h is associated with a low risk of symptom progression, USN TT6 rather than USN TT5 is still recommended since clinical response often occurs hours or even days after onset.[12]

END-POINT TO TREATMENT

Approximately two-thirds of the respondents chose to treat with one additional session after there was no further improvement as the endpoint to treatment for all DCI. Failure to institute follow-up treatment after initial recompression may cause delayed progression of initial symptoms. In sensory or pain-predominant DCS, symptoms often wax and wane daily.[13] Documenting improvement after each

treatment avoids unnecessarily prolonging the hyperbaric treatment course and reduces the risks of side effects such as oxygen toxicity. This preference is aligned with both the UHMS 2011 guidelines and Republic of Singapore Navy protocols for severe DCI. However, the choice of this option for mild DCS is inconsistent with existing guidelines.

The second most common preference was to stop after there is no further improvement. It is difficult to establish a fixed end point of treatment. This stems from DCS being a clinical diagnosis with a lack of objective diagnostic criteria from laboratory or imaging parameters. Clinical examination remains the best means of assessment despite it being an inadequate surrogate for assessing resolution of reperfusion injury.

Two of our respondents recommended treatment until complete resolution of symptoms. Most patients with residual neurological manifestations need only two or three treatments to reach a clinical plateau. Patients with residual symptoms post treatment may also remain anxious and stressed, and prefer to continue HBOT sessions in the hope for complete resolution, despite having reached a clinical plateau. This is further complicated by the nature of DCS symptoms often being sensory or pain sensations, which tend to fluctuate.

TREATMENT ADJUVANTS

Analgesia

About a third of our respondents would use analgesia in HBOT treatment. In pain-only DCS, physicians are only able to ascertain the success of treatment by resolution of pain. As analgesia may mask pain, physicians may feel that they are unable to accurately judge whether the symptoms of DCS have resolved. This hinders treatment decisions as to whether there is a need to continue HBOT. However in an RCT, tenoxicam was shown to reduce the number of recompressions needed to achieve symptom resolution, but did not change the final outcome.[5] It is surprising, then, that NSAIDs were not advocated more often by this group.

Steroids

Only a few respondents would use steroids in HBOT. Two respondents qualified their usage to only in cases of severe DCI. As well as reducing tissue oedema, steroids help to reduce ischaemia and intravascular platelet aggregation. However, steroids are generally not recommended in the treatment of DCI.[12]

Lidocaine

A quarter of respondents would use lidocaine in DCI. Lidocaine has been effective only in animal studies for AGE.[14] There is insufficient clinical evidence to recommend its use in DCS, although anecdotally its use may be justified in serious neurological DCI, when the response to recompression is poor.[15] The anti-inflammatory effect of lidocaine, coupled with its beneficial effects of membrane stabilisation, favourable haemodynamic properties in the ischaemic brain and increased cerebral blood flow, make lidocaine a good, yet unproven candidate for adjuvant use in DCI.[16]

Aspirin

Possible reasons why aspirin was little advocated in these scenarios may include concerns about its potential to cause or worsen central nervous system bleeding. There are possible bleeding complications associated with barotrauma during recompression. The ability of aspirin to inhibit platelet aggregation may be useful in prophylaxis for DCS but there is no convincing evidence that it is effective in therapy.[17] However, there are schools of thought that still consider aspirin as a mainstay of treatment. For example, many French hyperbaric centres, as of 2009, still prescribed aspirin routinely, possibly on the basis of preclinical trials that showed that the inhibition of platelet aggregation using aspirin or clopidogrel attenuates the clinical course of DCS.[18]

Conclusions

There was clear agreement amongst diving physicians in Singapore for a need for recompression, mainly using a USN TT6, for all cases of DCI of whatever severity or delay to treatment. However, there was no consensus regarding other aspects of management. This is consistent with previous surveys and reinforces the need for robust RCTs to validate the existing recommendations for DCI treatment.

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Case reports

Superior canal dehiscence syndrome associated with scuba diving

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Abstract

(Kitajima N, Sugita- Kitajima A, Kitajima S. Superior canal dehiscence syndrome associated with scuba diving. *Diving and Hyperbaric Medicine*. 2017 June;47(2):123-126.)
A 28-year-old female diver presented with dizziness and difficulty clearing her left ear whilst scuba diving. Her pure-tone audiometry and tympanometry were normal. Testing of Eustachian tube function revealed tubal stenosis. Video-oculography revealed a predominantly torsional nystagmus while the patient was in the lordotic position. Fistula signs were positive. High-resolution computed tomography (HRCT) of the temporal bone revealed a diagnosis of bilateral superior semicircular canal dehiscence (SCDS). Cervical vestibular-evoked myogenic potential (cVEMP) testing showed that the amplitude of the cVEMP measured from her left ear was larger than that from the right. In electronystagmography (ENG), nose-pinched Valsalva manoeuvres caused eye movements to be mainly directed counterclockwise with a vertical component. Tullio phenomenon was also positive for both ears. SCDS patients tend to be misdiagnosed and misunderstood; common misdiagnoses in these cases are alternobaric vertigo (AV), inner ear barotrauma, and inner-ear decompression sickness. It is difficult to diagnose vertigo attacks after scuba diving as SCDS; however, when the patient develops sound- and/or pressure-induced vertical-torsional nystagmus, HRCT should be conducted to confirm a diagnosis of SCDS.

Key words
ENT; Scuba diving; Injuries; Inner ear; Ear barotrauma; Radiological imaging, Valsalva manoeuvre; Case report

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Introduction

The dramatic ambient pressure changes that are experienced during scuba diving rarely result in sudden-onset vertigo and/or hearing loss. Rapid and strong changes in pressure within the middle ear are thought to cause alternobaric vertigo (AV) and inner ear barotrauma (IEBt).[1,2] Divers who have chronic Eustachian tube dysfunction are at higher risk of experiencing middle-ear disease.[1,2] Semicircular canal dehiscence (SCD) involving the superior canal (superior canal dehiscence syndrome [SCDS]) was first described in 1998.[3] SCDS is a rare disorder caused by the dehiscence or fracture of the temporal bone overlying the superior semicircular canal. SCDS is characterized by vertigo and vertical-torsional eye movements induced by loud sounds or stimuli that change middle ear or intracranial pressure.

We report here a case of bilateral SCDS, for which the most prominent symptom was vertigo during scuba diving, especially when a Valsalva manoeuvre was executed. To put this case in context we also include a review of the literature.

Case report

A 28-year-old woman presented to our clinic for assessment and treatment because she experienced slight dizziness and difficulty in clearing her left ear during scuba diving. Her pure tone audiometry and tympanometry results were within normal ranges, but Eustachian tube function testing revealed tubal stenosis of her left ear. Testing of fixation, positional, and positioning nystagmus revealed nothing unusual. She was diagnosed with mild alternobaric vertigo (AV) due to tubal stenosis and was treated with anti-allergy agents and nasal steroid spray. After treatment, her symptoms subsided.

Four months later, she experienced continuous dizziness, apparently being triggered not only by pressure changes during diving but also by sneezing and coughing associated with a common cold. She returned to our clinic. Up to this time, she had not experienced any equilibration disturbances during her daily routine. She also reported never having sustained head trauma or having any ear-related disease. Moreover, she reported no severe inner ear injuries, such as inner ear barotrauma (IEBt) or inner ear decompression sickness (inner-ear DCS).

To test for inner-ear hearing loss, we conducted pure tone audiometry and tympanometry, both of which yielded normal results. Eustachian tube function testing at this second visit confirmed the tubal stenosis revealed during

Figure 1
Video-oculographic recording using infrared CCD camera of horizontal and vertical eye movements in a patient with bilateral superior canal dehiscence syndrome revealed a predominantly torsional nystagmus while the patient was in the lordotic position

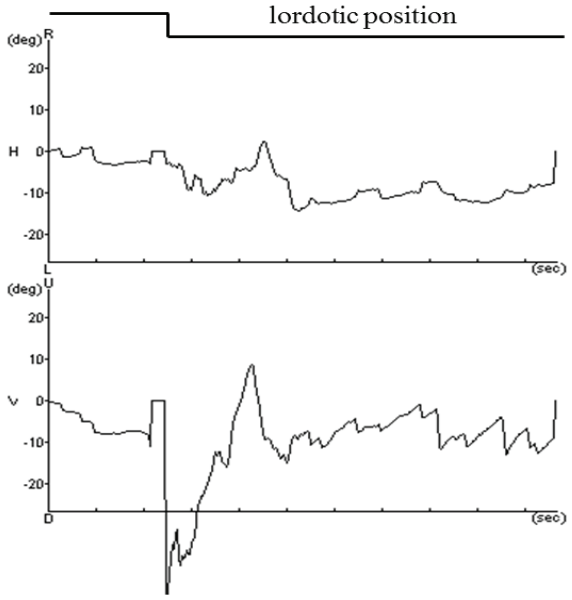


Figure 2
High-resolution CT images of the right and left temporal bones showing dehiscence (arrows) of the bone overlying the superior semicircular canal; coronal view (left panel) and Pöschl views (right panels, poor resolution images) through the right temporal bone

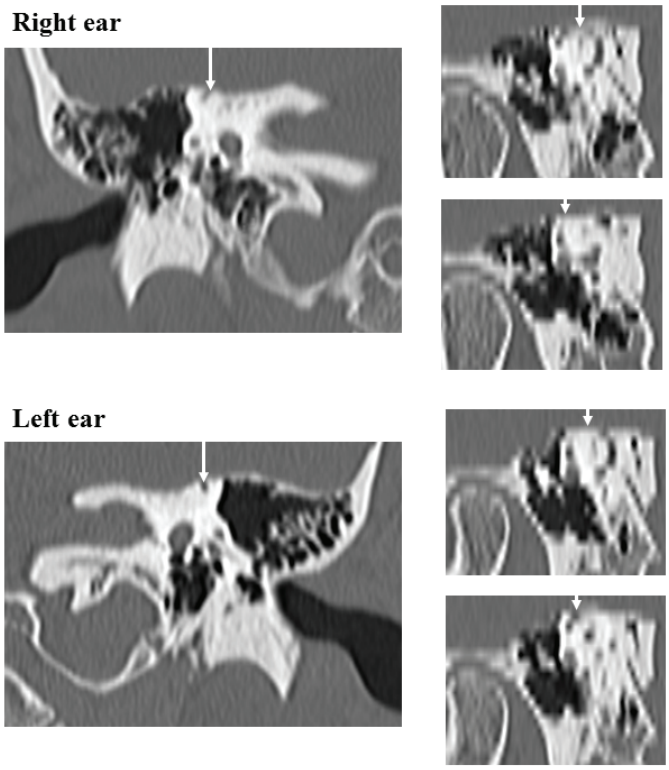


Figure 3
cVEMP testing results; the peak-to-peak (p13-n23) amplitude recorded from the left ear was greater than that from the right ear; the p13 peaks are indicated by black arrows, whereas n23 peaks are indicated by open arrows; the clicks were rarefactive square waves (length: 0.1 ms; intensity: 100 dB nHL)

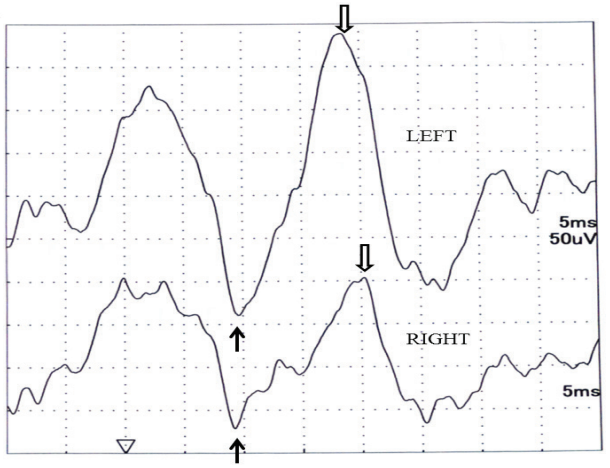
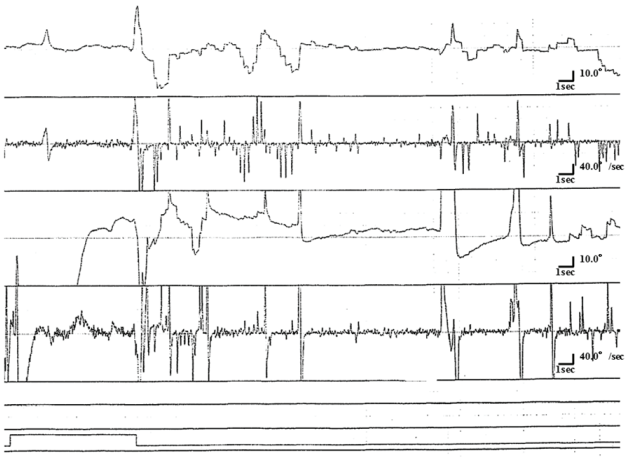


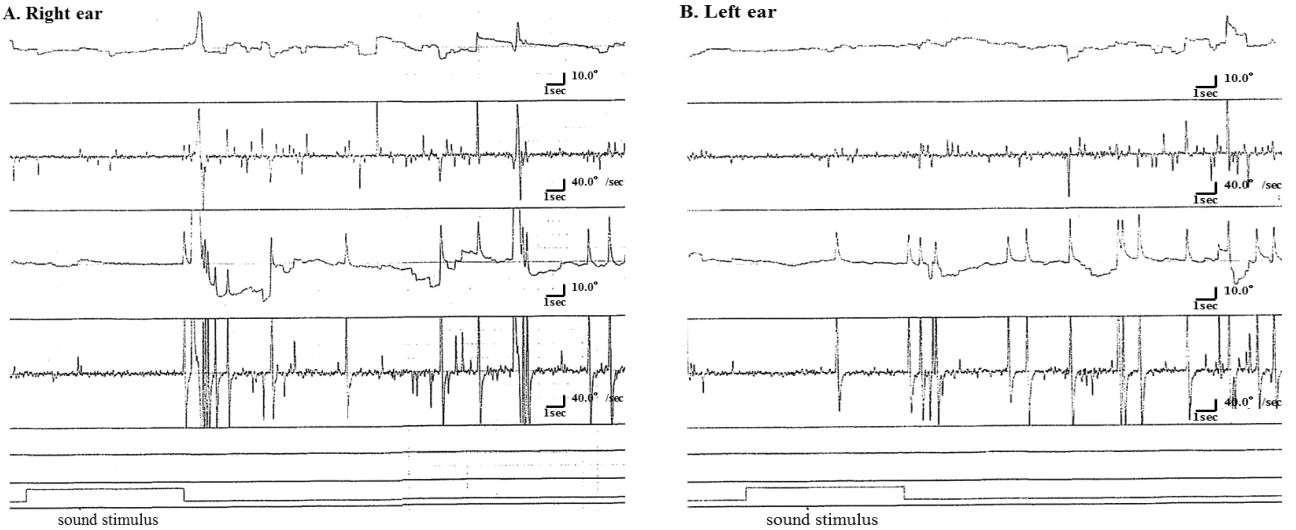
Figure 4
Electronystagmogram following a Valsalva manoeuvre; the manoeuvre induced nystagmus that was mainly directed counterclockwise and had a vertical component



her initial clinic visit. Nystagmus testing using an infrared CCD camera revealed a predominantly torsional nystagmus, especially while she was in the lordotic position. Slow phases were directed counterclockwise (Figure 1). Fistula signs were positive, because the patient exhibited very slight horizontal nystagmus beating to the right when positive pressure was applied to the left ear canal using a Politzer bag. These clinical findings led us to suspect a perilymph fistula in the left ear, which prompted us to carry out high-resolution computed tomography (HRCT). HRCT of the temporal bone was negative for perilymph fistula. However, it revealed bilateral dehiscence of the bone overlying the superior semicircular canals, consistent with a bilateral SCDS (Figure 2).

Figure 5

Electronystagmograms of the right (A) and left (B) ears recorded during a Tullio phenomenon; loud sound stimuli (100dB nHL at 1000 Hz) delivered to each ear induced nystagmus



She was admitted to the Tokyo Medical University hospital for further investigations, employing cervical vestibular-evoked myogenic potential (cVEMP) and electronystagmography (ENG) testing. cVEMP revealed a peak-to-peak (p13-n23) amplitude difference between ears, with a larger peak-to-peak amplitude originating from her left ear (Figure 3). In ENG, after nose-pinched Valsalva manoeuvres, the slow phases were directed counterclockwise or clockwise, but they were mainly counterclockwise with a vertical component (Figure 4). Tullio phenomenon was positive for both ears; loud auditory stimulation (100 dB nHL at 1000 Hz) induced nystagmus (Figure 5). Taken together, these results led us to diagnose her with bilateral SCDS, dominated by the left ear.

The patient declined medical therapy. However, we advised her to make lifestyle changes, such as avoiding excessive exercise, including diving; ceasing performing Valsalva manoeuvres and reducing excessive straining when blowing her nose. Six months after her second visit, her ear symptoms had improved.

This study was conducted in accordance with the Declaration of Helsinki for the ethical treatment of human subjects. All procedures were carried out with the patient's written informed consent and her consent to the publication of this case study. The review board of Tokyo Medical University approved all procedures (No. 3032).

Discussion

SCDS is diagnosed radiologically and is associated with the Tullio's phenomenon and Hennebert's sign. Tullio's phenomenon is the feeling of a spinning sensation evoked by sound. Hennebert's sign is nystagmus produced by applied pressure into the external auditory canal. These signs may arise in some cases from the development of a third mobile window within the bony labyrinth, which permits transmission of vibration into the vestibular apparatus, resulting in vertigo or dizziness.[3,4] Positive pressure applied to the external auditory canal and nose-pinched Valsalva manoeuvres cause endolymph motion with ampullofugal (excitatory) deflection of the cupula, which in turn induces a torsional-vertical nystagmus.[5] The nystagmus has slow-phase components directed upward and away from the affected labyrinth.

In the present case, the patient had bilateral SCDS. After performing nose-pinch Valsalva manoeuvres, she exhibited torsional-vertical nystagmus directed mainly away from her left side (Figure 4). In addition, cVEMP recordings revealed that cVEMP amplitude of the left ear was larger than that of the right ear (Figure 3). These findings led us to conclude that the dominantly affected ear was the left ear. Patients with a larger superior canal dehiscence show significantly more vestibulocochlear signs and symptoms and lower cVEMP thresholds compared to patients with a smaller superior canal dehiscence.[6] Thus, the results of diagnostic examinations may be associated with the size of the superior canal dehiscence as in this case.

Generally, in most SCDS patients, audiometry tests reveal low-frequency conductive hearing loss with normal or characteristically negative bone-conduction thresholds.[3,7] SCDS patients also suffer from recurrent vertigo attacks with vertical-rotational oscillopsia induced by pressure changes or loud sounds.[8] However, in our patient, audiometry test results were within normal ranges. Moreover, the patient had never experienced vertical oscillopsia, except when she was scuba diving. These findings indicate that the severity of her

Table 1
Differential diagnosis of barotraumatic inner-ear disease due to diving; entries in the last three columns derived from Kitajima, et al.[1] and Farmer and Gillespie;[9] DCS – decompression sickness; PLF – perilymphatic fistula; SCDS – superior canal dehiscence syndrome

	SCDS	**Alternobaric vertigo**	**Inner ear barotrauma**	**Inner-ear DCS**
Frequency	Very rare	Mostly	Second most common	Rare
Dive exposure	Any	Any	Any	Near or exceeding decompression limits
Onset	Descent, ascent or post-dive	Ascent or post-dive	Descent, ascent or post-dive	At depth, ascent or post-dive
Inner ear symptoms	Vestibular +/- cochlear	Vestibular	Cochlear +/- vestibular	About 50% vestibular, 30% cochlear, 20% both
Eustachian tube dysfunction	Yes	Yes	Yes	No
Tullio phenomenon and Hennebert's sign	Yes	No	Yes (if with PLF)	No
Clinical associations	Ear barotrauma	Ear barotrauma	Ear barotrauma	Other DCS symptoms; deep or saturation dive
Diagnostic imaging	Semicircular canal dehiscence	No abnormality	Leak of inner ear fluid into middle ear (if with PLF)	No abnormality
Type of gas breathed	Mainly air	Mainly air	Mainly air	Mainly helium or hydrogen
Treatment	Conservative/surgery	Conservative	Conservative/surgery	Recompression/oxygen

SCDS was mild and explains why it was difficult to diagnose her dehiscence. Our initial examination led us to believe that her vertigo attacks were triggered not only by excessive pressure changes during diving but also by Eustachian tube dysfunction, which made it difficult for her to equalize the pressure within the middle ear. The latter caused her to perform excessive Valsalva manoeuvres, which, together with rhinitis, caused her Eustachian tube function to worsen.

In a clinical setting, patients presenting with SCDS tend to be misdiagnosed and misunderstood. Vestibular signs and symptoms induced by pressure changes in the middle ear might lead to a misdiagnosis, such as AV, IEBt (including perilymph fistula) or inner-ear DCS. Table 1 presents a summary of the differential diagnosis of barotraumatic inner-ear disease related to scuba diving, including SCDS and AV. As it is difficult to distinguish SCDS from several other inner-ear diseases caused by scuba diving, we suggest performing HRCT of the temporal bone, because this is the most effective way to diagnose SCDS.

Conclusions

We encountered a young female patient with bilateral SCDS. She experienced dizziness correlated not only with scuba diving but also with sneezing and coughing. It is difficult to determine whether vertigo attacks that occur during diving arise from SCDS. However, when patients develop sound- and/or pressure-induced vertical-torsional nystagmus, clinicians need to consider the possibility of SCDS and then perform HRCT. These conclusions will be strengthened with more similar cases, which could lead to more accurate and consistent diagnoses in the future.

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A technical diving-related burns case: treatment in a remote location

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Abstract

(Sharp FC, Sayer MDJ. A technical diving-related burns case: treatment in a remote location. *Diving and Hyperbaric Medicine*. 2017 June;47(2):127-130.)
Injuries suffered as a result of a rebreather oxygen explosion and fire occurred to a diver on vacation in the island state of Chuuk, Micronesia. The medical and logistical management of the diver in a remote location are described. The mechanism of both the fire and the subsequent blast and burn injuries are discussed. Prevention of and preparation for such incidents are discussed in the context of the increasing frequency of dive and adventure travel to remote areas.

Key words
Burns; Fire or explosion; First aid; Medical kits; Rebreathers/closed circuit; Remote locations; Case reports

Introduction

Chuuk (or Truk) Lagoon, is part of the Chuuk State of Micronesia in the Western Pacific. It is a popular destination for wreck diving with many Japanese World War II shipwrecks lying in tropical waters.[1] The depth of some of the wrecks in the lagoon attracts technical and rebreather divers to Chuuk. Recreational technical diving methods and related decompression issues have been reviewed recently.[2,3] Chuuk is considered a remote diving location as medical facilities in the islands are limited and the commercial airline link *via* the island of Guam, which occurs once every one to two days, is frequently subject to cancellations and delays.

In 2013, a group of rebreather, technical and open-water scuba divers visited Chuuk to dive the wrecks. With organizational support from a diving travel company, the local dive operation provides helium, nitrox and oxygen to support rebreather, trimix and enriched air decompression diving. Compressed gases with oxygen percentages (PO_2) ranging up to 95% require special handling and precautions to prevent oxygen fires through frictional or adiabatic heating.[4] This case report describes the management of a critical incident caused by the explosion of a cylinder of oxygen-rich gas and the attached rebreather fire. Management is discussed within the context of a remote location.

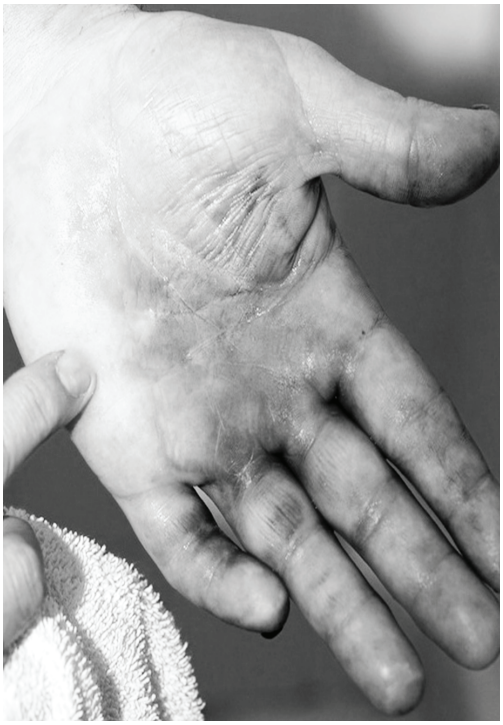
Case report

An experienced, 37-year-old male diver suffered a serious injury on the fifth dive day of the trip. The incident occurred on the dive boat prior to leaving the dock. Three rebreather divers had placed their equipment on a small, motorized diving boat (see cover) after setting up and checking them on land, where the divers had also performed their pre-breathe routines.[5] On completion of their preparations, the divers had turned off the cylinders to wait for departure.

With the rebreather on the floor of the boat, the diver leant over and turned on the diluent and oxygen cylinders; the oxygen cylinder had a water capacity of 3 litres (L) and was assumed to have been pressurized to approximately 200 bar. The oxygen first stage regulator exploded, causing a blast injury to the diver's hand (Figure 1) and the top of the rebreather caught fire (Figure 2). The subsequent fire burnt the diver significantly on the left upper arm (Figure 3), shoulder and neck; his lower arm and face were also partially affected. The diver promptly and voluntarily fell over the side of the small boat into the 1.5 m deep water to cool the burn. The rebreather burnt itself out, with no-one else injured, and minimal damage to the boat. The diver was removed from the water after approximately five minutes, and cooling of the burns continued under an outdoor shower. He was visibly shaken with a rapid, weak pulse of approximately 120 beats per minutes (bpm); blood pressure was not monitored at that time.

The travel company responsible for this diving group has a policy of employing a physician trained in diving medicine to accompany technical and deep diving expeditions. In the present case, the group doctor was a specialist anaesthetist (FCS) who was on-site when the explosion occurred and so was in immediate attendance. The diver was placed on a chair under the shower as he was getting syncope. He had severe pain from the burn on his arm. After removal of a short sleeve rash-guard, a full thickness burn was evident distal to the sleeve (Figure 3), with a partial thickness burn

Figure 1
Blast injuries to the diver's hand



surrounding this area. There was no evidence for or any symptoms of an airway burn or other signs of blast injury. His eardrums were not examined.

Cooling with freshwater continued in the diver's hotel room. IV cannulation was achieved with some difficulty, and analgesia and sedation were administered (morphine 15 mg IV, midazolam 10 mg IV total) with good effect. Antibiotics (cephazolin 2 g) and IV fluids (Plasmalyte 2 L total) were commenced after checking for allergies. Wound care was provided with antiseptic cream (Sulphasalazine) and cling-film dressings. The patient's blood pressure was taken for the first time and was 150/110 with a heart rate of 120 bpm. Pain relief was supplemented with oral paracetamol and his pain score remained 6 out of 10 on an analogue scale. With the supply of morphine now exhausted, a supply of oral analgesics was obtained from local sources (paracetamol/codeine 500 mg/30 mg, ibuprofen 200 mg and tramadol 100 mg). With these medications the diver was more comfortable that evening and was able to ambulate and eat.

The patient and buddy arranged for transfer back to Australia for definite care on the next flight available from Chuuk, three days following the injury. The plastic surgical unit at an Australian hospital advised by phone on on-going management of the patient's injuries. The wound was cleaned in the shower prior to dressing with an application of silver sulfadiazine and continued wrap with the cling film.

On day two, the patient awoke with malaise, lethargy and was apathetic. He was dehydrated with marked oedema of

Figure 2
The rebreather after the fire with explosive and thermal damage to the oxygen cylinder (A), the damaged head of the rebreather (B), burnt counter lung (C) and scrubber casing (D)

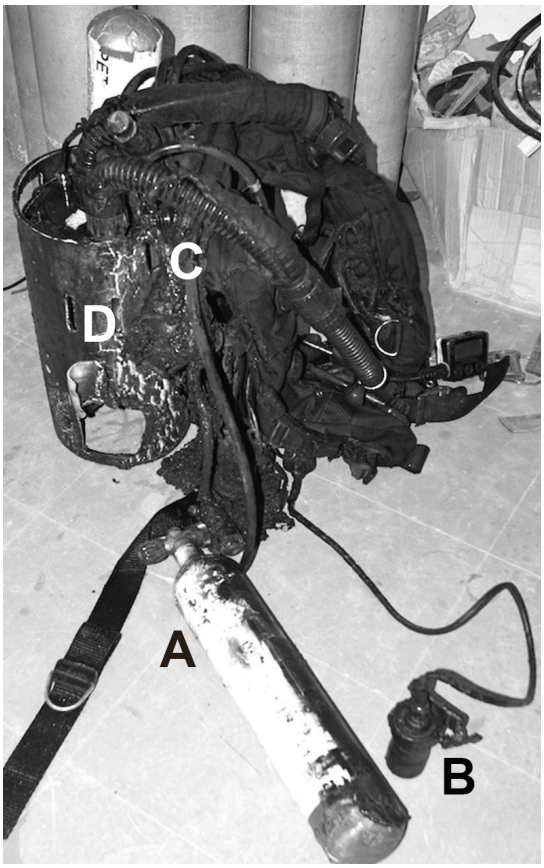
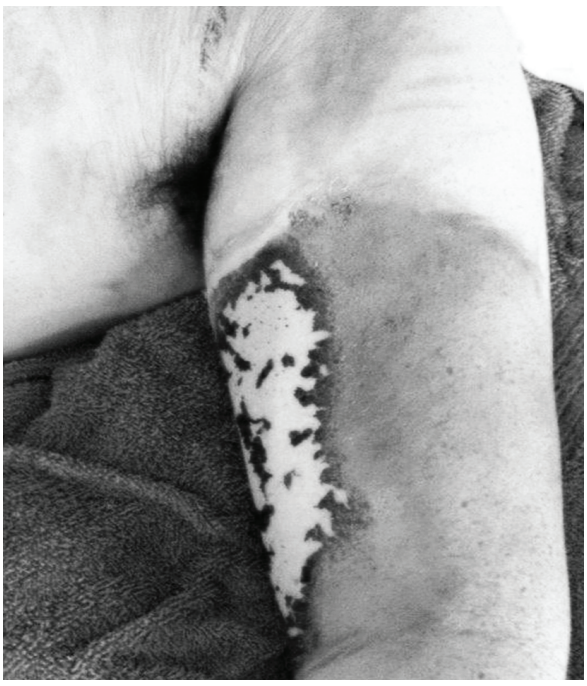


Figure 3
The diver's arm after being cleaned on day 1



the left arm and the wound dressing had an offensive smell. The wound was redressed after cleaning in the shower, and the antibiotic dose was increased. He increased oral fluids whilst keeping his arm elevated; the analgesics were continued with good effect. He had improved sufficiently the next day to be repatriated to Australia under medical escort. On the morning following his arrival to his home city he underwent debridement and skin grafting to the arm wound. He has healed well with minimal scarring.

Discussion

Diving with closed-circuit rebreathers on wrecks in relatively deep water offers numerous advantages. These include the lack of bubbles, their gas efficiency and the optimized decompression that constant PO_2 diving permits.[6] There are many confounding factors associated with wreck diving but, in general, studies of decompression illness (DCI) indicate incident rates of between 0.25 and 1.12 cases per 1,000 person-dives for wreck diving[7,8] compared with rates of between 0.05 and 0.10 for other recreational scuba diving.[9–12] The added risks of using mixed gases are largely unknown, but studies of diving deaths show that using a closed-circuit rebreather possibly carries a four- to ten-fold increase in the risk of dying while diving.[13] The combined additional risks of diving wrecks using rebreathers, while also in remote locations with limited medical support, are the reasons that many tour groups will employ physicians with practical experience in emergency medicine.

Previous reports of treating diving accidents in remote locations have focussed mainly on DCI from the perspective of managing that illness alone and the potential effects delays in treatment may have on subsequent outcomes.[14–17] Chuuk does have a stand-alone recompression facility but this is only sporadically operational, depending on whether the technical operator is on the island. The lack of many fundamental medical services complicates the treatment of non-DCI diving-related incidents.

Diving rebreather fires are very rare. Of 153 incidents reported during a series of 14,000 rebreather dives undertaken by the French military, none involved explosions or fires.[18] A fire has been reported in a Canadian underwater mine-countermeasure rebreather unit.[19] In that case, the fire occurred as the oxygen cylinder was being opened by the diver while on the surface; the subsequent investigation indicated that the origin of the fire was in the first stage regulator. There has been one case reported of a technical diver, diving at a depth of 90 m, sustaining severe burns when wearing a drysuit along with four air-activated heat packs.[20] The burns were caused by the exothermic chemical reaction of the heat packs accelerating out of control because the diver was using his decompression gas, which contained 83% oxygen, for suit inflation.

The risk of an oxygen cylinder fire is low; for example, it has been estimated that there are several million medical oxygen cylinders in service in the UK annually, that are filled many times each year with very few reported incidents.[21,22] One UK incident of an oxygen cylinder that exploded in an intensive care unit causing a fatal burn injury was reported in 2013,[21] with a further three oxygen cylinder fires occurring in the UK during a recent four-year period.[22]

It is suggested that the oxygen fire in the intensive care unit was caused when the cylinder valve was turned on;[21] this was the same in the present case. The internal design of a cylinder valve includes O-rings, valve seats and lubricants, all of which will have an auto-ignition temperature (AIT). Components designed for high-pressure cylinders have AIT values of over 300^{O}C in a 100% oxygen environment.[22] Impeding the flow of pure oxygen from high-pressure cylinders causes instantaneous compression and adiabatic heating. If that heating exceeds the AIT of one or more of the valve components then spontaneous ignition can occur; that ignition releases more energy which raises the temperature further igniting other adjacent materials with higher AIT. This is known as a "*kindling chain*" whereby the fire escalates rapidly in the valve causing an explosion.[22] Reducing the likelihood of adiabatic heating of oxygen decreases the probability of fires and explosions and is why valves on high content oxygen cylinders should be a 'needle' design. However, there is still a need to open needle valves slowly when dealing with high-pressure oxygen.

The present case reports on a cause of morbidity (burns and blast injury) other than DCI when diving on rebreathers and in a remote location. Non-governmental deep-diving groups travelling to remote locations where medical support may be lacking should have available to them sufficient medical supplies, medical expertise and communication options as deemed appropriate by the group's organisers. There are many published examples of medical kits that should be available to support diving operations or remote expeditions, such as that of the Diving Medical Advisory Committee in the United Kingdom.[23] The contents of the medical kit will be determined by a variety of factors, including the training and skills of personnel involved, medical registration and local drug regulations, the geographical location and its available health service resources, meteorological conditions, whether ship- or shore-based and weight limitations (e.g., for commercial flights).[17,24] The contents of kits used by the authors in different settings can be obtained by contacting them. What did turn out to be essential in the present case, so that narcotics could be included, was that a letter of recognition that the kit was for use by a qualified medical practitioner was carried along with copies of the doctor's current Medical Board certificate; one copy accompanied the medical kit while the doctor carried another copy.

In the present case, even though a comprehensive medical kit was carried, there was still a need to seek additional supplies as soon as it became apparent that the treatment would become prolonged. An assessment of what medical support is likely to be available in the location to be visited

should be used to prioritise what is in the medical kit, whilst accepting local legal restrictions. However, treatment should always be started immediately based on what the treating physician or other has to hand. Wider area searches should only be initiated after the patient has been stabilised.

Conclusions

Deep-diving and rebreather divers, along with remote dive expedition organisers should always be cautious of the use of cylinders containing pressurised high concentration oxygen gases. Divers should continue to remember or to be reminded to turn on oxygen cylinders slowly and to avoid contamination of first-stage valves in particular. Some diving-related travel companies employ physicians with specialist knowledge in diving medicine (and preferably with emergency medicine experience) to accompany deep technical-diving orientated expeditions. In planning a medical kit to support such expeditions, it is possible that involved organisers, paramedics and physicians may become overly focused on the potential management of DCI. This is understandable; however, because oxygen fires are known to occur with rebreather systems and other non-DCI problems are by far commoner, the medical kit should reflect this. Remember the adage, "*expect the unexpected*"!

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Correction to Mathieu D, Marroni A, Kot J: Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. *Diving Hyperb Med*. 2017 Mar;47(1):24-32.

Consistent with the Committee on Publication Ethics guidelines, we the above authors are initiating a partial retraction and correction of our paper: Mathieu D, Marroni A, Kot J: Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. *Diving Hyperb Med*. 2017 Mar;47(1): 24-32.

We wish to make the following statement:
"*Regardless of the strict process of editing and proof-reading of tables included in the above-mentioned publication, we received some comments from readers which showed us that imperfect layout of Table 1 and incorrect layout of Table 2 changed significantly the conclusions which could be drawn from them.*

Table 1 described the relation between strength of recommendations given by the Jury of the Consensus Conference and the level of evidence based on the GRADE system. There should be a clear and straight relation showing that Level 1 "strong recommendation" should be based on GRADE A "high level of evidence (LOE)", Level 2 "weak recommendation" should be based on GRADE B "moderate LOE", Level 3 "neutral recommendation" should be based on GRADE C "low LOE" and finally no recommendation should be given when only GRADE D "very low LOE" are present. Note that there is no change to the content of the table, but only visual representation of this relationship.

Table 2 has been incorrectly printed. In fact, there is no GRADE A LOE. All X marks placed in the column A should be moved to the right, to GRADE B LOE. In the same way, all X marks placed in the column B should be moved to the right, to GRADE C LOE.

We voluntarily retract these tables from the above-mentioned publication, expressing our regret for the situation."

Daniel Mathieu[1], Alessandro Marroni[2], Jacek Kot[3]

[1] European Committee for Hyperbaric Medicine: President, Professor of Critical Care Medicine, Critical care Department, Medical University and Hospital of Lille, France
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The corrected Tables 1 and 2 are published below and have been corrected in the pdf version of the March 2017 issue on the society websites.

Table 1
Consensus-based and GRADE scaling for recommendations;
GRADE – Grading of Recommendations Assessment, Development and Evaluation System

Strength of Recommendation (Consensus-Based)	**Level of Evidence (Based on GRADE System)**
Level 1 = Strong recommendation = "*We recommend…*" The course of action is considered appropriate by the large majority of experts with no major dissension. The panel is confident that the desirable effects of adherence to the recommendation outweigh the undesirable effects.	**Grade A** = High level of evidence The true effect lies close to our estimate effect.
Level 2 = Weak recommendation = "*We suggest…*" The course of action is considered appropriate by the majority of experts but some degree of dissension exists amongst the panel. The desirable effects of adherence to the recommendation probably outweigh the undesirable effects.	**Grade B** = Moderate level of evidence The true effect is likely to be close to our estimate of the effect, but there is a possibility that it is substantially different.
Level 3 = Neutral recommendation = "*It would be reasonable…*" The course of action could be considered appropriate in the right context.	**Grade C** = Low level of evidence The true effect may be substantially different from our estimate of the effect
No recommendation No agreement was reached by the group of experts.	**Grade D** = Very low level of evidence Our estimate of the effect is just a guess, and it is very likely that the true effect is substantially different from our estimate of the effect.

Table 2
Recommendations on the indications accepted for HBOT; there was no Level A evidence.

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

Submitted: 29 April 2017
Accepted: 02 May 2017

Key words
European Committee for Hyperbaric Medicine; Retraction

Letters to the Editor

ECHM Consensus Conference and levels of evidence

The ECHM Consensus Conference on indications for hyperbaric oxygen treatment (HBOT) was a welcome update of the evidence for HBOT use.[1,2] However, clarification is requested in relation to how the GRADE system (Grades of Recommendation, Assessment, Development and Evaluation) was modified and how levels of evidence were applied in the case of idiopathic sudden sensorineural hearing loss (ISSHL). GRADE has a low kappa value for inter-observer agreement, so is modification valid?[3]

The original GRADE criteria, using consensus, grades evidence (defined as high, low and very low) and uses this to adjust the strength of recommendations.[4,5] Randomised controlled trials (RCTs) score highly. The ECHM have modified the GRADE system without explanation, assigning grades as levels 1 to 4 and have asserted that RCTs which are double-blinded constitute level 1 or 2 evidence. This has important implications for HBOT research. The term double-blinded is not used in the abstract, which leads the reader to wonder; where do RCTs which are not double-blinded fit in? The ECHM, by including the term double blinded as a requirement for level 1 or 2, has lifted the evidence bar. Does this constitute a form of research "*bracket creep*"?

Double-blinding is viewed by many to require a 'sham' treatment in hyperbaric research. Many conditions require multiple doses requiring daily hospital attendance with associated costs of lost time from work and daily transport costs. Even with a crossover after the sham, a requirement of many ethics committees, the lost time for a patient is a considerable burden. Delaying HBOT until crossover in those randomised to the control group in a disease that has a narrow therapeutic temporal window, such as idiopathic sudden sensorineural hearing loss (ISSHL), may affect the chance of recovery. Double blinding is logistically difficult with HBOT. A sham treatment may be achieved by using air instead of oxygen; however, this exposes the non-intervention group to a risk that the intervention group does not have, that of decompression sickness (DCS). This may be considered to be unethical.[6] Researchers have used hypoxic air mixtures to compensate for the higher oxygen partial pressure at depth as the control, but this is complex and increases the nitrogen load (and thus the risk of DCS). RCTs which control by other methods should still be considered high level evidence (as the original GRADE system recognised). Many indications for HBOT have multiple therapies against which to compare, which could act as a control. The requirement for double-blinding to achieve level 1 or 2 evidence may hamper research; an unintended negative consequence.

There is lack of consistency of definitions in relation to levels of evidence used by the ECHM. The authors state that for clinical research the levels of evidence are; levels A to F, which they defined. The ECHM jury used a grading scale of level 1 to 4. For ISSHL, this results in a recommendation to treat based on level B evidence. Is this the same as level 2 in their modified system? This is confusing. The authors have not explained why they modified the GRADE system which is itself non-validated.[2]

The lack of references to the publications which provide the foundation for the strength of the recommendations leaves the reader unable to determine the true strength of the evidence. The GRADE system has been criticised as it dissociates recommendations from the evidence that the recommendation is founded upon.[3] Further, the application of the GRADE system has been questioned when strong recommendations are made with it as this may cause ethics committees to question whether equipoise exists, further hampering research. How do we present a well-designed trial for ISSHL to an ethics committee when a strong recommendation has already been made despite the Cochrane review on ISSHL concluding there is a need for large, well designed RCTs in this area?[7]

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Key words
Hyperbaric oxygen therapy; Medical conditions and problems; Evidence; European Committee for Hyperbaric Medicine; Letters (to the Editor)

Reply:

Dr Sherlock asks for clarification on the approach adopted by the European Committee on Hyperbaric Medicine (ECHM) to assessing evidence for establishing indications for hyperbaric oxygen treatment (HBOT).[1]

Firstly, regardless of the strict process of editing and proof-reading of tables included in the above-mentioned publication, we received comments from some readers that identified imperfect layout of Table 1 and incorrect layout of Table 2 which significantly changed the conclusions to be drawn from them. This concerned both the details of the methodology used and description of the ECHM recommendations and associated levels of evidence. Therefore, those tables are republished in their correct forms in this issue, hoping that this will explain at least some of the doubts and misunderstandings.[2] Both the Editor and ourselves apologise for these errors of publication.

Secondly, in the ECHM Consensus Conference methodology, we scored the evidence for clinical studies requiring double-blind randomised controlled trials (RCT) as Level A and B when, at the same time, some scoring scales require simply 'RCT', as correctly pointed out by Dr Sherlock. Long experience in organising evidence based medicine (EBM) meetings and discussions has taught us that RCTs that are not double blinded are often criticised as having serious potential bias and so are denied as level A evidence. Although we acknowledge that double blinding a clinical study in HBOT is a source of difficulty, we chose *a priori* to consider only double-blinded RCTs in our grading scale to avoid endless discussions about this potential bias. We are well aware that doing so means that Level A evidence is a difficult target for the hyperbaric community.

We agree that many evidence scoring systems have a low level of inter-observer agreement. This is why we treat the Consensus Conference as a valuable tool that provides a better opportunity for discussing the evidence than analysis by a small group of 'experts'. This is because the whole process is transparent and available to all participants' comments and input. The final process of voting by the audience after the general discussion thus truly reflects the position of the professional hyperbaric community in Europe on the issued recommendations. By these two mechanisms, the blind application of disputable evidence scoring systems may be avoided or, at least, decreased.

Thirdly, the problem of 'sham' treatments in hyperbaric research has been raised. While this has been discussed many times in the past, hyperbaric research is not the sole field where such sham treatment raises some difficulty. Surgery is probably the best example where RCTs with control arms utilising sham surgical procedures (possibly including the administration of anaesthesia) are rare and can raise major ethical problems. Nevertheless, from an EBM viewpoint, the difficulty of designing a double-blind study is never taken into account during evaluation of clinical studies.

Finally, Dr Sherlock pointed out her doubts on the recommendations issued by the ECHM on idiopathic sudden sensorineural hearing loss (ISSHL). While there is no possibility to cite here the full experts' report on that issue presented during the conference, we understand that a detailed report from the Conference is being prepared for publication. In brief, the strength of evidence has been scored as Level B, in general agreement with the last Cochrane review and the UHMS Committee report.[3,4] Based on this level of evidence, the Type 1 recommendation was issued with the agreement of the large majority of the Consensus Conference participants.

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Key words
Hyperbaric oxygen therapy; Medical conditions and problems; Evidence; European Committee for Hyperbaric Medicine; Letters (to the Editor)

Launch of the ANZCA Diploma of Advanced Diving and Hyperbaric Medicine

In April 2016, the Australian and New Zealand College of Anaesthetists (ANZCA) Council supported a limited restructure of the ANZCA Certificate in Diving and Hyperbaric Medicine (DHM). A project group was established in June 2016 and is leading the change of the Certificate to a 12-month, full-time equivalent qualification entitled the ANZCA Diploma of Advanced DHM.The ANZCA Diploma of Advanced DHM will launch on 31 July 2017 under the governance of the ANZCA DHM Sub-Committee.

Training program documents were released on 01 May 2017 on the ANZCA website <www.anzca.edu.au/training/diving-and-hyperbaric-medicine> and include:

- The ANZCA Advanced Diving and Hyperbaric Medicine Curriculum;
- The ANZCA Handbook for Advanced Diving and Hyperbaric Medicine Training;
- The ANZCA Handbook for Advanced Diving and Hyperbaric Medicine Accreditation.

Diploma requirements include:

- Clinical experience (time) in an ANZCA-accredited training unit;
- Specific clinical activities (termed "*volume of practice*") such as "*assessment of fitness to dive (recreational or occupational diving) or hyperbaric attendance*";
- Formative workplace-based assessments to provide feedback on performance;
- Clinical placement reviews at which supervisors review the trainee's progress through the diploma;
- Formal learning/instruction including the South Pacific Underwater Medicine Diploma of Diving and Hyperbaric Medicine, an advanced life support course and two diving and hyperbaric medicine courses;
- The DHM examination;
- Completion of a Specialist qualification (FANZCA, FACEM, FCICM, FRACP, FRACGP, FRNZCGP, FACRRM or another qualification recognised by the ANZCA Council for this purpose).

Eligibility requirements and provisions are available for those transitioning from the Certificate in DHM to the Diploma of Advanced DHM. To be eligible to apply for transition credits, transition applicants must fit into one of the two groups defined below:

- Those who registered as Certificate trainees and have not been awarded the Certificate by 31 July, 2017; this may include trainees who have completed part or all of the certificate requirements;
- Applicants who are in, or have been in supervised positions in ANZCA-accredited DHM units at any time prior to 31 July 2017, but who did not register as DHM trainees prior to 01 August 2013.

Transition applicants' individual situations will be reviewed by the Director of Professional Affairs Assessor.

Applications for transition credits must be made no later than 28 August 2017.

Those who do not indicate an interest in completing the Diploma and do not apply for transition credits within the permitted timeframes may register at a later date and can apply for recognition of prior learning.

Please direct any queries to <dhm@anzca.edu.au>.

ANZCA Diploma of Advanced DHM Project Group:
Professor Michael Bennett FANZCA (Chair), Dr Damian Castanelli, FANZCA, Associate Professor Ian Gawthrope, FACEM, Dr Glen Hawkins, FANZCA, Dr Simon Jenkins, FANZCA, Associate Professor Simon Mitchell, FANZCA, Dr Lindy Roberts, FANZCA, Associate Professor David Smart, FACEM, Dr Suzy Szekely, FANZCA, Dr David Wilkinson, FANZCA.

Key words
Education; Training; Qualifications; Letters (to the Editor)

Errata

Incorrect date in *The Editor's offering*, March 2017 issue

In the March 2017 issue, there is an incorrect date attribution (2006) in the text (page 1, left column, third paragraph, fourth line) to the editorial by Mutluoglu et al that was published in Diving and Hyperbaric Medicine in September 2016.

Wrong photographer, March 2017 issue

The photographer for the front-page image in the December 2016 issue of *Diving and Hyperbaric Medicine* was wrongly attributed. The photographer was Dr Andrew Fock of Melbourne.

These errors have been corrected in the pdf version of the March issue available to members on the websites.

Notices and news

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

43rd EUBS Annual Scientific Meeting 2017

Dates: 13–16 September
Venue: Ravenna, Italy

Organising Committee: Paolo Pelaia (Ancona), Monica Rocco (Roma) and Pasquale Longobardi (Ravenna)
Scientific Committee: Paolo Pelaia, Costantino Balestra, Zjelko Dujic, Jacek Kot, Monica Rocco and Pasquale Longobardi

The EUBS Executive Committee and the local organising committee welcome you to Ravenna for the 43rd Annual Scientific Meeting of EUBS.

The dedicated conference website <www.eubs2017.org/en/> is now active and provides practical information and registration for the conference. On-site registration opens 12 September, 1200–1300 h

DMAC workshop: Nutrition and hydration for saturation divers and medical aspects of hyperbaric evacuation
Other workshops include those of the ECHM and EBAss and master classes for young investigators

Post-conference events
Saturday 16 September 1300–1930 h: DAN Divers Day
Sunday 17 September 0900–1800 h: SIMSI Tours – diving experience into the oil platform wreck *Paguro*

The EUBS ASM programme is available at: http://www.eubs2017.org/en/program/

Do not forget to apply for the EUBS Student Travel Grant, the EUBS Research Grant, the Zetterstrom Award or the Musimu Award (all details can be found on the EUBS2017 website)

Follow us on Facebook: https://www.facebook.com/eubs2017/

EUBS Member-at-large Election

A new Member-at-large to serve a three-year term on the EUBS Executive Committee (ExCom) needs to be elected, either proposed by the current ExCom or by sponsorship from 15 EUBS members. EUBS members are invited to propose candidates for this position by e-mail to <secretary@eubs.org>. Candidates for this three-year term position will be presenting themselves on the EUBS website with a picture and short CV.

Election will be conducted by internet ballot and will open on 01 July, 2017. If you have not received such an e-mail by the end of June, please notify us at <secretary@eubs.org>, and we will work with you to find out the reasons why. As the system works via e-mail, it is possible the message ended up in your spam folder. There may be other reasons but usually we are able to solve them.

EUBS Affiliate Society agreements

As of April, the Swiss Society for Diving and Hyperbaric Medicine (SUHMS) has been added to the Affiliates list. Members of our Affiliate Societies can benefit from a 10% discount on EUBS membership (this can be indicated upon membership application or renewal).

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

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

Second Tricontinental Scientific Conference on Diving and Hyperbaric Medicine

Dates: 23–29 September 2018
Venue: Durban, South Africa

After a very successful first Tricontinental Conference on Reunion Island in 2013, the Joint Organising Committee of EUBS, SPUMS, SAUHMA and the Scott Haldane Foundation have proposed Durban as the venue for the next Tricontinental Scientific Conference (TRICON2018). This has been accepted unanimously by the Society ExComs.

There will be a week full of scientific and social events, including but not limited to workshops, discussion sessions, special topic conference, welcome and other parties, diving (Aliwal Shoal is nearby), wildlife, rugby, Zulu culture, etc.

The combination of easy access, nice weather, friendly people, rich culture and nature and affordable prices makes this an opportunity not to be missed.A dedicated website will soon be available for all information.
Start planning your trip right now!

Notices and news

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

Australian and New Zealand College of Anaesthetists news

The Certificate in Diving and Hyperbaric Medicine of the ANZCA has been under review for the past three years. The new programme, for the qualification of *Diploma of Advanced Diving and Hyperbaric Medicine*, is announced elsewhere in this edition of the journal.[1] The training programme for this qualification has been developed and modelled along the lines of the current training programme for the ANZCA Fellowship and the Fellowship of the Faculty of Pain Medicine. There are substantial documents informing the revised curriculum, training portfolio, and assessment of trainees, as well as a new process for the accreditation of hyperbaric facilities wishing to train Diploma candidates.

I would encourage you all to read the announcement from the College. This is the culmination of intensive activity on the part of the working parties and College staff, with the aim of making this higher qualification in diving and hyperbaric medicine more achievable and accessible without in any way compromising the quality of the training programme. My sincere thanks go to the many members of the working parties and the innumerable ANZCA staff who have contributed to this process.

Reference

1 Launch of the ANZCA Diploma of Advanced Diving and Hyperbaric Medicine. *Diving Hyperb Med.* 2017;47:135.

Suzy Szekely
Chair, ANZCA Diving and Hyperbaric Medicine Special Interest Group
Suzy.Szekely@health.sa.gov.au

SPUMS Diploma in Diving and Hyperbaric Medicine

Requirements for candidates (May 2014)

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

1 (S)he must be medically qualified, and remain a current financial member of the Society at least until they have completed all requirements of the Diploma.
2 (S)he must supply evidence of satisfactory completion of an examined two-week full-time course in diving and hyperbaric medicine at an approved facility. The list of such approved facilities may be found on the SPUMS website.
3 (S)he must have completed the equivalent (as determined by the Education Officer) of at least six months' full-time clinical training in an approved Hyperbaric Medicine Unit.
4 (S)he must submit a written proposal for research in a relevant area of underwater or hyperbaric medicine, in a standard format, for approval before commencing the research project.
5 (S)he must produce, to the satisfaction of the Academic Board, a written report on the approved research project, in the form of a scientific paper suitable for publication. Accompanying this report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–4 above.

In the absence of other documentation, it will be assumed that the paper is to be submitted for publication in *Diving and Hyperbaric Medicine*. As such, the structure of the paper needs to broadly comply with the 'Instructions to authors' available on the SPUMS website <www.spums.org.au> or at <www.dhmjournal.com>.

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

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

Additional information – prospective approval of projects is required

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

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

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

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

Projects will be deemed to have lapsed if:

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

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

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

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

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

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

Royal Adelaide Hospital Medical Officers' Course in Diving and Hyperbaric Medicine 2017

Dates: 28 August–08 September
Venue: The Royal Adelaide Hospital, Adelaide
Cost: AUD2,500.00 (inclusive of GST)

Course Conveners: David Wilkinson and Suzy Szekely

Invited faculty includes: Professors Michael Bennett and Simon Mitchell

The course content includes:
- Physics and physiology of diving
- Recreational fitness-to-dive
- Occupational fitness-to-dive
- Decompression illness and non-dysbaric injuries
- Medical management and return to diving
- Technical and professional diving
- Marine envenomation
- Introduction to hyperbaric medicine

Contact for information:
Ms Lorna Mirabelli, Course Administrator
Phone: +61-(0)8-8222-5116
Fax: +61-(0)8-8232-4207
E-mail: <Lorna.Mirabelli@sa.gov.au>

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

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

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

The new website has now been launched. Members are encouraged to log in and update their personal details.

Royal Australian Navy Medical Officers' Underwater Medicine Course 2017

Dates: 02–20 October
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. Emphasis is placed on the contraindications to diving and the diving medical assessment, together with the pathophysiology, diagnosis and management of common diving-related illnesses. The course includes scenario-based simulation focusing on the management of diving emergencies and workshops covering the key components of the diving medical.

Cost: AUD1,355 without accommodation
(AUD2,300 approx with accommodation and meals 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)2-9647-5117
E-mail: <Rajeev.Karekar@defence.gov.au>

Advertising in *Diving and Hyperbaric Medicine*

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

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

Copyright

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

Course calendar 2017

Saturday 04 November: Symposium on diving medicine: Disorders of the head, from ophthalmology to psychology

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

British Hyperbaric Association Annual Scientific Meeting 2017

Dates: 20–21 October
Venue: Jury's Inn, Birmingham

The meeting will be held jointly with the UK Diving Medical Committee and will be aligned to refresher training for HSE Approved Medical Examiners of Divers. The Dive Show is also being held in Birmingham 21–22 October.

For more information: < http://www.ukhyperbaric.com/meetings/2017-annual-scientific-meeting-and-agm/>

Hyperbaric Oxygen, Karolinska

Welcome to: <http://www.hyperbaricoxygen.se/>
This site, supported by the Karolinska University Hospital, Stockholm, Sweden, offers publications and high-quality lectures from leading investigators in hyperbaric medicine. Please register to obtain a password via e-mail. Once registered, watch online, or download to your iPhone, iPad or computer for later viewing.
For further information contact:
E-mail: <folke.lind@karolinska.se>

The Science of Diving

Support EUBS by buying the PHYPODE book "*The science of diving*". Written for anyone with an interest in the latest research in diving physiology and pathology. The royalties from this book are being donated to the EUBS.
Need more reason to buy? We don't think so!
Available from: Morebooks <https://www.morebooks.de/store/gb/book/the-science-of-diving/isbn/978-3-659-66233-1>

DAN Europe

DAN Europe has a fresh, multilingual selection of recent news, articles and events featuring DAN and its staff.
Go to the website: <http://www.daneurope.org/web/guest/>

Scott Haldane Foundation

As an institute dedicated to education in diving medicine, the Scott Haldane Foundation has organized more than 230 courses over the past 20 years. SHF is targetting a more and more international audience with courses worldwide.

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

SHF Course Calendar 2017
04–11 November: Basic course part 1, Flores/Komodo, Indonesia
11–18 November: 25th in-depth course diving medicine, Flores/Komodo, Indonesia
18–25 November: 25th in-depth course diving medicine, Flores/Komodo, Indonesia

On request: Internship different types of diving (DMP certification), NL
On request: Internship hyperbaric medicine (DMP certification), NL/Belgium
For further information: <www.scotthaldane.org>

German Society for Diving and Hyperbaric Medicine (GTÜeM)

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

Instructions for authors

A downloadable pdf of the 'Instructions to authors' (revised June 2017) and other guidance for preparing a submission can be found on the *Diving and Hyperbaric Medicine* (DHM) website: <www.dhmjournal.com>.

Authors must read and follow these instructions carefully.

All submissions to *DHM* should be made using the portal at <http://www.manuscriptmanager.com/dhm>. Before submitting, please view the video on how to prepare a submission at: <https://www.youtube.com/watch?v=gpMsPAX4pWA&t=41s>.

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

DIVER EMERGENCY SERVICES PHONE NUMBERS

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

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

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

SOUTHERN AFRICA
0800-020111 (in South Africa, toll-free)
+27-828-106010 (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 incidents. 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 email: <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 authors and are not necessarily representative of the policies or views of the SPUMS, EUBS or the Editor and Board.

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