The Editor's Offering

This issue opens with the second part of Michal Kluger's erudite and informative discussion of the implications of hyperbaric medicine for anaesthesia and intensive care. All members should photocopy this and give the copy to their anaesthesia and intensive care colleagues. The Editor would like to suggest lending the Journal, but it might never be returned!

Risk assessment gets a guernsey in this issue with presentations from Australia, New Zealand and Scotland. All three papers emphasise that risk prediction requires knowledge of the actual happenings which occur rather than predicting from theory, which may be clear and obvious but at the same time wide of the mark when it comes to results. An everyday example is the economists' predictions that all those thrown out of work by tariff and business changes will immediately find other work. The last 15 years in Australia have shown that this does not happen but even last week an Australian economic think tank made this assumption in its predictions! One hopes that doctors are better at weighing evidence than economists and that as many diving doctors as possible will assist those who are trying to establish data bases about the real diving world. The Editor has lost touch with one diver he knew in the early 1980s, who took his asthma medication regularly and had survived at least 10 years of regular and frequent diving, including cave diving at Mount Gambier in water which never exceeds 12°C. I hope he has hung up his fins by now but quite certainly he has not figured in the published series of reports on Australian diving-related deaths.

There is no doubt that the theoretical risks of asthma and insulin dependant diabetes are frightening and occasionally occur. What one has seen colours the conclusions drawn from evidence. Especially if one only sees the disasters, which stick in the memory and overshadow the fact that most people do not have disasters when diving. Medicine is starting the process of assessing treatments. Admittedly one reason is that showing which treatments are most effective allows doctors to use the money provided by hospital administrators more efficiently to treat more patients at less cash per head. Another is that many treatments have very little effect on the course of an illness and if this can be clearly shown patients can be spared the inconvenience, pain, undesirable side effects and suffering which unsuccessful treatments can cause. Diving doctors are involved with a recreation which does involve danger, for the sea makes no allowances for human frailty. Very few of the diving disasters are caused by pre-existing illness. This could be due to excellent screening by diving doctors, but we all know that some diving candidates tell lies to the examining doctor so that they can pass their medical and get underwater. Many more divers come to grief from incompetence in the water than from medical problems. Perhaps our contribution to safety should be to monitor effectiveness of medical screening honestly and at the same time monitor the effectiveness of diving training by studying incidents (already being done by the diving incidents monitoring study {DIMS}), by collecting Australia-wide statistics of diving accidents and bringing the results to the notice of the diving training organisations so that they can use the evidence to improve diver training. Almost every dead diver is still wearing the weight belt when the body is recovered. This has not changed in the last 25 years. Perhaps it is fear that a rapid ascent will cause an air embolus which prevents people from dropping their weight belts. From the available statistics it seems likely that a rapid ascent is more likely to result in decompression sickness (DCS) than air embolism. DCS is a treatable condition, death is not.

The results of treatment for DCI in Australasia are less than optimal. This is probably because the vast majority of affected divers present for treatment many hours and even days after the onset of symptoms. But commercial divers (occupational divers in the oil and gas industries) have a very high rate of cure. The basic difference in their treatment is that it is prompt, within minutes of symptoms occurring. David Elliott's paper about the treatment of DCI after recreational technical diving emphasises this point. He expects to cure, completely, with the first recompression treatment. Otherwise the diver may well have residua and no longer be an acceptable employee to the diving companies. Recreational divers who have spent many hours making their way to the recompression chamber may have let their disease progress past the easily treated stage. DCI is a sequential disease, changes follow on changes. Cure is straightforward if the disease is not overwhelming the body's defences and it is treated immediately. Much the same can be said about the effects of blood loss following trauma. Early, large volume resuscitation can prevent the disaster of renal shut down. There is a window of opportunity, time limited, which was well exploited in the Viet Nam war by helicopter evacuation direct to a hospital which was equipped to carry out definitive treatment. Both the Australian and American hospitals were achieving survival rates of about 92%, far better than had ever been achieved with war injured before.

All concerned divers, both medical and lay, should be striving to educate the diving population to recognise the symptoms of DCI and to use oxygen as soon as they can after recognising the problem and to continue to use it until they get to a treatment centre. Oxygen at atmospheric pressure takes about 12 to 24 hours to cause any pulmonary oxygen toxicity. Pulmonary oxygen toxicity is a small price to pay for reducing the effects of DCI.

ORIGINAL PAPERS

IMPLICATIONS OF HYPERBARIC MEDICINE FOR ANAESTHESIA AND INTENSIVE CARE PART 2

Continued from *SPUMS J* 1997; 27 (1): 2-11

Michal Kluger

Summary

Hyperbaric medicine is becoming increasingly accepted as an important adjunctive therapy for many diseases. There are important considerations for anaesthesia and intensive care when interfacing with hyperbaric medicine. These include awareness of the indications for hyperbaric oxygen (HBO), physiological changes associated with HBO, potential complications and drug interactions. Awareness of these considerations will aid in the safe management of patients across these specialties.

Key Words

Anaesthesia, equipment, hyperbaric facilities, hyperbaric oxygen, hyperbaric research, medical conditions and problems, physiology, treatment, ventilators.

Intensive Care Unit (ICU)

Hyperbaric oxygen therapy may be required for patients who have severe, life threatening diseases that require ICU admission. These include patients who are unconscious (CO intoxication), have respiratory failure (smoke inhalation, CO intoxication), sepsis (clostridial, streptococcal and other soft tissue infections) and gas embolism (secondary to diving, open heart surgery and laparoscopic surgery). Careful consideration needs to be given to transportation, monitoring, airway and cardiovascular manipulations.

TRANSPORT OF THE CRITICALLY ILL

Intensive care patients may require HBO for acute, aggressive soft tissue infections and carbon monoxide intoxication. Recent animal and uncontrolled human data suggest that thermal burns may also benefit from HBO. Trends in plastic surgery dictate early debridement and grafting, hence these patients, often still ventilated and inotrope dependent, may require HBO in the acute phase.

It is well recognised that both inter- and intra-hospital transfers produce unwanted cardiorespiratory instability in critically ill patients. Treatments can mean that patients are away from the ICU for 2-3 hours, which may be repeated two to three times in a 24 hour period. While the absolute duration of time spent away from the ICU may not correlate with post-transfer respiratory performance, ventilatory manipulations, circuitry changes and patient movement may be more significant. Patients who require positive end-expiratory pressure (PEEP) are at increased risk of post transfer respiratory disturbance, which may last for more than 24 hours.[60] This can be minimised by minimising patient movement (e.g. using dedicated hyperbaric beds and/or barouches which do not require excessive patient movement during HBO sessions) and maintaining similar ventilatory parameters to those carried out in the ICU, including PEEP and intermittent mandatory ventilation (IMV). Inotrope infusions can be employed, using dedicated hyperbaric pumps. Skilled maintenance of critical care nursing is probably the most important variable in ensuring transfer stability.

Temperature maintenance can be difficult, especially in those patients who have extensive burns or other losses of skin cover. Pre-transfer temperature stability is essential. Many multiplace units have air conditioning to heat and cool the chamber. This is especially useful during phases of compression and decompression, when the chamber temperature can change several degrees over a few minutes due to adiabatic cooling and heating. These problems are further compounded by transfer through cool corridors and operating rooms.

As with most areas in medicine, the risk-benefit ratio must be assessed when considering treatment of these high risk patients. Potential instability needs to be balanced against the beneficial effects of enhanced tissue oxygenation, reduction in bubble size, stimulation of new blood vessel formation and augmentation of neutrophil function.

POSITIVE END EXPIRATORY PRESSURE

PEEP may be required to increase lung functional residual capacity (FRC) through recruitment, stabilisation and distension of alveoli, with resultant decrease in shunt fraction. Failure to maintain PEEP can lead to prolonged respiratory deterioration.[60] Modern ICU ventilators have internal, integrated valves which use the exhaust valve to produce PEEP. The airway pressure is constantly monitored and adjusted accordingly. External PEEP valves can be classified into either threshold (flow independent) or orificial (flow dependent), although most are hybrids of both.

In a study looking at four external PEEP valves, Youn identified that all valves produced an increase in preset PEEP by between 2 and 4 cm of water (0.2-0.4 kPa) in the hyperbaric environment.[61] The valves tested were; water column (Emerson®), spring type (Siemens®), magnetic type

(Instrumentation Industries®) and floating ball (Boerhinger®). Floating ball types are not adjustable, therefore less versatile in changing clinical circumstances. The water column was least affected by pressure change from 1 (sea level) to 6 bar (100-600 kPa). Awareness of these changes with HBO is noteworthy, as small unexpected increases in PEEP can potentially lead to reduced preload, septal shift, reduced ventricular size, increased dead space and barotrauma. PEEP levels need to be monitored closely and adjusted during different phases of the HBO treatment profile. Some authorities recommend that external PEEP be removed during phases of compression and decompression.[62] Other workers reported "occult PEEP" during positive pressure ventilation during HBO therapy.[63] Accurate airway monitoring and awareness of changes within the HBO environment can prevent many of these problems.

ENDOTRACHEAL TUBE (ETT) CUFFS

Boyle's law dictates that gas filled ETT cuffs will become smaller during periods of increased pressure. This problem can be overcome by routinely filling cuffs with saline or water. The increased mucosal pressure generated by these cuffs needs to be considered, especially with prolonged or frequent treatments. ETTs which use foam filled self inflating cuffs may be useful in this situation, but are not commonly available. A further option is to measure ETT cuff pressure continuously using a manometer and adjusting accordingly.

VENTILATORS

Critically ill patients with acute CO poisoning or fulminant soft tissue infections often require ventilatory support. The characteristics of an ideal hyperbaric ventilator are shown in Table 4.[64] Not surprisingly, no one ventilator, at present available, fulfils all the desired criteria.

Limitation of space and access mandates the use of small, compact ventilators. As with all hyperbaric appliances, electrical powered equipment presents a possible ignition source, which is of greater importance in the 100% oxygen environment of the monoplace chamber than in the multiplace facility. Maintenance of the same ventilatory parameters as carried out in the intensive care unit provides continuity of care and also promotes cardiorespiratory stability. Patients who are PEEP dependent also benefit from a ventilator which provides this modality in an accurate and minimally variable way. There are many methods employed in weaning patients from ventilation. It is useful if these can be employed in the hyperbaric unit for two reasons. Firstly, patient weaning may be delayed by continued HBO therapy if conventional IPPV is the only method available, leading to possible airway and systemic problems. Secondly, the work of breathing increases at depth due to increased gas density.

TABLE 4

DESIRED CHARACTERISTICS OF A HYPERBARIC VENTILATOR

Modified from Moon[63]

Small, compact.
No electrical requirements.
No flammable lubricants.
Wide range of minute volume with varying tidal volumes.
Constant inspiratory-expiratory time (I-E) ratio.
Minimum work of breathing with continuous positive airway pressure (CPAP) and T piece modes.
Weaning modes, pressure support synchronised intermittent mandatory ventilation (SIMV).
Constant positive end-expiratory pressure (PEEP).
Wide bore circuitry.
Powered by compressed air or chamber environment gas.
Driving gas vented to outside chamber.
Continuous monitoring of tidal volume, frequency, minute volume, peak and mean air pressure, PEEP, I-E ratio.
Control and display panels unaffected by pressure.
Similar to other ventilators in the Intensive Care Unit (ICU) and High Dependency Unit (HDU).

Patients who have been weaned onto a T-piece or pressure support ventilation may not ventilate adequately during HBO treatment if the only option is self ventilation via a modified BIBS circuit or head tent. Therefore continuous positive airway pressure, pressure support and synchronised intermittent mandatory ventilation are useful options to have in a hyperbaric ventilator.[65]

Ideally the driving gas should be that of the chamber environment, so that vented gas does not contaminate the chamber atmosphere. This would most commonly be air, which is safer from a fire perspective than oxygen. Finally, from an educational and safety perspective, ventilators similar to those used in other acute care areas e.g. intensive care and high dependency, are easy to use and reduce potential operator error because they are familiar.

There is a wide range of ventilators used in Australian and New Zealand Hyperbaric Medicine Units. These include Hyperlog (Dräger), Bird, Oxylog (Dräger), Oxford Mk II (Penlon). The hyperbaric literature has several studies which have looked at the efficacy of various breathing circuits and ventilators at depths from 2 to 31 bar (200-3,100 kPa).[64-78]

Early work from Lamy's group in Belgium identified problems with ventilators in the hyperbaric environment.[69] The Celog 03 was limited by a lack of external controls once the patient was pressurised, whilst the Assistor was a fragile ventilator which required frequent interventions to alter inspiratory flow, expiratory pause and cycling pressure limit. It also had a low initiating trigger pressure, causing excessive cycling. The Logic 03 required several modifications to allow it to function at test pressures up to 3 bar. Using a test lung, it was found that both delivered tidal and minute volume decreased with increasing pressure, whilst the respiratory rate increased. The ventilatory pattern could be easily adjusted by a single alteration of the respiratory rate.

The Emerson, Urgency, IMV, and modified Mark 2 Bird were tested for performance using a test lung up to 6 bar (600 kPa). [70] While the Emerson (pneumatically powered piston) had no changes to preset parameters up to 6 bar, the Urgency and IMV Birds (pneumatic flow cartridges and venturi systems) failed at pressures greater than 3 bar and the Modified Mark 2 would not work above 4 bar. In addition respiratory rate increased as a function of more rapid pressurisation of the timing circuit. As the Emerson has bellows lubricated with mineral oil, this would have required further modification to allow it to meet accepted safety standards.

The Oxford ventilator (Penlon®) was evaluated using both air (up to 6 bar) and oxy-helium (up to 31 bar {3,100 kPa}) as driving gases.[71] Characteristics of ventilation were virtually unaffected up to 6 bar in air, but oxy-helium gas led to an increase in respiratory rate secondary to the less dense medium. Luckily, as the inspiratory and expiratory valves were identical, the set I-E ratios were maintained over a wide range of treatment pressures. A commonly used intensive care ventilator, the Monaghan 225 was reviewed by Moon to pressures of up to 6 bar. [64] There was no significant change in delivered tidal or minute volume, but respiratory rate decreased to almost half at 3 bar compared with 1 bar (sea level) and maximum minute volume decreased from 50 l/min to 18 l/min. Increasing both inspiratory flow rate and circuitry bore size can minimise this effect. The Pneupac range of ventilators have been assessed for both monoplace (Pneupac Variant HB) and multiplace (Pneupac HC) environment.[73,74] Reduction in flow through the flow limiting needle valve in the chamber produced a reduction in preset minute volume in both models.

Youn also looked at the Penlon Oxford using a test lung simulating pathological lung conditions utilising resistors and adjustable compliance springs.[75] Respiratory rate decreased with increasing resistance and decreasing compliance. With moderate resistance and compliance of 15 ml/cm H_2O, auto-PEEP [62,79] generated was 0, 2, 6 and 25 cm H_2O (0, 0.2, 0.6 and 2.5 kPa); peak airway pressure was 45, 50, 58 and 65 cm H_2O (4.5, 5, 5.8 and 6.5 kPa) at 1, 2, 3 and 6 bar respectively. Similar preliminary studies have been carried out with the Bird Avian ventilator.[68] The popular Siemens® Series has been used successfully in several centres for HBO patients. Some advocate a degree of modification to separate the power supply from the pneumatics,[76] whilst others report it to work effectively and safely using all its modalities under pressure (CPAP, PS, SIMV).

Weaning patients from ventilatory support can be associated with increased work of breathing which may be compounded by increased gas density at depth and work done against the ventilator. Oxorn compared a demand IMV system with a continuous flow device at 2 bar using a test lung.[65] The continuous flow system was associated with an increased work of breathing of 30% compared with a 200% increase with the IMV system over control at ambient pressure (1 bar). This has important implications for maintenance of such modes within the hyperbaric environment.

The Sechrist 500A monoplace ventilator is probably the most common monoplace ventilator in the US.[67] Like the other ventilators described above, there is a marked reduction in tidal volume which occurs in lungs with low compliance. Close monitoring is essential as injudicious increase in respiratory rate and/or tidal volume can predispose to auto-PEEP with its cardiovascular and barotrauma complications.[79] Air breaks can be easily administered to patients within a multiplace chamber, thus minimising CNS and pulmonary toxicity. These can also be carried out in the monoplace chamber in both conscious, cooperative patients and in those who are being mechanically ventilated.[47,80]

MONITORING

Minimum standards of monitoring are well recognised and followed in anaesthesia and intensive care practice, but this is not yet established in hyperbaric medicine.[81] Despite this, most units would recognise the need for a similar spectrum of monitoring as that employed in other acute care areas. Attendant and environmental monitoring are also essential in addition to patient monitoring. Normal clinical observation can be difficult in HBO environments for technical reasons. These include limitation of patient access, noise, decreased ambient lighting and altered sound transmission, making a simple technique such as chest auscultation difficult and unreliable. Specific criteria and standards need to be met for electrical and/or battery operated equipment within the HBO environment.[82] All equipment should have a dual power supply in case of primary source failure and all are required to be waterproof, explosion proof and protected from the chamber's sprinkler system. Finally, all equipment needs to be specifically designed for use in the hyperbaric environment, or tested for that specific purpose. However, the majority of monitors can work effectively with the electrical module on the outside, connected to the patient through dedicated penetrations in the chamber wall.

Pulse oximetry may have a place in hyperbaric practice in selected cases. Hypoxaemia and desaturation can occur even with a patient breathing HBO. A saturation of 97% along with measured PaO_2 of 346 mm Hg (0.45 bar or 45 kPa), on 100% oxygen at 2.5 bar, helped in diagnosing a right main bronchus intubation in a patient with severe rhino-cerebral mucormycosis.[83] Pulse oximetry can also be used to titrate a reduced FiO_2 during air breaks, again in an attempt to avoid CNS and pulmonary oxygen toxicity. This can be verified by performing arterial blood gas analysis using dedicated portable blood gas analysers. These have been shown to be accurate in both hypo- and hyperbaric environments.[84] An alternative method is to send a sample to a machine on the outside of the chamber. This is limited by rapid release of dissolved oxygen and the requirement for the machine to be calibrated within the hyperbaric range of partial pressure of oxygen.

The Anaesthetic Incident Monitoring Study recognised the limitations of routine electrocardiogram (ECG) monitoring,[85] however several conditions which present for emergency care have important cardiac complications. These include myocardial ischaemia and infarction with acute CO poisoning, atrial fibrillation and other supraventricular dysrhythmias with sepsis, and a multitude of ECG changes secondary to metabolic, endocrine or pharmacological reasons. Continuous ECG monitoring is recommended in some cases of DCI which present with rhythm problems, e.g. ventricular ectopic beats[86] and during adjunctive lignocaine therapy, which has been reported to be of benefit in refractory cases of DCI.

End-tidal carbon dioxide ($ETCO_2$) monitoring is mandatory for all intubated patients, yet is used infrequently during HBO therapy. The most common types are main stream and side stream capnographs. In a study comparing the accuracy of these at 1 and 3 bar, it was suggested that the main stream machines were less accurate than side stream models at pressure.[87] However, modification to the chamber of the side stream analyser, necessitating addition of a flowmeter and dump valve for the exiting gases to the outside, limits its feasibility. A relatively new chemical indicator, Easycap (Fenem) incorporated into an ETT connector, which changes colour, breath by breath, can provide inexpensive capnometry within the chamber.[88] It has been used during HBO treatment, but is limited by lack of alarms and difficulty in viewing the indicator from outside the chamber. Disconnection from the ventilator can be missed in an area where there is significant background noise and capnography is not universally used. The Ohmeda volume monitor was shown to work effectively and accurately in the hyperbaric environment up to pressures of 6 bar, and proved an essential monitor for use with critically ill patients.[89]

The use of advanced monitoring techniques, e.g. pulmonary artery (PA) catheterisation, are relatively easy to perform within a multiplace chamber with the appropriate technical alterations to the chamber. Apart from ensuring that the PA balloon is not inflated during decompression, because of the potential for PA rupture, there are no specific difficulties. This contrasts to their use in the monoplace chamber, where complex engineering is required to modify the chamber.[90] In addition, rapid removal of the patient is difficult due to limitation of mobility and attachment of monitoring. This limits the efficacy of such a monitor within a monoplace chamber.

DEFIBRILLATION AND PACEMAKERS

Problems associated with defibrillation inside a chamber include fire and explosion along with equipment malfunction, e.g. cathode ray screen implosion. Prerequisites for generating a fire or explosion include a source of flammable material, source of combustion and oxygen. Static electricity generated by clothing is eliminated by the use of cotton materials in the chamber. In addition, potential sources of electrical discharge, e.g. batteries, brush-motors and lighters, are prohibited. Fires have been reported in both monoplace and, less commonly, multiplace facilities.[91] There have been concerns about spark generation from defibrillation. This is especially valid in monoplace chambers where there are 100% oxygen environments; here defibrillation cannot be safely carried out. In this situation the patient needs to be decompressed and resuscitated once well outside the chamber. Multiplace chambers on the other hand, with an upper oxygen limit of 23%, have a much increased safety margin. While altered thoracic impedance may be present at higher partial pressures of oxygen, due to altered blood volume and flow secondary to oxygen-induced vasoconstriction, successful defibrillation has been carried out without complications. Some authorities recommend that, during defibrillation, one inside attendant wears emergency breathing apparatus and readies the fire hose while defibrillation is proceeding.[92] Another method of avoiding the problem is to site the defibrillator outside the chamber with leads extending through the chamber wall dedicated penetrations to specially designed gelled monitoring defibrillation pads.[93] Although the delivered energy was reduced by approximately 9%, this was within the accepted limits of the machine operating specifications. This minimises many of the problems and additionally reduces any potential operator error due to inert gas effects at increased ambient pressure.

Temporary transvenous external pacemakers have been reported to have failed under hyperbaric conditions.[94] Katz tested twenty permanent and eighteen external pacemakers in pressures from 1 to 6.7 bar (100-600 kPa) in 100% oxygen environments.[95] All permanent pacemakers functioned normally up to 6.7 bar, however the external pacemakers failed at 3-4 bar, with completely normal function before failure. Normal function spontaneously returned during decompression. Subsequent animal experiments gave the same results. Therefore, while patients with implanted pacemakers can safely undergo HBO therapy, emergency patients may require close observation if treatment pressure exceeds 3 bar. Automatic implanted cardiac defibrillators (AICD) can also tolerate pressures up to 6 bar. The use of external transthoracic pacing has not been reported in the hyperbaric literature and limited data exits on the feasibility of intra-aortic balloon pumps within this environment. [96]

FLUID MANAGEMENT

The debate continues as to whether crystalloid or colloid is the optimum fluid for resuscitation. In a series of dog experiments, Gross[97] examined the haemodynamic effects of induced hypovolaemia during HBO therapy and the effects of infused intravenous fluids. Exposure to pressures from 2.8 to 6 bar did not change the haemodynamic responses to shock compared with controls at ambient pressure (1bar). In addition there was no change in the volume of colloid (dextran 70) required to resuscitate the dogs at depth compared with at the surface. The conclusion was drawn were that fluid management during HBO should not differ from that outside the chamber and that HBO per se did not alter the normal homeostatic mechanisms involved with hypovolaemia.

Anaesthesia

BACKGROUND

Anaesthesia in the clinical hyperbaric environment was first reported by Bert in 1879. It became more common in the 1950s and 1960s, but is rarely performed today with possible exceptions being therapeutic lung lavage for pulmonary alveolar proteinosis[98] or emergency surgery for commercial saturation divers who cannot be rapidly decompressed. There is some experimental evidence that anaesthesia per se may have a protective role against the development of pulmonary and central nervous system oxygen toxicity[99] and it may also have a synergistic effect in tumour killing with HBO and radiotherapy.[100]

Boerema described the use of halothane, curare and pethidine in cardiac surgery, but did not expand on techniques or problems. Later workers reported their experiences more specifically and mentioned limitations with hyperbaric anaesthesia.[101-106] In particular, temperature changes, flowmeter problems and vaporiser outputs were discussed. Potential solubility problems and DCI associated with the use of nitrous oxide were considered by Smith some 30 years ago.[103] It is interesting to note the case reports regarding DCI and N_2O in the recent medical literature.[107,108]

Anaesthetists may increasingly have contact with patients who have undergone repeated HBO exposures. The early work investigating the effects of HBO plus radiotherapy[7] on tumour growth is being re-examined today.[100] Patients may require surgery and hence anaesthetics during prolonged HBO courses. This is also true of patients with a history of osteoradionecrosis who have prophylactic HBO treatments (up to 30) before surgery. Debridement, resection and reconstructions are carried out, followed by postoperative HBO. Again the anaesthetist needs to be aware of the potential interactions between HBO and anaesthesia and, in particular, respiratory alterations with prolonged HBO therapy and potential drug interaction with chemotherapeutic agents.

EQUIPMENT

Historically, most of the earliest anaesthetics were nitrous oxide and oxygen with some added volatile agent. Early workers noted that as the pressure increased the output from the flowmeters decreased. This entailed calibrating each flowmeter for individual gases at the intended depth of treatment.

The vapour pressure of a liquid remains constant with variations in ambient pressure. Therefore, theoretically, at increased partial pressure the output of vaporisers should be constant. McDowall demonstrated that Fluotec vaporisers delivered accurately from 2-4% but, at lower settings, tended to over-deliver halothane at high ambient pressure.[102] This has not been repeated with modern vaporisers, but may be irrelevant as total intravenous anaesthesia (TIVA) is probably preferable in the modern hyperbaric medicine setting.

Any air-fluid interface will have potential problems in the hyperbaric environment if not allowed to equalise during compression and decompression. Gravity-fed intravenous giving sets need to be monitored closely to avoid collapse of drip chambers. Infusion pumps, commonly used in the anaesthesia and ICU setting, require to be reviewed and tested prior to any exposure in the hyperbaric environment. The accuracy must also be tested under hyperbaric conditions. The 350 Controller infusion device failed to function at depth due to the retrograde filling of the drip chamber.[109] In contrast the volumetric IMED® pumps, (960 & 928) functioned accurately at pressures from 1 to 6 bar. Syringe drivers, modified to remove flammable grease, are the most effective and efficient pump for use in TIVA. This anaesthetic technique can provide hypnosis, muscle relaxation and analgesia without the need for anaesthetic machines, complex circuitry and scavenging, and importantly avoids environmental pollution with expired hydrocarbons and nitrous oxide.

NITROUS OXIDE

Nitrous oxide anaesthesia was the sole agent used in the early days of hyperbaric anaesthesia. However two recent case reports illustrate a potential problem with nitrous oxide anaesthesia and the development of decompression illness (DCI). Acott and Gorman reported a patient who developed transient symptoms of DCI following a provocative dive profile.[107] He subsequently underwent a nasal operation, during which nitrous oxide was administered. Symptoms consistent with DCI developed over the following two weeks, when he presented to the hyperbaric unit for recompression therapy. This provided immediate resolution of his symptoms.

The second reported case presented with symptoms of DCI following general anaesthesia (nitrous oxide) for relocation of a shoulder, which had been dislocated a few hours previously during the scuba dive.[108] Again the symptoms responded to HBO. As nitrous oxide has a blood gas partition coefficient 13 times that of nitrogen, any air bubble present in the body exposed to nitrous oxide will rapidly increase in size, causing symptoms of DCI. This has important implications for anaesthesia as in vivo bubbles have been identified in tissues for several weeks after diving.

To this end, a diving history should be sought for any patient presenting for surgery, nitrous oxide should be withheld from anyone who has participated in a dive over the past six weeks and entonox should not be given to any dive-related accident victim.

Miscellaneous

HBO is an accepted treatment in pregnancy, with no apparent detrimental effect to either mother or foetus. Van Hoesen documented the treatment of a mother with accidental CO intoxication.[110] She had a depressed Glasgow Coma Score with an accompanying carboxyhaemoglobin level of 47% (normal range <5%) with an associated foetal tachycardia and poor heart rate variability. The drowsiness and foetal cardiovascular changes rapidly resolved with HBO therapy. The use of HBO in pregnancy has potential adverse effects. These include teratogenicity, retrolental fibroplasia, reduction in placental blood flow and premature closure of the ductus arteriosus. None have been shown to be significant in man despite conflicting animal data. Practically, the acutely ill pregnant patient can be treated in the same way as other hyperbaric patients. Additionally, constant foetal heart and cardiotochogram monitoring should be routinely monitored during HBO treatments.

Finally, patients who have external fixateurs or complex traction devices can be easily accommodated in a multiplace chamber. Greater care needs to be taken in a monoplace chamber, where repeated scratching of the acrylic shell by these metallic devices may weaken the monoplace wall.[22]

Pain management

ACUTE PAIN

Patients who have had recent surgery, e.g. bone grafting in chronic osteomyelitis, debridement in gas gangrene or necrotising soft tissue infections, require analgesia. Patient controlled analgesia (PCA) is an effective method of providing immediate, effective pain relief yet requires a dedicated infusion pump, which may not be suitable for use in the hyperbaric environment. A Bard PCA device was subjected to pressure tests at 1, 2 and 6 bar (100, 200 and 600 kPa).[111] There was no evidence of battery leakage (using alkaline rather than lithium batteries), no alteration in PCA pump display or face plate and it was shown to deliver a test fluid within the specifications of the pump. It was also demonstrated to be clinically effective when used on 3 cases within a multiplace chamber.

The use of battery powered devices in a monoplace chamber is, however, not recommended. The combination of plastic and polymers which are combustible in 100% environments, along with threshold energy levels for combustion (in the vicinity of 1 microjoule), mean that these devices should not be used in monoplace chambers. The pump could be used via a nurse from the outside of a monoplace chamber and was shown to be accurate at 2 bar. Pumps which do not rely on battery power would be an advantage. An infusion pump using an elastomeric reservoir through a flow restrictor was tested with clinically relevant fluids at pressures of 1 and 2.3 bar.[112] All fluids demonstrated a statistically higher volume delivered under hyperbaric conditions compared to control, however these differences were not considered to be clinically relevant. Another variation, utilising a spring loaded infusion pump and flow restrictor, has been described for use in the intensive care setting, however it has not yet been subjected to hyperbaric environmental testing. These pumps might be ideal for use in both monoplace and multiplace environments.

CHRONIC PAIN

The observation that pain perception in patients with peripheral vascular disease was reduced by HBO led Tufano to study its effect in patients with acute and chronic vascular disease.[113] Subjective visual analogue pain scores were measured, along with plasma ACTH and endorphin levels. Both groups showed resolution of pain; this might be predicted in the acute traumatic ischaemia group, but less so in the chronic pain group. In addition ACTH decreased in both groups after HBO compared with before HBO. Plasma endorphins were reduced after HBO compared with before HBO values, more so in the chronic group. Animal experiments with Cu^{+2} as the oxidative agent produced oxidation of opioid receptor SH groups to SS disulfide bridges.[114] This may lead to a stronger link between endogenous opioids and receptor sites causing a fall in observed endorphins and ACTH. As HBO also causes oxidation of these receptor SH groups, a similar mechanism for the effect of HBO on analgesia can be postulated. Other refractory chronic pain conditions, such as reflex sympathetic dystrophy, have also anectdotally responded to HBO.[115] Interestingly, Boerema in his report on the early use of HBO commented in passing on its effect on pain, "..the preliminary results are promising, the pain decreased considerably..".[116] Further study in this area is needed.

Drug interaction with HBO

Inter- and intra-patient variability in drug response is well recognised. What is less well understood is the compounding effect of HBO on drug pharmacokinetics and pharmacodynamics. This has important implications for patients requiring sedation, anaesthesia and intensive care within the hyperbaric environment. In addition, it must be emphasised that the pressure and oxygen parameters also change during HBO, thus any pathophysiological effects are in constant flux. Difficulty is encountered in extrapolating much of the present research data which is deep diving oriented (20-30 ATA) to normal clinical ranges (2-6 ATA).

ANAESTHETIC AGENTS

Johnson and Flager first demonstrated pressure reversal of anaesthesia in tadpoles anaesthetised with ethanol and urethrane.[117] Various animal models were subsequently examined, looking at mechanisms of general anaesthesia. With increasing pressure, there was a concomitant increase in anaesthetic requirement, inhalational agents being affected less than intravenous ones.[118] In most studies however, pressures far above those clinically relevant were investigated.

Intravenous thiopentone and ketamine were administered to guinea pigs who underwent exposure to 1, 20 and 31 bar (100, 2,00 and 3,100 kPa) breathing a mixture of helium and oxygen. Increasing pressure led to an increased dose requirement for inducing anaesthesia (2-3 fold), whilst shortening the duration of anaesthesia (up to 50% reduction).[119] Kramer tried to identify the aetiology of antagonism of pentobarbital anaesthesia, looking at drug pharmacokinetics and pharmacodynamics. Dogs were exposed to clinically relevant pressures of up to 6 bar and given intravenous pentobarbital. There was no significant effect on elimination half life, volume of distribution or plasma clearance, suggesting that changes in drug disposition, i.e. pharmacokinetics, did not play a role in reversal of anaesthesia.[120] This study design was repeated with pethidine and aminophylline, again showing no change in drug pharmacokinetics at 1, 2.8 and 6 bar (100, 280 and 600 kPa).[121,122] Dundas reported on a study from the Royal Navy which demonstrated that the dose of Althesin (alphaxalone/alphadalone) was increased by 30-34% at 300 m pressure (31 bar or 3,100 kPa)).[123] Although there tends to be an increased requirement for anaesthetic agents at pressures of 2-6 bar, little data exits for this clinical area.

SEDATIVES

The effect of HBO on the antihistamine clemastine fumarate showed that at 6.1 bar, breathing air, there were no significant CNS depressant or cardiovascular effects.[124] As these medications are in common use in the population for allergic phenomena, it is reassuring to note that hyperbaric therapy seems to be devoid of important interactions. This may have implications for chamber attendants who are on concomitant medication. The sedative effects of alcohol have also been antagonised in murine models, but at 12 bar in heliox environments.[125]

MUSCLE RELAXANTS AND SYNAPTIC TRANSMISSION

Muscle relaxants may be used in the management of the critically ill patient, although this is becoming less common. They may be advocated in certain cases, e.g. poor patient compliance with ventilation and minimisation of sedation, but consideration needs to be given to masking potential hyperoxic seizures. Direct EEG monitoring can be used in this situation, however a more practical approach is to monitor neuromuscular function using a peripheral nerve stimulator, minimising the degree of block or by using an isolated limb technique.

Pressure associated alterations in muscle contraction were first recorded by Regnard in 1891. Subsequent studies have suggested that there are important interactions between neuromuscular physiology and hyperbaric environments. Increasing pressure alone (137 bar or 13,700 kPa)) enhanced twitch tension, but did not change the electromyogram (EMG) response to phrenic nerve stimulation.[126] In the same study, using d-tubocurare and suxamethonium, EMG was depressed but twitch tension was enhanced, with non depolarising relaxant block being enhanced to a greater degree than the depolarising block. It has been suggested that pressure decreases acetylcholine release, but there is enhancement of some aspect of muscle excitation-contraction coupling. Although the net effect in this study was antagonism of neuromuscular block, the relative importance of pressure effects on neuromuscular transmission and excitation-contraction coupling are still unclear. What is even less clear are these effects at lower pressures, as there have been anecdotal reports of increasing relaxant requirements at 2-3 bar.

ANTIHYPERGLYCAEMICS

Diabetic patients are commonly treated with HBO for chronic non healing wounds, acute soft tissue infections and chronic osteomyelitis. Blood sugar control can be unstable during HBO treatment, and hypoglycaemia is well documented. This may be related to reduction in plasma glucagon[127] or possibly increased sensitivity to insulin. In addition to hypoglycaemia, pre-hyperbaric administration of glucose may decrease the incidence of hyperoxic seizures.[128] Recent cases within the author's institution have shown that hypoglycaemia can be rapid and unpredictable, with blood sugars falling from 12 mmol to less than 2.0 mmol in the space of one hour's HBO therapy. Testing of blood within the chamber may not be accurate, leading to overestimation of actual blood sugar.[129] Due to the glucose oxidase mechanism involved in the reagent strips, it has also been suggested that blood removed from patients and passed outside may also over read correct values.[130] Whilst accurate measurement is problematic, clinical hypoglycaemia, manifest by confusion, agitation and loss of consciousness, is real[131] and often occurs in previously well controlled diabetics.

CHEMOTHERAPEUTIC AGENTS

Cancer patients may present for HBO for incidental reasons or primarily related to their tumour e.g. osteoradionecrosis. Bleomycin, an antitumour antibiotic, is used for squamous cell cancer, lymphoma and testicular cancer, but has significant pulmonary toxicity when associated with high concentrations of oxygen (PiO_2 >228 mm Hg = 30.4 kPa = 0.3 bar).[132] Patients are particularly prone to pulmonary toxicity (pulmonary oedema, pulmonary fibrosis and adult respiratory distress syndrome) if they have pre-existing lung pathology or bleomycin therapy within the previous 1-2 months. These problems may not be seen with the newer antitumour agent, peploycin. Cisplatinum, when studied in animal models, inhibited wound healing by blocking fibroblast production and collagen synthesis, whilst doxorubicin was associated with an increased mortality in animals co-treated with HBO.[133,134]

MISCELLANEOUS

Commonly used medications including aspirin, paracetamol, caffeine, diphenhydramine and dimenhydrinate were evaluated for learning and performance tasks during hyperbaric exposure to 2.8, 5 and 7 bar (280, 500 and 700 kPa).[135] Subtle cognitive deficits were demonstrated with the antihistamine, diphenhydramine, and even less with caffeine and dimenhydrinate. There were no effects with the simple analgesics. Performance evaluation showed no difference with any of these drugs at any pressure. This has important implications for patients and also for attendants who may be required to monitor, interpret and act appropriately under hyperbaric conditions.

The unpredictablity of drug behaviour at depth was demonstrated in rats given amphetamine and chlordiazepoxide at 10 bar breathing air. Both agents produced dose-related accentuation of some parameters at depth, however these were not predictable from the effects of the agents at ambient pressure.[136] Walsh, using amphetamine in a rat model at 7.1 bar, demonstrated a synergistic effect with pressure, a result not consistent with inert gas narcosis but with over stimulation of the CNS at depth.[137]

In summary, many of the studies looking at the effect of HBO on drugs have been in vitro or in vivo animal studies. Few have looked at interactions at clinically relevant pressures. However it would appear that drug effects are unpredictable compared with their effects at sea level (1 ATA, 1 bar or 100 kPa).

Surgery in the hyperbaric environment.

The earliest reports of surgery under hyperbaric conditions came from Fontaine who performed 27 procedures in an air hyperbaric environment, pressurised between 1.25 and 1.33 bar. Nitrous oxide was the anaesthetic agent employed, but while a portable operating room was constructed, a formal fixed surgical facility was never produced. HBO was subsequently employed for rational (reduction of hernias, production of bloodless operating fields) and completely irrational procedures (reduction of dislocated hips!). The first true fully equipped hyperbaric surgical facility was built by Boerema in 1959 in the grounds of the Wilhelmina Hospital in Amsterdam.[116] The operating area covered 24 square metres and was constructed in a cylindrical shape from metal. Landmark studies into HBO therapy were carried out in this facility. Duration of circulatory arrest could be increased using mild hypothermia and HBO compared with hypothermia and normobaric pressure.[138] Exsanguinated pigs, made normovolaemic with colloid solution and pressurised to 3 ATA, remained alive and showed no signs of myocardial ischaemia.[10] Subsequently Boerema successfully performed open heart surgery for procedures such as Tetralogy of Fallot with HBO. There was continued debate as to the lack of controlled data, even in those cases which appeared to have a sound physiological basis. When Bernhard's review of 86 operations performed with HBO was analysed it appeared that, in the group of infants with Tetralogy of Fallot, there was an increased mortality rate compared to those children operated upon under normobaric conditions.[139] The routine use of surgery within a hyperbaric environment was short lived due to the subsequent development of extracorporeal circulation.

The potentially beneficial effects on enhanced tissue oxygenation were investigated in the 1970s. Pulmonary embolectomy, using adjunctive HBO, was carried out successfully in a patient with marked desaturation and acidosis. It was suggested that this form of therapy might be beneficial to reduce the requirement for cardiopulmonary bypass.[140] Minimisation of extremity hypoxia and spinal cord ischaemia during abdominal and thoracic aortic procedures were examined experimentally, but never gained clinical acceptance.[141] Similarly the potential advantage of preventing cerebral ischaemia during carotid endarterectomy and minimising graft rejection during transplantation were investigated, but never proved clinically effective.[141,142] In other hyperbaric areas, e.g. saturation diving complexes, emergencies such as acute appendicitis are generally treated conservatively, avoiding the need for surgery and anaesthesia at high pressure.[143] Broad spectrum antibiotics may prevent the need for surgery and anaesthesia, along with other problems of altered physiology of deep diving (450 m, 46 bar or 4,600 kPa)). These include infection from pseudomonas species, common in saturation habitats, immunosuppression and thrombocytopaenia.[144] Today, apart from surgery on saturation divers, the only other potential indication for surgery in HBO is in the treatment of pulmonary alveolar proteinosis. This procedure, designed to wash protein casts from the pulmonary tree, is associated with significant desaturation. Selective lung ventilation and washout in the hyperbaric environment can prevent such desaturation and allow effective lavage to be undertaken.[98]

Conclusions

HBO is established as an important adjunct for a variety of medical and surgical procedures. There are important cardiovascular and respiratory changes which occur that have important implications for the anaesthetist and intensivist. This type of therapy is not without problems, which include DCI, inert gas narcosis and barotrauma for the attendants. Patients are also at risk from pneumothorax, arterial embolism, ear and sinus barotrauma. Severely ill patients who require intensive care management pose a particular problem. HBO may be associated with major and prolonged physiological shifts, which can be prevented by close monitoring of cardiovascular and respiratory parameters, using dedicated hyperbaric ventilators and being aware of the limitations and efficacy of emergency procedures such as cardiac pacing. Although pressure reversal effects are well documented with general anaesthetics, drug effects are not well known within clinical hyperbaric pressure ranges of 2-6 bar. There are important interactions between anaesthesia, hyperbaric medicine and intensive care which need to be identified and considered. Knowledge of such can improve treatment efficacy whilst reducing potential incidents and resulting morbidity. Further research is needed to investigate the effects of anaesthesia and intensive care during exposures to hyperbaric pressures between 2 and 6 bar.

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Michal T Kluger, FANZCA, FRCA, DipDHM, is a Staff Specialist, Department of Anaesthesia, Auckland Hospital, Park Road, Auckland, New Zealand.

The above paper is Part 2 of the thesis submitted for the Diploma of Diving and Hyperbaric Medicine which was awarded to Dr Kluger in 1996. At that time he was working in the Hyperbaric Medicine Unit at the Royal Adelaide Hospital, Adelaide, South Australia. Part 1 was published in the March issue of the Journal (SPUMS J 1997; 27 (2): 2-11).

AN ESSENTIAL RESEARCH PROJECT: LIVING WITH THE "AMERICANS WITH DISABILITIES" ACT

Douglas Walker

Key Words

Fitness to dive, legal, medical conditions and problems, research, safety.

The Americans with Disabilities Act[1] (AWDA) is one sign of the profound changes in community attitudes towards any perceived discrimination which prevents a person from either obtaining training or employment, or undertaking any other activity, solely on the grounds of some condition (physical, mental or behavioural) they may have. This Act has been presented by politicians as a caring measure in defence of the civil rights of such persons but, unfortunately, is equally likely to have results far beyond those imagined or desired by its creators.

It is very likely that this act will be manipulated by a few individuals, intent on obtaining a financial gain,[2] using the inevitable loopholes which will exist in this, as in all, legislation. There will be claims of unfair or unjustified restrictions imposed because of medical advice and common work-safety beliefs. Regrettably there will be some who may suffer an injury because they are allowed to undertake activities which their "disability" renders less safe for them to undertake than for those not so affected.

There is, however, a potentially positive aspect to implementation of this Act (AWDA). The enforced employment of such persons will make employers consider designing much needed improvements in the work environment. In the recreational industries, those having a responsibility for the safety of participants will be in the same situation. If these improvements are carried over they should reduce the risk levels for all, and so benefit everyone exposed to such work or recreational environments.[3]

The diving community will undoubtedly be significantly affected by this Act, at first in the United States but ultimately world wide, because of the direct and indirect influence of the major diver training organisations.[4-6] These organisations originated in the USA and still dictate the content of training programs of their many overseas dependencies. The effect may well be delayed initially in America through the writing of effective "disclaimer" contracts.[7-9] However what one lawyer devises is usually eventually circumvented by another. The "American disease", of litigation at the least excuse, is spreading to other countries where such disclaimers of liability are far less protective.

The instructor organisations appear to have made a rod for their own backs by their strict enforcement of the rule that no changes can be made by instructors to the written training programs. This rigidity may be welcomed by their insurers and legal advisers as providing a convenient justification for all actions which rigidly follow these hitherto unquestioned protocols. However there is a down side. It appears that the organisations fear to modify their training protocols in line with incident and morbidity reports. It has been suggested that the reason is that any changes could later be represented, in court, as an admission that some parts of the present training programs were either inadequate or contained errors.

This paper is not to discuss the training programs of the instructor organisations beyond stating that there is obviously scope for discussion on the correctness of awarding the somewhat misleading title of "advanced diver" to some divers after they have made only nine scuba dives. In my opinion, the conclusions reached by the UMS (now UHMS) and SPUMS workshops,[10,11] about the necessity for including a practice of shared air ascents in basic training, were reached without a sufficient regard to incident and morbidity data, which was available and should have been more fully considered. These workshop decisions will be a delight to any litigant's lawyer, as there was obviously an acceptance by those involved that to run out of air is a situation which is so common and unavoidable that it should be accepted. This training module is justified to reduce the very obvious dangers of running out of air. The presumption in AWDA is that predictable risk factors must be removed, not accepted, so it could be cited to back a claim that the avoidance of such out-of-air situations should be the focus of diver training. This would reduce the risks that diver inexperience and low-air situations pose.

However it is the medical involvement in assessment of medical fitness to dive problems which is the primary interest here. Doctors first became interested in pressure-related problems in response to exposure to the disabilities resulting from "caisson disease".[12] This was affecting the workers employed in some French coal mines, and where caissons were being used to sink shafts to obtain secure foundations for bridges. Doctors' involvement increased once the engineers made it easier for divers to reach ever greater depths. Later the development of scuba made possible the evolution of a group which dived for recreation. Recreational diving now has millions of certified divers. Dives have become longer and deeper and now sometimes involve the use of breathing gases other than air.

Without recreational divers, Diving Medicine would be a very small sub-speciality indeed. As a result of the efforts of employers, and regulatory authorities, to reduce the risk of occupational diving the occurrence of diving accidents in the North Sea is so low that doctors now have to learn treatment routines treating recreational divers! Prompt (at the time of onset) treatment for decompression illness (DCI) is almost always successful. A far cry from the old days of pearl diving in Australia.[13-16] Without the inventiveness of engineers, diving problems would have remained limited to the treatment of (near) drowning and of air embolism. Experience shows that every technical response to a diving problem is likely to produce at least one new medical problem which will require the attention of physiologists, physicians, or even undertakers.

Once involved with diving, doctors soon became convinced that medical fitness was the key element in safe diving and that they alone knew the cut-off between safe and unsafe conditions. It was a case of "better safe than sorry". In the interests of diver safety they set their opinions in absolute terms in relation to a list of certain named conditions and relative terms for many others. There was little known about the effects of diving on these conditions and what *was* known were the disasters. There are some in the diving community who appear to wish that medical involvement was still limited to treating air embolism and decompression sickness and developing even more "generous" decompression tables. But the instructor organisations, their lawyers and their insurers are presumably delighted to pass over the responsibility for certifying that an applicant is "medically fit to dive" to the medical profession, which has not realised that this franchise is a poisoned chalice.

When developing the Medical Fitness Standards for Australian divers, no allowances were made for the great variability in the severity of effect of most medical conditions with the same diagnostic label in different people, nor of the existence of so many exceptions to the theoretically predicted outcome in persons who have apparently similar clinical findings. The absence of any critical analysis, matching predictions against the data of diving morbidity reports, indeed the absence of attempts to collect and analyse such data, casts serious doubt on the validity of many commonly held beliefs. These days published data is likely to be required to justify the medical opinions advanced in court. Reliance on precedent in medical matters is no longer always accepted by judges and any lawyer could draw attention to the differing medical fitness standards in different countries.[17]

It is unfortunate for those who may be called upon to defend the status quo in court that there are many who dive with apparent safety despite having "disallowing" medical conditions.[18-20] There are also many who are litigiously inclined who may enjoy setting lawyers to demand a sourced proof of the degree of risk which their medical condition has been shown to pose. This is a legitimate tactic which the diving medicine fraternity has not always approached in a scientific manner. Although our present views may well be largely correct, they have been developed without facing any rigorous critical questioning. It is because of the supposed difficulty of defending a medical fitness decision which differs from that promulgated in the Australian Standard that there has been a reluctance to risk a change to a "guidelines" protocol where applicants who have a medical or physical condition are assessed on a case-by-case basis. It should no longer be acceptable to apply a Procrustean Bed template (one size fits all) as a completely satisfactory basis by which to reach a decision on medical fitness to dive.

One problem to be faced in collecting the necessary data arises from the success achieved in persuading the diving community of the evils of allowing diving by those who have asthma or insulin dependent diabetes (or other conditions). These people are naturally reluctant to admit to having any such conditions if they have managed to escape detection by the medical net. They are therefore usually only identified if they are involved in a reported incident. Very rarely do they reveal their condition otherwise. The result is that the number of those who are diving safely with such conditions is unknown and so the degree of risk is undefinable. For many years any history of epilepsy was an absolute bar to holding a driving licence, but epileptics drove and they only admitted to their condition when this absolved them from a far more serious charge. Now that their condition can be declared and matters decided on a case by case basis the predicted-risk question can be openly discussed and managed. There has been no morbidity cost to this change.

This looming threat can be met by developing and utilising a data base containing information from and about divers (past or present) who have any type of medical or physical "problem", regardless of severity or the apparent significance to diver safety, and disregarding whether they have experienced any diving-related problems. Indeed it will be helpful to have as complete details as possible of not only their medical condition but also about diving problems they have experienced, including those clearly unrelated to their index condition.

A first step would be the development of a team of doctors and other interested persons to research the contentious matter of those who have an "asthmatic" history.[21-23] Some with such a history should obviously be strongly advised they should not to dive,[24-28] but there will be others who have shown that they can and indeed have dived safely for many years. The task ahead is to attempt to determine where in the middle ground to define the point which indicates progression from an acceptable to an unacceptable risk, though first it will be necessary to define the term "acceptable risk"!

A significant number of the doctors are assigning a "medically fit to dive" finding to applicants whose asthmatic history is problematical or whose asthma is reportedly not active, subject to them satisfying a "provocation" protocol which uses nebulised hypertonic saline or methacholine.[29-31] There should be no ethical problems in following up this cohort of divers to discover whether they *have* experienced any asthma symptoms while they have been diving. Such a medically confidential survey would provide much useful information and it would greatly assist the designing and management of an expanded investigation, one involving the wider diving community, at a later date. It would be essential to ensure that those providing such personal information will be at no risk of losing diving certification nor of the certifying organisations learning their identity. This fear of loss of certification may be completely unfounded for many, as the only time most recreational divers require a medical certificate of fitness is when learning to dive. Some training organisations may require them for further courses.

Individuals in many countries are interested in this problem but the information is at present so scattered that it loses much of its value,[32-34] or it has been pre-digested to appear in papers which present the writer's conclusions but necessarily omit all details. Once such a data bank containing pooled material has been set up and shown to be useful, it is hoped that this will be an encouragement to others to come forward to join the original contributors. This will enable the focus of interest to be widened to include many other conditions. Indeed it is possible that, in time, instructor organisations and diving medicine societies will come to recognise the importance of becoming actively involved in the collection and analysis of such information.

This is a plea to the diving community to develop evidence based benchmarks now, against which to assess the true risk to applicants with a medical condition or history which has a potential adverse effect on diving safety.[35-37] Whether the medical risks are different in those who wish to dive using gas mixtures other than air could be one matter to consider. There will be great value in knowing the track record of those who have been diving with any of the many "adverse" medical conditions which are now listed.

The end point of improving information might well be that a doctor would in the future state not that the applicant was found to be either "fit" or "unfit" to (scuba) dive but would be given a less rigid statement, an opinion stating the possible significance to a trained and careful diver of any medical conditions which have been noted. The fully informed applicant would then be expected to choose whether or not he or she would accept the potential added risk factor. For an informed choice to be made the potential risks must be accurately presented and unfortunately this is not possible at present for lack of data. One must remember that nothing in life can ever be completely safe, but understanding the critical factors minimises the risks.

Interested parties are asked to write to the author.

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Dr D G Walker is a foundation member of SPUMS. He has been gathering statistics about diving accidents and deaths since the early 1970s. He is the author of the series of Provisional Reports on Australian Diving-related Deaths which have been published in the Journal covering 1972 to 1992. His address is P.O. Box 120, Narrabeen, New South Wales 2101, Australia. Fax + 61-02-9970-6004.

THE WORLD AS IT IS

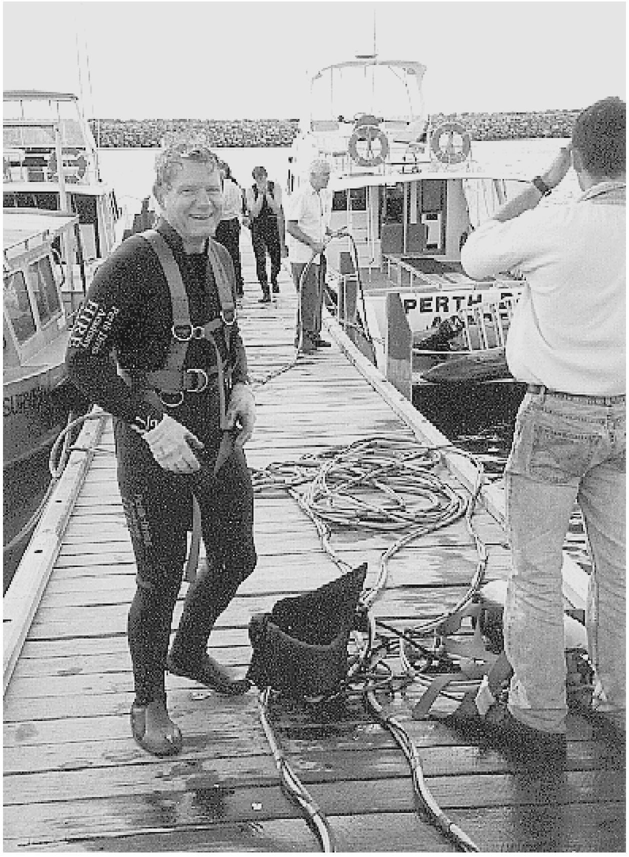
DOCTORS DO IT DEEPER

Harry Oxer

An international group of doctors were given the opportunity to find out how the off-shore occupational diver (who used to be known as a commercial diver) lives and works, at a recent course held at the Fremantle Hospital Hyperbaric Medicine Unit in Western Australia. "Bennett and Elliott" came to Australia and worked with the Hyperbaric Medicine Unit in Fremantle Hospital, in October 1996 to conduct the two week course entitled "Medical Support of Commercial Diving". Its aims were to introduce specialist doctors to the working environment and tasks of working divers. The participants discussed the particular aspects of physics, physiology, and medicine associated with the work of many different groups of working divers.

Fremantle offered unique opportunities because of its excellent relationship with the commercial diving and other organisations as well as the Hyperbaric Unit's own facilities for chamber experience and dry dives. The students, who came from Australia and nine other countries, were able to visit Coflexip Stena Offshore's dive support vessel the "CSO Venturer" and look at the saturation diving system and hyperbaric lifeboat on that vessel. Dave Jenkins, Coflexip Safety Officer shared his expertise with the class. Pat Washington and Bill Wallace from Oceaneering Australia came to Fremantle and lectured, drawing on their vast experience in the commercial diving field. Craig Roberts of Subsea International lectured and also arranged a visit to the Subsea facility to examine in detail their vertical chamber transportable saturation system, a dive bell and a hyperbaric lifeboat. The class also examined a large ROV (Remotely Operated Vehicle).

Contract Diving Australia made available diving experience using commercial diving equipment. Dusty Miller told the class about the equipment and supervised the diving. All members dived, using Kirby Band Masks, an extended full-face mask with gas supply and communications built in which is held in place by a zip up



Dr David Griffiths, Director of the Hyperbaric Medicine Unit in Townsville, after a dive. His Kirby-Morgan Band Mask is face-down at his feet. Further down the jetty Professor Elliott acts as tender for another diver.

hood and octopus straps, and commercial gear, at the excellent recreational dive training facility belonging to Perth Diving Academy. Dives were also made in the harbour, carrying out examples of underwater tasks, such as using pneumatic and hydraulic tools. Non-divers used the Perth Diving Academy training pool, and two who had never been underwater before dived successfully to 3 m in commercial gear. They found this a valuable experience in understanding the commercial diver's work environment.

The International Foundation for Accident Prevention (IFAP) put participants through its helicopter escape training operation. Some of the participants had to jump from 4 m into Fremantle Harbour, on a wind chilling day, right and board a large life raft. The group also visited the Submarine Escape Training Tower at the Royal Australian Navy Base at HMAS Stirling.

All the trainees felt that they had benefited greatly, gaining an understanding of the way in which the working diver earns a living. Ken from Canada found that he had to come all the way to Fremantle to find out what being cold in the water really was!

Professor David Elliott's course is well recognised throughout the world as the definitive course. This is the first time it has been run outside Europe and outside the Northern Hemisphere. Another group of doctors now have a greater understanding of the environment and the tasks of the diver's work.

Dr Harry F Oxer is the Director of the Hyperbaric Medicine Unit, Fremantle Hospital, PO Box 480, Fremantle, Western Australia 6160. Phone +61-(08)-9431-2233. Fax +61-(08)-9431-2819.

DIVING SAFETY IN QUEENSLAND: SOME OBSERVATIONS

Jeffrey Wilks

Key Words

Decompression illness, safety, tourism.

Introduction

In recent years there have been several attempts to quantify the number of dives made annually off the Queensland coast, particularly dives on the Great Barrier Reef. Some efforts have provided detailed methodology;[1,2] while in other published reports it is unclear how a final figure was obtained.[3-6]

A useful contribution to this developing data base is the new market research report by Windsor.[7] He suggests that there were 1,290,500 dives undertaken on the Great Barrier Reef during 1994. While rounding of figures to the nearest 500 or 1000 throughout the report indicates that the calculations are largely approximations, the study nevertheless provides a valuable baseline for examining diving safety in Queensland during that period. Only by linking diving numbers to injury reports can overall rates of safety be determined.[8]

In a study just completed,[9] we examined medical records to determine the numbers and principal diagnoses of tourists admitted to Queensland hospitals during the financial year 1993/1994. Following the recommendation of Walker and her colleagues, that tourist health research should target hospitals at the major tourist destinations in Queensland,[10] we chose to study seven regional hospitals in Cairns, Townsville, Mackay, Proserpine, Rockhampton, Nambour and the Gold Coast. These facilities were chosen because they are the main hospitals in each of Queensland's major coastal tourist destinations, as identified by the Queensland Tourist and Travel Corporation.[11]

TABLE 1

QUEENSLAND HOSPITAL ADMISSIONS FOR DECOMPRESSION ILLNESS (1993/1994)

Tourist group	All injuries	DCI patients	DCI as %	DCI ranking in all injuries
Overseas	261	35	13.4	2
Interstate	535	11	2.1	10
Intrastate	997	23	2.3	9
Total	**1793**	**69**	**3.8**	**6**

Tourists were defined as all people visiting Queensland destinations who were not residents of the Regional Health Authority in which they were admitted to hospital. A total of 135,128 patients were admitted to the seven hospitals over the one year study period.

Table 1 shows that decompression illness (DCI) was the second most frequent type of injury requiring hospitalisation for overseas tourists (following fractures). For interstate tourists and residents from other parts of Queensland, decompression illness was less prevalent as a serious injury.

Use of Hospital Inpatient Data

The present seven hospital sample is only suggestive of the total number of visitors to Queensland who may have experienced decompression illness during 1993/1994. Among the limitations in this type of epidemiological research are that some cases of DCI may be missed if all hospitals in Queensland are not included in the sample and any study of hospital inpatients will not include those who died before being admitted to hospital. Therefore deaths related to scuba diving will not be included. Information about diving deaths will need to be obtained from coroners' records; a procedure well documented by Project Stickybeak.[12] Also some tourists may not be correctly identified if the address given suggests that they are local residents[10].

As a general indicator of diving safety the hospital figures presented here can be viewed against the background of scuba activity provided by Windsor[7] for roughly the same period. From the 1,290,500 dives he reported the major coastal hospitals identified 69 tourists with DCI (0.53 per 10,000 dives)

Demographic profiles from the Townsville Hyperbaric Unit, the main hyperbaric facility in Queensland, show that many patients treated are from outside the local hospital area.[13-15] It has been suggested that overseas visitors may be at particular risk for diving accidents due to factors such as language barriers, poor initial scuba training, limited diving experience and unfamiliarity with local diving conditions.[9,16] However, these factors have not been empirically investigated for tourist divers within Australia.

Since decompression illness has now been identified as the second main type of injury requiring hospital admission for overseas tourists in Queensland, greater attention should be given to understanding and correcting factors that may contribute to diving injuries for overseas visitors who are economically very important to the Queensland recreational diving industry.[17]

A concerted effort to develop safety initiatives and improve risk management will also benefit the public image of the recreational diving industry by reducing adverse media stories of injuries experienced by overseas visitors to Queensland.[18] By linking market research findings with accurate medical data on morbidity and mortality some firmly based statements may emerge about the safety of scuba diving in Queensland.

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Dr Jeffrey Wilks, PhD, is a psychologist and Attwood Marshall Fellow in the School of Law, Bond University. His address is School of Law, Bond University, Gold Coast, Queensland 4229, Australia.

SPUMS NOTICES

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY DIPLOMA OF DIVING AND HYPERBARIC MEDICINE.

Requirements for candidates

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

1 The candidate must be a financial member of the Society.

2 The candidate must supply documentary evidence of satisfactory completion of examined courses in both Basic and Advanced Hyperbaric and Diving Medicine at an institution approved by the Board of Censors of the Society.

3 The candidate must have completed at least six months full time, or equivalent part time, training in an approved Hyperbaric Medicine Unit.

4 All candidates will be required to advise the Board of Censors of their intended candidacy and to discuss the proposed subject matter of their thesis.

5 Having received prior approval of the subject matter by the Board of Censors, the candidate must submit a thesis, treatise or paper, in a form suitable for publication, for consideration by the Board of Censors.

Candidates are advised that preference will be given to papers reporting original basic or clinical research work. All clinical research material must be accompanied by documentary evidence of approval by an appropriate Ethics Committee.

Case reports may be acceptable provided they are thoroughly documented, the subject is extensively researched and is then discussed in depth. Reports of a single case will be deemed insufficient.

Review articles may be acceptable only if the review is of the world literature, it is thoroughly analysed and discussed and the subject matter has not received a similar review in recent times.

6 All successful thesis material becomes the property of the Society to be published as it deems fit.

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

MINUTES OF THE SPUMS EXECUTIVE COMMITTEE MEETING

held on Saturday 19th October 1996 at the Hyperbaric Medicine Unit, Alfred Hospital, Melbourne.

Opened at 1320 Eastern Summer Time

Present

Drs G Williams (President), C Meehan (Secretary), R Walker (Treasurer), J Knight (Editor), D Davies (Education Officer), M. Davis (NZ Chairperson), C Acott, V Haller and M Kluger (Committee members).

Apologies

Dr Des Gorman (Past-President)

1 Minutes of the previous meeting (28/07/96)

Read and accepted as a true record after minor adjustments. Proposed John Knight, seconded Vanessa Haller.

2 Matters arising from the minutes

2.1 North American chapter update. There is still some finalising to do with the closing of the account of the North American Chapter and the change over to the new committee.

2.2 New Zealand 1997 ASM Update. Any queries with regards to the domestic arrangements are to be made direct to Fullers Northland. It is very expensive to have two speakers from the Northern Hemisphere attend and so the registration fee will reflect this. The registration fee has been calculated on an expected attendance of 100 full delegates and 50 non-delegates for a break even level. On top of this there has been $10,000 of sponsorship incorporated into the funds covering the registration fee expenses. Part of this is made of the New Zealand Chapter donation of $5,000, and donations from North Power of $1,000, and PADI of $2,500. There will also be several trade displays. The air travel costs so far are expensive, but there is hope that there will be some discounting closer to the date. The transfers will be via chartered flights and the heavy luggage will go by coach. If there are any FOCs generated, it will be up to the convener to decide how these should be utilised.

2.3 Future ASM venues. 1998 Palau, 1999 perhaps Layang Layang. The UHMS meeting is to be held in Seattle around the 18 May 1998. It may be possible to hold the SPUMS ASM before that in the first or second week of May. Dr Acott will be the convenor for this meeting and he has chosen to use Allways Dive Expeditions for the travel arrangements. The theme of the meeting will be "The History of Diving Medicine", and the workshop will be "The Aging Diver". There will also be inclusion of "Fisherman Divers".

2.4 Indemnity policy update from Dr Williams. This is still being researched.

2.5 Reprinting of the schedules for SPUMS Diving Medical and Statements of Purposes and Rules. This has been completed, and will be circulated to the membership.

2.6 Role of convenor to be defined and guidelines written. This is to be given to the Editor.

2.7 Ex-Presidents Committee. At this stage there was nothing to report. The committee did not convene at this time.

2.8 Subscription Renewal Notice to be redesigned. This has been completed and the new forms will be sent out in November.

2.9 Diving Doctors List update. This is in the process of being formatted by Steve Goble at the hyperbaric unit at Royal Adelaide. There will be an asterisk beside all doctors who have completed a course of 10 or more days duration. A new DDL application form needs to be designed to facilitate this. The compiled data will then go to the editor for printing.

2.10 Update on the index of SPUMS journals being produced on a disk. This is still in the process of being converted into IBM format

2.11 Oxygen equipment for the dive boats at the ASM. Some research will be done on this by Dr Davis and presented at the next meeting.

2.12 Suggested changes to the packaging of the SPUMS journal i.e. plastic covering. This was to be discussed at a later date.

2.13 Inventory of all the SPUMS equipment and furnishings held by members to be given to Dr Walker at the next meeting.

2.14 SPUMS European representative update. It was suggested that Dr Henrik Staunstrup should be written to with regard to this.

2.15 SPUMS on the internet This is still being formalised.

2.16 Request for financial assistance for DES. An update from Dr Acott. There was some discussion about how the costs of the telephone service could be decreased. One suggestion was to approach Telstra and enquire about discounting. The other was to have another way for medical practitioners to access a hyperbaric doctor readily for dive medical fitness queries without using the 1800 number and so reduce the costs. It was suggested that the person on call carry a mobile.

3 Treasurer's report

Any monies outstanding from the previous conferences was to go to New Zealand to help with the initial conference expenses. It was pointed out the SPUMS was already dipping into its reserves. The cost and the benefit of a yearly face to face committee meeting was discussed. It was decided at this stage that there was benefit in these meetings, where more lengthy discussions could be carried out on topics such as the philosophy of SPUMS and its future path. The cost benefit of each of these meetings should be weighed up before and after each meeting.

4 Correspondence

4.1 Letter re student passed fit to dive with asthma. This was discussed and it was decided that it would be appropriate to leave it to Workplace Health and Safety to follow this up.

4.2 Letter from Yearbook of International Organisations. It was decided not to purchase this.

4.3 Letter from the Singapore Convention Bureau was viewed by the committee.

4.4 Letter from Dr J Marwood re Disabled divers read. To be published in the Journal.

5 Other Business

5.1 Update on the data base of committee members details was made.

5.2 Some discussion was entered into about the committee positions being for two year terms.

Closed at 1700.

LETTERS TO THE EDITOR

DIVER EMERGENCY SERVICE

Hyperbaric Medicine Unit
Royal Adelaide Hospital
North Terrace, Adelaide
South Australia 5000
28/4/97

Dear Editor

It should now be known and appreciated by the recreational diving and diving medical fraternity that the funding for the Divers Emergency Service Australia (DES Australia) telephone (1-800-088-200 or +61-8-8373-5312 from outside Australia) is now being provided, with no strings whatever, solely by Divers Alert Network South-East Asia Pacific (DAN SEAP). This has been so since 1996, and DAN SEAP have so far contributed a total of $Aust 5000. Funding directly from recreational diving sources has long since ceased.

DAN SEAP generates its funds from membership subscriptions from divers, together with the income it earns from its excellent DAN SEAP Oxygen Courses for divers.

DES Australia is manned 24 hours a day, 365 days a year by voluntary, unpaid senior diving medical and professional ambulance expertise, and currently deals with about 500 calls annually from all over the Australian and Indo-Pacific regions.

It is quite certain that, but for DAN SEAP, DES Australia would have foundered many months ago, as divers, who are happy to use this service around the clock without a thought as to the cost and time involved, now contribute (with a few exceptions) not a jot to its financial survival. Reflecting the mindset of the dependent society we now live in, we know that many divers think that “the government” pays for DES Australia, and for the doctors and ambulance persons who man it! Some users of the service also expect DES call records to be available and precise (which they usually are!) when they call back months or years later for their own medico-legal purposes.

DES Australia is one of the world’s original and most successful emergency diving medical services, and Australian Diving Medicine has every right to be proud of its contribution to diving safety to date. Many Australian (and beyond) divers owe their successful outcome from their diving injury directly to the existence and early response of DES Australia.

While acknowledging the past episodic support of some factions of the recreational diving industry, as time and experience have now clearly shown, expectation of reliable direct funding from recreational diving ranks is fruitless. Divers should now appreciate that the best way they can contribute to the maintenance of the DES Australia facility is to undertake and encourage regular membership of DAN SEAP, and to do the DAN SEAP Oxygen Course.

John Williamson
Director

Key Words
Diver Emergency Service.

PATENT FORAMEN OVALE AND DECOMPRESSION ILLNESS

Royal Shrewsbury Hospital
Mytton Oak Road
Shrewsbury SY3 8XQ, UK
6/12/96

Dear Editor

Two articles[1,2] in the September 1996 issue of the SPUMS Journal considered the role of patent foramen ovale (PFO) in aetiology of decompression illness. I consider that your journal has allowed a proponent of one view to attempt to undermine research suggesting a contrary theory by use of unsubstantiated and unreferenced statements. Dr Bove stated that “Some people argue that the way Wilmshurst did his statistics was not quite valid.” Which people and in what way?

Those who have read the original papers quoted by Dr Bove will be aware that there are numerical misquotations and technical errors in the text and meta-analysis. Most glaring is the suggestion by Dr Bove in his meta-analysis that the paper by Moon in the Lancet[3] included 176 divers who did not have decompression illness. This is untrue. The paper by Moon and colleagues had no control group. Moon et al. compared the prevalence of PFO in divers with decompression illness with the prevalence of PFO in two non-diving populations reported in studies from other centres, one of which was a study of prevalence of PFO in stroke patients. It is spurious for Dr Bove to classify individuals who were not exposed to risk, because they did not dive, as “No DCS”. It is ironic for Bove to question our statistical analysis. Bove’s meta-analysis was also far from comprehensive, since it contained less than half the publications on prevalence of PFOs in bent divers available at the time that his presentation was made. The limit on the number of references imposed on letters published in SPUMS journal prevents me quoting them all.*

Incomplete literature review also means that Dr Langton has failed to mention publications[4-6] which challenge the validity of the paper[7] and refute the letter[8] by Cross and colleagues which he quoted. Langton suggests that small numbers and subgroup analysis limit the validity of observation by me and colleagues in our Lancet paper.[9] At the time, our paper was the largest investigation of the role of shunts in the aetiology of decompression illness and was the only one which was controlled; in distinction from earlier observational studies. We have since extended and confirmed the number of observations in over 300 divers reported in a further 6 publications. Our subgroup analysis was entirely valid, because it was predetermined, as mentioned in the paper, for the reasons described. We required significance to be established at the 1% level (rather than at 5%) to allow for the 4 subgroups, and in most cases of significance we found $p<0.001$.

Dr Bove expressed the opinion that if PFOs are going to cause trouble it would be in the situation of multiple days of repeat diving. Like much in his article this opinion is contrary to the scientific data.[10] Most of Dr Bove's article on "Cardiovascular problems and diving" is personal opinion unsupported by references.

Peter Wilmshurst
Consultant Cardiologist

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Key Words

Cardiovascular, decompression sickness, letter.

* *The Instructions to Authors allows four references for letters which should be of 400 words only. Dr Wilmshurst's first version of his letter contained 22 references, 2 more than are considered a reasonable number for an original article. He was asked to reduce his letter to under 800 words and ten references.*

43 Daglish Street
Wembley WA 6014
27/1/97

Dear Editor

Thank you for the opportunity to reply to Dr Wilmshurst's comments. For your readers' convenience I have used the same numbers as Dr Wilmshurst has used for references common to our two letters. The one reference not used by Dr Wilmshurst is numbered 11 to stay in the same sequence.

The "incomplete literature review" refers to three Letters to the Editor by Dr Wilmshurst,[4-6] commenting on the publications of Cross et al.[7,8] The letters themselves do not contain additional information and hence were not referenced. The two included references from Cross et al. contained observational information which is relevant to the discussion, namely the incidence of patent foramen ovale (PFO) in a small control group of divers,[7] and a further uncontrolled series of the incidence of PFO in divers with neurological DCI.[8] I have paraphrased one of the omitted references in discussing relative and absolute risks of DCI, and have referenced this to another of Wilmshurst's articles.[11] Interestingly, this editorial makes no reference to the work of Cross et al.[11]

My comments regarding "subgroup analysis ... validity" is in reference to the historically based division of patients into those with "risk factors for decompression sickness" versus "safe" dives. I have not questioned Wilmshurst et al.'s predetermined clinical sub-groupings. The numbers of patients with joint pain alone (6) or rash alone (2) are small, and meaningful statistical comparison is not possible.

I do not dispute the major findings of Wilmshurst's study,[9] that PFO may predispose to early onset neurological DCI, as indicated in my summary and abstract. Indeed my overall conclusions are similar to that published by Wilmshurst and de Belder.[11] PFO is a common incidental finding in the population; the absolute risk of DCI remains low regardless of the presence of PFO.

Paul Langton

References

4-9 as per Wilmshurst's letter

11 Wilmshurst PT and de Belder MA. Patent foramen ovale in adult life. (editorial) *Brit Heart J* 1994; 71: 209-212

Key Words

Cardiovascular, decompression sickness, letter.

Cardiology Section
Temple University School of Medicine,
3401 N. Broad Street, Philadelphia
Pennsylvania 19140, U.S.A.
27/3/97

Dear Editor

I appreciate the comments of Dr Wilmshurst and have recalculated the metanalysis after removing Moon's non-diver controls. The recalculated odds ratio for all DCS is 1.96 (CI 1.33-2.89) and for serious DCS is 2.63 (CI 1.64-4.23). These ratios are significant at $p < 0.001$. The original ratios were 5.45 ((CI 3.88- 7.67) for all DCS and 5.48 (CI 3.64- 8.24) for serious DCS. Both analyses show an increased risk of DCS when a PFO is present.

The comment regarding personal opinion on cardiac problems in diving is noted. There is little information available on cardiovascular problems in diving from the published literature. For diving one must extrapolate information from the sports environment to the diving environment, with some exceptions specific to diving. I would not expect to find clinical studies of cardiovascular disorders in divers, thus most decision making comes from clinical experience with other sports, and from diving and exercise physiology.

Use of individual T tests without the Bonferroni correction has been criticised in other studies with multiple T tests. This comment has been made regarding the Wilmshurst findings in unpublished commentaries. I did not suggest that the data are analysed incorrectly rather that the results are valid because of the statistical analysis.

Studies by DAN (Divers Alert Network) and by PADI on multi-day repetitive diving show that multi-day repetitive diving increases the risk for bubble formation. Dunsford's review of the PADI data indicated that multi-day repetitive diving exposures demonstrated a high incidence of asymptomatic bubbles. Absence of bubbles in the right atrium eliminates concern for shunting across the PFO. Since multi-day repetitive diving is likely to produce asymptomatic bubbling, a PFO may become more important under these circumstances.

I hope these comments provide clarification of my paper.

Alfred A Bove
Bernheimer Professor of Medicine and Cardiology

Key Words

Cardiovascular, decompression illness, letter.

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

PO Box 2064
Normanville, South Australia 5204
25/5/97

Dear Editor

The objective of the Diving Historical Society (DHS), which is a Non Profit Body registered in South Australia, is to establish contact with others interested in diving history, older diving equipment, written and photographic material identified with diving. Also the Society will provide an avenue for the collection and exchange of information. Our diving heritage needs to be preserved and others educated in the fascinating past of diving. We invite you and your readers to become part of the procedure and enjoy the history of diving.

While, for most, the major advantage in joining the DHS will be to access the Historical Diving Society USA (HDS USA) magazine the *Historical Diver* at the same cost as domestic HDS USA members, it is hoped that membership will mean more than just receiving the award winning magazine (excellent that it is) and that informal regional groups may form and meet. These activities when they happen, will be covered in the regional newsletter that will be enclosed with the quarterly mail out of the *Historical Diver*. Regional members will receive their first issue of the four issue annual membership in July. Our thanks go to the HDS USA for their encouragement and support of our new regional Society.

Working Equipment Groups (WEGs) are not official functions of DHS Australia SE Asia. Due to liability laws DHS does not conduct any in water activities. However it is common that if a meeting with speakers and other activities is arranged then some members do dive their restored classic and antique equipment around these meetings.

Dates have been selected for DHS meetings in Adelaide and Melbourne. At both events there will be talks and equipment displays, books and photographs. Furthermore tall tales will possibly be part of the weekends. Social events fill the evenings, and some partners will be conducting a program if the old divers and their gear are not as strong an attraction for them. We hope that meetings in other States will be arranged soon.

Adelaide will be over the weekend of 9th and 10th August, with a social get together planned the Friday evening. Melbourne will be the same but over the weekend 11th and 12th October. WEGs will be conducted at each. In Adelaide at least I will be diving my 1944 DESCO Mk 5 helmet, a complete original set from the boots right through to the communications unit. In Melbourne we issue an invitation to all working Helmet sets to participate in the world record attempt for Line Dancing Helmet Divers. It will be a sight to see, at least five helmeted divers (confirmed so far) thumbs tucked in the braces (weight belt) strutting their stuff with the best boot scooting boots you ever did see. It will not be a stylish affair but it will be fun. When we thought we would get a few helmets to dive, we thought what could we do, other than just walk around the bottom. A helmet diver pyramid was suggested, but John Riley from Sydney suggested 'Line Dancing'. Singapore members will meet for the first time during September. There will be more details on all regional meetings in the next members' newsletter.

To make this all happen we need new members. Diving history is great fun and the recreational divers of the first generation are still around and, in some cases, diving. Please join us, it is your history too. The cost for four magazines and one copy of the Members Register over twelve months is $47 Australian. This cost is similar to the domestic HDS USA Member cost and a saving on the HDS USA overseas membership cost. Application forms are available by phoning (+61 (08) 8558 2970), faxing (+61 (08) 8558 3490), e-mailing (bramsay@iaccess.com.au) or writing.

Bob Ramsay
President DHS

Key Words
General interest, history.

For further information about Historical Diver read the book review on page 87

BOOK REVIEWS

SCIENTIFIC DIVING: A GENERAL CODE OF PRACTICE. 2nd Edition. ISBN 0-941332-51-9

Edited by N C Fleming and M D Max on behalf of the World Underwater Federation (CMAS)
Best Publishing Company - UNESCO Publishing,
P.O.Box 30100, Flagstaff, Arizona 86003-0100, U.S.A.
Price from the publishers $US 37.95. Postage and packing extra.

Key Words

Diving operations, equipment, occupational diving, qualifications.

This document, which covers all possible aspects of Scientific Diving practice, has an interesting pedigree which goes back considerable further than the first UNESCO/CMAS edition published in 1988. Its evolution can be directly traced to a document collated with considerable foresight by one of the current authors, Nic Flemming, and published in the UK ten years earlier as the Underwater Association Code of Practice for Scientific Diving. At that time scientific divers were blissfully unaware of the future crippling blows their discipline would be dealt in many countries when their research sites suddenly became workplaces and subject to the machinations of Occupational Health and Safety (OH&S) regulations and regulators.

Much new information has been added to the 1988 edition and this has required extensive revision of the layout and much rewriting of most sections. New or totally revised information includes material on a range of medical topics as well as the use of oxygen in diving emergencies, diver stress, decompression tables, mixed-gas training, dive computers, diving systems other than scuba, diving in a range of special and extreme conditions including recent maritime war-zones and using explosives or radioisotopes underwater. There are even a few comments on one atmosphere diving which serve mainly to emphasise the cost-effectiveness of scientific scuba diving. There is no actual index, although the careful subdivision of topics in the Contents permits use as a reference volume. There is, however, much to be gained by thoroughly reading the text from start to finish.

There are many Appendices, one of which is an extensive bibliography containing more than 400 wide-ranging references, whilst another discusses several commonly-used decompression tables and has another 40 references. The major involvement of the CMAS (which translates to the World Underwater Federation) becomes particularly evident in many of the other appendices, and quite rightly so as that organisation has been a major vehicle for maintaining the international cohesion of scientific diving. Hopefully, CMAS's global infrastructure will allow something like their Scientific Diver Brevet to become a de facto international qualification in due course. Meanwhile, the international comparison of diving qualfications as set out in Appendix 7 is invaluable, even if one now has to look under almost the last entry (United States) to discover the equivalence of the most widespread recreational qualifications of all, PADI.

This is a Code of Practice. It is not a prescriptive document in the manner of, say, the Australian and National Standards for Occupational Diving. Neither is it a diving manual. Instead, it presents a wealth of detailed information and advice, provided by active practitioners of scientific diving, on just about everything a scientific diver might consider doing underwater anywhere. The list of 122 contributors, in yet another Appendix, reads like a Who's Who of the international scientific diving community. This is certainly a timely update of a primary source of information for those of us in Australia charged with writing the detailed Employer's Diving Operations Manual which we shall all be required to have very soon.

The comprehensive, authoritative and international coverage of the new edition makes it an essential acquisition for libraries, OH&S professionals and diving officers of all institutions world-wide who directly employ, or contract the services of, scientific divers.

Ed Drew

LIVING AND WORKING IN THE SEA 2nd Edition.

J W Miller and I G Koblick.
Illustrated; pp 438.
Five Corners Publication Ltd., available from Best Publishing Company, P.O. Box 30100, Flagstaff, Arizona, 86003-0100, U.S.A. RRP $US 29.95. Postage and packing extra.

Key Words

Book review, deep diving, diving industry, diving operations, equipment, hyperbaric research, occupational diving, saturation diving.

This is both an interesting and well referenced source book for the already knowledgable and a fascinating general account of as many diving habitats and devices as could be dreamt up by the minds of underwater scientists. You may have worked in the diving industry, you may have been a Navy diver or doctor, you may be a keen sport diver or marine archaeologist but whatever your interest stems from you will find something fascinating in this book. It is easy to underestimate its voluminous content when first glancing through it. Its compilation is a major achievement in its own right. The authors' collective experience is also woven through the pages. It is not a simple descriptive tome. There are many first hand experiences that account for a lot of the information. Note the near death experience [on p 260] during the La Chalupa series, in the "near misses" section. Pioneers mentioned include Cousteau, Link, George Bond and Claude, the world's first avian aquanaut, yes, a trusty parrot.

The pattern of the book gives historical background, basic studies, the operation of the better known subsea habitats, Hydrolab, Tektite, La Chalupa, Conshelf etc., documented in detail with sound information on life support, atmosphere control, communication and electronics, food and water, emergencies, medical and psychological support and open water operations. The scientific programs assigned to each project are also discussed along with their objectives and achievements. Later comes a habitat list section with enough information (in some instances) to tantalise, leaving the reader wanting to know more, e.g. the "habitat that breathes" as Selena I is referred to in the Russian literature. In some cases of course, details are simply not available to the authors.

Find out:- Why live in the sea? Can you cook an egg or smoke a cigarette in a chamber? Who are the aquanauts? What is it like on the sea floor? What are the stresses (not smoking or not drinking wine?), strains and hazards. What are the restrictions limiting potential benefits? What are the major achievements of the programs described? Is there a place for more of such work?

There are one or two minor errors in calculation and typing, e.g some PPO_2 calculations are inaccurate or wrong, throwing the reader momentarily. A depth of 13.6 msw breathing 100% O_2 does not equate to a PPO_2 of 1.5 ATA (p 18). However the basic calculations are simple to follow and easily illustrate the reasons why subsequent experiments were conducted.

One chapter reports experiments devised and executed in the late sixties and early seventies on air saturation in particular. What would be the safe excursion limits? How deep was it reasonable to saturate on air before a nitrox mix would be required? How deep was it feasible to saturate without decompression?

It was satisfying to note mention of PRUNE I, HYDROLAB and NOAA-OPS I in the references for a nitrox saturation dive in which I was involved in recent years. Many of us would find the basic work that underpins our recent diving achievements referred to in this text.

The final section (naturally) goes on to refer to liquid breathing. Thankfully they do not overexpand on the concepts of future possibilities, the "futuristic" systems are possible now, it is more a question of having the right circumstances and, inevitably, enough money at the same time.

In summary this is a book for:- specialists with a serious interest in system planning and development; marine scientists researching method; those studying isolation and performance; technical and enthusiastic sports divers; plus all who would purport to be knowledgable about saturation diving. The latter will see why and how it came about. It is also a highly readable and well illustrated account of diving research at the time of its greatest expansion. It will hold its place on any diving reference shelf and represents excellent value for money. Finally take a close look at the world's first aquanaut and smallest habitat on the frontispiece, Argyroneta. He is worthy of some thought!

John Houston

HISTORICAL DIVER

The magazine of the Historical Diving Society USA.
Historical Diving Society, C/o 2022 Cliff Drive #119, Santa Barbara, California 93109, USA.
Individual overseas membership $US 45.00.

Key Words

General interest, history.

A complimentary copy of this magazine arrived on the Editor's desk recently. A copy was probably sent to all members of the Undersea and Hyperbaric Medical Society (UHMS). Number 8, Summer 1996 is a fascinating read. The Historical Diving Society (HDS) is only one of a number of such societies. Another is the UK Historical Diving Society, whose collected newsletters from 1991-1995 are available from the US Society.

The Summer 1996 issue contains an article on John Lethbridge's "Diving Machine" from the early 1700s and another equally interesting one about Joe Savoie, whose hand-made diving helmets for commercial divers were considered "the Cadillac by many" and "revolutionised diving". These helmets appeared in 1964, made from Italian fibreglass motorcycle crash helmets and stainless steel fittings. The early ones had the face plate as a lifting visor. They were much more comfortable and gave a better field of view than the old brass standard helmet.

Another major article is about an early 20th century Japanese face mask and regulator. The story is muddied by the fact that the original description is in English with the manufacturer's name translated but there is no Japanese record of a name that would translate to Tokyo Submarine Industrial Company.

Among the book reviews is Niagara's Gold by Jeff Maynard, a well known Australian author who tells the story of war time salvage operations in a mine field off New Zealand.

The Editor encourages readers to join him in subscribing to the Historical Diving Society. If this issue is typical there is a lot to learn about the past.

John Knight

OCEAN REALM

Published by Friends of the Sea Inc., 4067 Broadway, San Antonio, Texas 78209, USA.
Six issues (outside USA) $US 49.95

Key Words

Environment, general interest.

Among the Editor's mail was an unsolicited copy of the Autumn 1996 issue of Ocean Realm. It is a 112 page diving magazine, printed on high quality paper with excellent articles and photographs. It is aim is "To present a catholic selection of timely marine environmental topics to a broad audience of concerned individuals".

Certainly this aim is well fulfilled in this issue. There are articles on the overfishing of reefs using cyanide to provide large, live, reef fish for Asian restaurants, where the diners choose their fish from those swimming in the tank. The size of the desirable fish means that they require high concentrations of cyanide to capture. Not all recover from the cyanide, and the concentrations are so high that the small reef fish die from the poison.

Another paper covers the life of the Bluefin tuna, the world's most valuable animal, as seen from Port Lincoln. It lists the good and the bad about tuna farming, but there is no mention of the workload put on the Royal Adelaide Hospital Hyperbaric Unit.

Later on there is an article on the various by-catches, many more tons than the desired fishes provide, of ocean fisheries. Other offerings are 16 pages of magnificent photographs of whales and dolphins, and 7 pages on the ecology and conservation of the Hawksbill turtle. There are many other interesting articles, but not the usual dive travelogues that provide the staple diet of most diving magazines.

Ocean Realm is aimed at the same readership as National Geographic (USA), Australian Geographic and Australian Nature Magazine (published by the Australian Museum). It is strongly recommended reading for anyone interested in the sea and its animals.

John Knight

SPUMS ANNUAL SCIENTIFIC MEETING 1996

IN-WATER OXYGEN DECOMPRESSION AS AN EXAMPLE OF LIVING AND WORKING WITH RISK

Des Gorman

Key Words

Accident, injury, oxygen, risk, safety, tables

Introduction

The process of risk management is central to activity-related health and should be a central feature of all diving practice. However, such management is not widespread and most divers adhere to a naive concept of safe versus unsafe diving practice; an essential reliance on a mythical practical threshold of inevitably favourable outcome. Indeed, many recreational diving instructor groups and individual schools market themselves as "teachers of safe diving". It is possible that this safe-diving faith-system results in a stigma of fault and hence denial in the event of a diving accident. This phenomenon is one of the major reasons why divers suffering from DCI in Australasia take more than a day from the onset of their symptoms to report for treatment.[1]

The process of risk management is now well defined and readily applicable to diving.

In-water oxygen decompression is frequently used in deep diving to avoid dilutional hypoxia and to accelerate inert gas elimination. There are however real risks in using oxygen in this way and hence the decision to undertake oxygen decompression in the water should only ever be made in the context of a risk-benefit analysis and a consequent risk management system.

The process of risk management

In the context of health and safety practice, the process of risk management is based on the following steps.

The identification of the relevant hazards.

The assessment of the risks involved (This is often very difficult unless there is a comprehensive database.).

The development of control measures. (These measures should be, and in some countries must be, introduced in the following sequence;

the elimination of the hazard,

the substitution of the hazard,

the minimisation of the hazard,

the protection of the individual from the hazard,

and finally,

compensation for the person who is exposed to the hazard.).

Communication and acceptance of the net risk(s).

An audit of the ongoing process and a refinement of the control measures.

A diving task

An Insurance Company wants a container retrieved from a flooded mine shaft. The container is at a depth of 90 m. The nature of the shaft precludes the use of any diving stage or bell and the visibility is so poor as to render both manned and un-manned submersibles useless.

You are asked to oversee a diving recovery of the container. Initial inquiries show that the container is reasonably accessible, such that the diver(s) will be able to reach the container within the length of your 120 m umbilical (so that surface supplied gas is possible). The entire dive should take about 30 minutes.

Your review of available decompression schedules shows that all of those with established rates of decompression illness of less than 1% include in-water oxygen decompression.

You decide to use a mixture of 16% oxygen and 84% helium to avoid oxygen toxicity during the dive and because air will be too dense to breathe and severely narcotic.[2]

In-water oxygen decompression

The decision to use in-water oxygen decompression in general is based on the need to avoid dilutional hypoxia and to accelerate decompression. The dive planned here is such that some in-water oxygen decompression is not only an invariable feature of all the established decompression schedules, but also will be needed if the dive is undertaken or the diver is almost certain to become unconscious from hypoxia during the latter stages of the decompression. Clearly a diver may elect not to accept the risks associated with such an activity and withdraw from the diving team.

The first stage of a risk related approach to in-water oxygen decompression is the identification of the associated risks (shown in Table 1 as a comparison of the advantages and disadvantages of in-water oxygen decompression) and a determination of the actual level of risk involved.

TABLE 1

ADVANTAGES AND RISKS OF IN WATER OXYGEN DECOMPRESSION TO THE DIVER

Advantages	Disadvantages (risks)
Avoid hypoxia	Oxygen toxicity
Accelerate decompression	Fire risk
Increase thermal comfort	Gas handling and switching
Improve communications	
Decrease costs	

It is quickly apparent that the major risk in this context is oxygen toxicity, and especially central nervous system toxicity.[2] For your specific undertaking, reference to standard databases[2] shows that the planned oxygen exposure has a real risk of an oxygen convulsion, although this probably is much less than a 1% risk if the time of exposure is brief and other factors (carbon dioxide tension, activity, anxiety, body temperature etc.) are controlled.

The second stage of a risk related approach is to identify the appropriate control measures. To avoid hypoxia, it is not possible to eliminate or substitute oxygen (or a progressively enriched oxygen-mixture) breathing during the decompression. It is nevertheless possible to minimise the risk and to protect the divers by using the following practices;

equipping the divers with full face masks (such that they will not drown if they become unconscious), underwater communications, lines and shot ropes that will prevent them from getting lost and will enable the decompression to be controlled;

choosing a decompression schedule that uses oxygen-enriched mixtures during the early phase of the decompression and only introduces 100% oxygen late in the decompression;

controlling the carbon dioxide levels to prevent hypercarbia;

allowing the divers to rest during the in-water oxygen decompression;

controlling the diver's body temperature;

ensuring adequate gas supplies;

providing an on-site recompression chamber to treat episodes of omitted decompression.

As the final phase of this risk related approach these risks and the adequacy of the control measures now need to be explained to your prospective divers so that they can make a decision about whether they will undertake the dive. Careful dive logging is needed to ensure that both the diving practice and outcome can be audited.

Summary

The management of risk is the central process in most human occupations. The established techniques in this context are directly applicable to diving.

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Dr D F Gorman FAFOM, PhD, is Associate Professor of Medicine and Head, Occupational Medicine, Faculty of Medicine and Health Sciences, University of Auckland, New Zealand. He is the immediate Past-President of SPUMS. His address is 52 Albert Road, Devonport, Auckland 9, New Zealand. Telephone + 64-9-373-7599. Fax + 64-9-308-2379. E-mail d.gorman@auckland.ac.nz .

TREATMENT OF DECOMPRESSION ILLNESS FOLLOWING MIXED GAS RECREATIONAL DIVES

David Elliott

Key Words

Decompression illness, hyperbaric oxygen, mixed gas, recreational, treatment.

Introduction

In 1995 the Undersea and Hyperbaric Medical Society held a two-day workshop jointly with the Aerospace Medical Association on the "Treatment of Decompression Illness". Three weeks after the 1996 Annual Meeting of SPUMS, there will be a two-day conference in Marseilles on "Decompression accidents among amateur scuba divers" organised by the European Committee for Hyperbaric Medicine and later in 1996 there will be a further workshop on "Decompression illness in recreational diving" at the International Joint Meeting on Hyperbaric and Underwater Medicine in Milan. From so many meetings in so short a space of time and on such a relatively rare condition, there can be only one conclusion. There is no consensus.

Yet the obstacles to consensus are slowly being cleared away. There is recognition of the need to use agreed descriptive nomenclature, to collect detailed case histories (not anecdotes) from different treatment centres for analysis and, wherever feasible, to conduct trials of therapy on a scientific basis. In the meanwhile, we are forced to rely upon personal observations and experience, based on case histories. These are traditional tools in medicine which are still useful and, at the very least, can lead to the development of new hypotheses.

In the continuous search for some unifying solution, reports are presented in which treatments are compared with other treatments when, from the diverse nature and time scales of the original decompressions, one should not expect such cases to have evolved comparable pathology. The pattern of illness appears to vary with the nature of the preceding pressure exposure. For example, there are the gross differences in clinical presentation and time-course between the "bends" (old terminology) of aviators, tunnel workers and divers. Within diving itself there are differences, not surprisingly, in the presentations of decompression illness between oxy-helium saturation, oxy-helium excursions, and surface-orientated diving. Similarly, within the broad range of compressed air recreational diving there seem to be clinical differences, for instance, between those who stick to the no-stop protocols of 2 tanks-a-day for 6 days of sub-tropical resort diving and those who dive on deep wrecks in cold waters. To take this example further one could run into trouble with confounding individual variables such as acclimatisation, complement levels and hangovers that might or might not be associated with some types of diving and/or decompression illness. So there is reason to suggest that the presentation, nature and severity of decompression illness arising from advanced recreational diving might not be the same as that arising from other types of recreational diving.

Also consider how the clinical features of any decompression illness change during the first few hours after onset. Bubbling is a dynamic condition as are the sequelae. The underlying pathological status when the initial manifestations first arise is quite different from that in the same individual some 12 hours later. Most algorithms for recompression fail to acknowledge this time factor. The "Time From Surfacing to Onset" and the "Time From Onset to Recompression" are part of the management assessment and these factors should feature in the decision-trees.

Diagnosis

It is not sufficiently acknowledged that an accurate pathological diagnosis is often impossible. Also the bubble has, so to speak, much to do before its host will be diagnosed. The bubble must cause sufficient symptoms so that the diver recognises that he or she has a problem. The threshold for reporting this to somebody else is likely to vary from the hardened professional, who has been through it all before, to the anxious novice who, as Carl Edmonds suggested,[1] may report anything if he feeling less than 110%. This reporting of subjective symptoms then needs to be interpreted by a third party, a diver or a doctor who may, or who may not, take appropriate action. Of course, *we* all know that *any* manifestation arising after a dive must be managed as a potential case of acute decompression illness, but there are many who do not. This sequence of decisions will affect diagnosis, management and outcome and so, in turn, they will influence any subsequent statistical analysis.

Management

In this discussion of the management of "tekkie bends", it seems wise to avoid considering symptoms that may be denied or subconsciously suppressed but, instead, consider a peripheral motor deficit of early onset that is more objective. The underlying pathology may be air embolism from pulmonary barotrauma, it may be decompression sickness from dissolved gas or it may be a combination of both but, for management at a remote location, does that matter? The essential issue is one of practical management, and not one of pathogenesis.

Diving first aid

Oxygen by tight-fitting mask leads the conventional list of actions to be taken without delay. A transient Trendelenberg, while the oxygen is being readied, does no harm and, in quite a few cases, may be associated with a rapid recovery. But that might have happened anyway and, if so, beware the "lucid interval", because the condition may return.

Immediate management

At this point one the actions that can be taken are very dependent on local circumstances and what has been done at the planning stage of the dive trip. Are team individuals each well trained for such an emergency? How good are the communications? Does the boat have a radio? Where to seek help? What equipment is available? In the case of a neurological deficit, treatment is needed urgently and much depends on what local support exists, if any. Possibly nothing.

Those who have participated in experimental diving in the navy or commercial diving in the North Sea, have always dived in the immediate vicinity of a chamber. This is kept at readiness for any decompression illness. *Recompress first and diagnose later* is the rule and, under these circumstances, an immediate recompression usually leads to immediate and complete relief. This experience has led to the concept of a "magic window", a period of up to some 60 minutes from the rapid onset of symptoms during which pressure seems able to reverse the pathological process completely. Sometimes this will not work because there may be just too many bubbles but in every case as time passes there is a potential deterioration of symptoms and an increasing difficulty of achieving full relief. Thus a treatment centre and its supporting emergency services could set targets, worthy of audit, for the time from reporting symptoms to recompression.

In the absence of a chamber on site, one has a different problem. One must consider either evacuation or in-water compression.

Evacuation

Picking up a diving casualty from a boat by helicopter for transfer to a hyperbaric centre relatively nearby is quite common in some parts of the USA and UK. This complies with the principle of urgency of treatment, but is not a standard to be expected at very many diving locations.

Evacuation to a more remote recompression chamber can take time to organise and, while waiting, catheterisation if needed, an intravenous drip and other therapeutic procedures can be started, as are well described elsewhere. With a simple semi-closed oxygen rebreathing circuit the useful life of a relatively small supply of oxygen can be extended to last for the whole period of evacuation. Several commercial versions are available and seem to provide an effective interim treatment until recompression becomes available.

Numerous reports suggest that less than 5 hours retrieval to hospital is considered rapid in some parts of the world and that, for some treatment centres, a 12 to 24 hour delay is fairly usual. Given remote geographical and other difficult logistical factors, achievement of such standards may be considered good for that area, but one should not forget that an earlier recompression might have led to better treatment results.

Recompression on site

Given the effectiveness of immediate recompression and the almost insurmountable problems from the delay associated with so many evacuations, the costs and benefits of on-site recompression for recreational diving, and "tekkie diving" in particular, deserve some reconsideration.

The choice falls between in-water recompression and having a chamber on site. The current possibilities for in-water recompression were reviewed by Pyle and Youngblood[2] but there has been no clinical trial on the relative effectiveness of the Hawaiian, US Navy or Australian in-water recompression procedures. For a number of reasons I would be reluctant to recommend the deep Hawaiian spike as a general procedure, so this leaves the two 9 m (30 ft) treatments on oxygen as practical options, the principle difference being that the US Navy version is twice as long as the Australian. Of these, the use of underwater oxygen, pioneered by the RAN,[1] appears to have been the most widely used. Success of in-water oxygen has spread by word of mouth but hard data is not available.[3] In contrast, in-water recompression using only compressed air is generally thought to have worsened more cases than it has cured.

A standard procedure for in-water oxygen recompression has been described[4] but 9 m (1.9 bar PO_2) seems to be rather shallow to be effective, so why does it work? If its effectiveness is true, one answer may be the relative immediacy of recompression in contrast to a delay potentially of many hours in evacuating to a distant chamber for an 2.8 bar recompression.

The use of a transportable one-man chamber for the evacuation of decompression casualties has been remarkably successful[5] but this too has its limitations, particularly the delay which occurs when the transportable chamber needs first to be taken to the casualty.[6]

For the provision of a prompt 18 m recompression on site there is now a more recent solution: a light-weight chamber which packs into a small volume and which can be kept close to the dive site, ready for use. This may be in a dive shop, on board a live-aboard or at any remote dive location. It can be taken there by the dive team themselves. When in use, the same chamber can be used also for airborne evacuation, at sea-level or raised pressure, and it has a small enough diameter that it can taken into most hyperbaric chambers so that a patient could be transferred while still at raised pressure. I also understand that the cost equates to that of one closed-circuit rebreather, so it would be worth considering by any isolated diving expedition. Of course, there is likely to be no doctor present when recompression is needed but this circumstance is true also for the working diver whenever he or she needs recompression. Each diving location should have one or two appropriately trained diver medics and a radio with which to call up a treatment centre for advice if needed. Not very sophisticated, but better than paraplegia.

Recompression at a treatment centre

The algorithms followed by different treatment centres are very varied. Much of the apparent difference in protocol and procedure between different centres may a consequence of their local circumstances, such as the availability of trained staff (e.g. a Grand Cayman modification of USN Table 6 enabling easier switching of attendants). Another factor is the local style of diving e.g. the deep dives of Hawaii which is associated with their use of a 66 m (220 ft) "deep spike" at the beginning of a modified USN Table 6A. Diving accidents arising in areas of French influence are likely to be treated on the GERS 30 m tables generated by the French Navy or their derivatives such as "Comex 30" which is also used regularly in commercial diving in the UK. Cases arising in many other locations worldwide will be treated by USN Table 6, extended if necessary, and possibly followed by 5 days or so of daily shallow HBO treatments for residual manifestations. Many such courses of repetitive HBO treatments are a result of geographic distances and associated delay over which a treatment centre has little or no control. In contrast, in chambers for the treatment of naval and offshore commercial divers recompression can be provided within *minutes* of onset and the divers expect to make a rapid 100% recovery on the first recompression. Indeed, any persistent residua would mean unfitness to resume diving.

Depth of dive

The majority of recreational treatment centres use the 18 m recompression algorithms, predominantly for cases arising from diving to less than 40 m and often after more than 6 hours delay from onset. Are the same procedures appropriate for decompression illness arising from shallow nitrox diving, from extreme air diving or from surface-orientated deep mixed gas diving? My answers are speculative but one must begin somewhere.

Nitrox cases can be regarded as suitable for the conventional algorithms designed for air decompression illness. Any pulmonary oxygen problems can be dealt with if and when they arise.

After deep dives on any breathing gas, if there has been a delay of some 6 or more hours from onset before recompression, one is in the salvage business and the odds are that the 18 m treatment will be a suitable approach. Given a chamber available within, say, some 3 hours then some debate is appropriate. If the condition of a deep diver is life-threatening then my personal experience would be to take a deep diver deeper than 18 m. Given a "blow-up" and a chamber immediately available on site I have taken several deeper than 50 m but the number of successful cases is probably insufficient to convince others.

Given a chamber on site that is capable of 18 m there is some evidence that this will be effective for the relatively rapid treatment of decompression illness arising from 270 feet (80 m) surface-orientated mixed gas dives. In 1966, thirteen cases of decompression illness arose from a naval series of oxy-helium dives with 20 minute bottom times, and symptoms arising within 3 hours were treated on site with the then experimental version of the Goodman and Workman 60 feet (18 m) oxygen tables. Of 8 cases so treated, all made a full and rapid recovery. After around 3 hours after each experimental dive the divers transferred to another location where the chamber staff were not authorised to use this shallow treatment and, of the 5 cases in whom the onset of symptoms was delayed more than 3 hours, all made a full recovery on a deeper air table. This is no more than an encouraging tale since it tells us nothing about deeper or longer dives or about the use of possibly more extreme decompression profiles.

Conclusion

The treatment of decompression illness arising after any type of diving is urgent. After only a few hours the medical emphasis is on neural salvage but, if recompression can be made almost immediately available at the diving site, the chances of a full recovery are likely to be maximised. This is probably true after any depth or breathing mix. The relative costs and benefits of having a small 18 m chamber on site need to be assessed before diving more than one to three hours away from a conventional hyperbaric treatment centre.

Audience participation

Unidentified speaker

Should one aim for complete resolution of all DCI symptoms and signs at the first treatment? Or should one accept some residual symptoms at the end of the first treatment and then give repeat treatments with hyperbaric oxygen?

David Elliott

I do not handle cases with a long delay before treatment so I go for complete resolution. The professional diver, if he has any residua, will lose his livelihood and therefore one wants to get, if one possibly can, a 100% recovery, even of numbness and tingling in the fingertips, before he comes out of his first recompression. Of five cases that have now settled in the courts, there were two relevant features. One was that all were suing because they were unfit to dive as a result of an incomplete initial treatment and because the subsequent hyperbaric oxygens did not cure them. The other interesting thing, all five also had a PFO (patent foramen ovale). When one looked through the records each had very unusual presentations that were not recognised by the diving superintendent. Hopefully education is now putting that right. So with anything after any dive, treat immediately.

John Knight

This is a request from a technical diver. One of his friends had two buoyancy compensator blow ups on a very deep dive in Sydney harbour. The dive boat skipper put the diver, who had missed a lot of decompression, back into the water on a hose with oxygen at 6 m (1.6 bar) for 30 minutes, then took her out and they set off straight for the hospital. She had developed a few symptoms by the time she got to the hospital and she was cured with her first treatment. Her diving buddies were sure that she would have developed symptoms much earlier if they had not put her in the water. My informant wanted to ask SPUMS, and this seems the best place to ask, whether they did the right thing or not. Can David Elliott and Bill Hamilton to give their opinions on what one should do with somebody who has missed decompression. Would it be reasonable to put them back in the water for oxygen decompression?

David Elliott

In the old days the British Sub-Aqua Club (BS-AC) used to put divers with omitted decompression back in the water to do a few prescribed stops and bring them out. It was based on naval experience and was a good routine. The current BS-AC manual says that one should keep them on deck and observe them for the onset of decompression sickness. There is current litigation by two divers who then were observed to develop decompression sickness. Their lawyer has agreed that this hazard is so serious that I am allowed to talk about it before it comes to court. I have been on to the BS-AC and hopefully they will produce a better omitted decompression routine. [*Editorial note. In fact surface oxygen is now (May 1997) recommended with no further diving for 24 hours provided the diver remains symptom free*.]

Omitted decompression is quite different from treatment. If there are no symptoms and the person has a blow up, it is a standard practice in commercial diving, and in the Navy, to get them back in the water to do the stops that they should have done and preferably a little bit extra. If one can do that within five to seven minutes missed decompression is not a problem. I think what these individuals did in Sydney is basically correct. There were no symptoms, therefore this was omitted decompression, therefore they gave the individual who had had the blow up some omitted decompression stops. I think they did the right thing. They had oxygen, they might have planned to do oxygen stops in the water which I regard as reasonably safe. I am not frightened of oxygen in the water if the person is at rest. It is when they are swimming hard that it is a problem.

Bill Hamilton

I agree entirely. I tell the people that if divers miss decompression, they should go back in the water and do it. It has to be done very quickly. I recommend using oxygen in the water if it is available. Donald showed that the 25 foot (7.5 m or 1.75 bar) oxygen fits were all in working divers. In resting divers, there were no fits or convulsions and just some minor symptoms. Even so, I do not advise using oxygen at nine metres if it can be avoided.

Chris Acott did not mention what I call the Catch 22 of in water recompression. If one has the capacity to evacuate one is going to a lot of trouble and a lot of risk to treat a sore knee. On the other hand if somebody really needs treatment because of a bad neurological hit, does one want to put that person back in the water?

Chris Acott

If the diver is paralysed one knows that Goodman and Workman showed that all those they treated at 33 feet (10 m or 2 bar) had to be treated again. At the Diver Emergency Service in Australia we get a lot of calls about people in remote locations outside Australia. Some of them are on normobaric oxygen. Sometimes their clinical condition has improved quite dramatically by the time we talk to the local doctors. Then it is often difficult to convince the patient to accept a medical evacuation because they are feeling so much better. We know that they will probably relapse as soon as the oxygen comes off but they do not believe us. So we lose twelve hours getting the plane up to them.

Des Gorman

In-water oxygen decompression is the single most commonly practiced form of decompression for virtually any form of diving below 50 m. It has significant advantages. There are discernible disadvantages.

The major disadvantage of in-water oxygen decompression is oxygen toxicity. I think a stage is inadequate for oxygen decompression deeper than 6 m. I do not believe there is any correct answer to the response to a fit in the water unless one has an open or a closed bell. Then the answer is to control the airway, go to a lower oxygen fraction and when the fits stop, resume oxygen and continue the decompression. In an open bell I can hook someone up. I can take their hat off. I can maintain their airway. The Royal New Zealand Navy practices exactly that when they use open bells. A closed bell is the complete answer. It enables one to do a transfer under pressure, the diver can have an oxygen fit in the comfort of a dry recompression chamber and anyway the chances of a fit are significantly lower once out of the water.

On a stage or with a free swimming diver my answer is simply to get the diver out of the water. But I believe that any action taken then should be the least obnoxious option and depends on the equipment being used and the risk of drowning.

Bill Hamilton

We have a room full of anaesthesiologists. Is the glottis going to be closed or not on a person who is having a convulsion and during what phase of the tonic/clonic seizure?

M Davis (Chairman)

As an anaesthetist I might answer that. I would suspect that during the tonic phase the glottis is almost certainly closed and in spasm along with all the rest of the musculature. But soon after that it is going to open again. However it is not only the glottis that determines the patency of the airway. In fact it is usually the position of the tongue, the jaw and the epiglottis.

Bill Hamilton

What are the contra-indications to trying to get the person to the surface? I am not talking about someone in a bell, or with a full face mask, but about someone who has spat out the mouth piece. My personal feeling is that one should avoid drowning them. Someone said earlier that when choosing between embolism and drowning, take drowning as one can treat that. I would say take the embolism because it probably will not happen and try to avoid having to treat the drowning.

David Elliott

I have no disagreement with what Des has said. When the odds are that the mouthpiece is going to be out, I think the PADI recommendation, of bringing them up, is correct. If the diver is actively fitting, *and has the mouthpiece in*, then postpone going to the surface until the fit is over.

Bill Hamilton

An AGA full face mask costs about 800 or 1,000 dollars. It is not cheap. But there are full face masks for a couple of hundred. It is claimed that wearing a full face mask results in about a 20-25% increase in gas use. With microphones used for communication divers use even more gas. It is increase in gas consumption which puts divers off buying full face masks. I do not understand why the diver uses more gas when using a full face mask. It should not be any different from any other demand valve. Even if it is true I think a full face mask is worth using when at risk of oxygen toxicity. I certainly would want one.

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Dr David H Elliott was one of the guest speakers at the SPUMS 1996 Annual Scientific Meeting. He is Co-Editor of The Physiology and Medicine of Diving, which was first published in 1969, with the most recent edition in 1993 and is also the civilian consultant in diving medicine to the Royal Navy. His address is 40 Petworth Road, Haslemere, Surrey GU27 2HX, United Kingdom. Fax + 44-1428-658-678. E-mail 106101.1722@compuserve.com

Dr C J Acott FANZCA, DipDHM, is the Co-ordinator of the Diving Incident Monitoring Study (DIMS) and a consultant for the Diver Emergency Service. His address is Hyperbaric Medicine Unit, Department of Anaesthesia and Intensive Care, Royal Adelaide Hospital, North Terrace, Adelaide, South Australia 5000, Australia. Phone +61-8-8222-5116. Fax +61-8-8232-4207

Dr Michael Davis, FANZCA, Dip DHM, is the Past-Chairman of the New Zealand Chapter of SPUMS and Director of the Hyperbaric Medicine Unit at Christchurch Hospital, Private Bag 4710, Christchurch, New Zealand. Phone +64-025-332-218. Fax +64-3-364-0187. E-mail hbu@smtpgate.chhlth.govt.nz .

Dr D F Gorman FAFOM, PhD, is Associate Professor of Medicine and Head, Occupational Medicine, Faculty of Medicine and Health Sciences, University of Auckland, New Zealand. He is the immediate Past-President of SPUMS. His address is 52 Albert Road, Devonport, Auckland 9, New Zealand. Telephone + 64 -9-373-7599. Fax + 64-9-308-2379. E-mail d.gorman@auckland.ac.nz .

R W (Bill) Hamilton PhD, who was one of the guest speakers at the 1996 SPUMS Annual Scientific Meeting, is principal of Hamilton Research, Ltd., Tarrytown, New York 10591-4138, USA. Telephone + 1-914-631-9194 Fax + 1- 914-631-6134 . E-mail 70521.1613@compuserve.com

Dr John Knight FANZCA, Dip DHM, is Editor of the SPUMS Journal. His address is Editor SPUMS Journal, C/o Australian and New Zealand College of Anaesthetists, 630 St Kilda Road, Melbourne, Victoria 3004, Australia. Telephone (61) (03) 9819-4898. Fax (61) (03) 9819-5298. E-mail spumsj@labyrinth.com.au .

A COMPLETE SUBMARINE ESCAPE AND RESCUE ORGANISATION

Robyn Walker

Abstract

A complete submarine escape and rescue organisation should allow the survivors of a submarine accident to exit the submarine, be rescued and be provided with appropriate medical treatment for resultant injuries. Survivors may leave the submarine in two ways. The first involves an “escape” where the survivors leave the submarine through an escape hatch and make a buoyant ascent to the surface. This is limited to a depth of 180 m. Alternatively the survivors can be “rescued” by a rescue vehicle and be transported back to the surface where subsequent decompression can be undertaken. Rescue is required to cover the depths from 180 m down to the crush depth of the submarine.

Predicted medical conditions in submarine accident survivors include decompression illness, gas toxicities, near drowning, traumatic injury, thermal stress, sea sickness and psychological trauma.

The Royal Australian Navy (RAN) has a commitment to provide a full submarine escape and rescue organisation for the benefit of the submarine arm. This paper discusses the development, and trial, of a medical contingency plan to treat 55 survivors of a submarine accident. The integration of a full rescue capability into this plan will be presented.

Key Words

Accident, bell diving, decompression illness, emergency ascent, hyperbaric facilities, surface decompression, transport, treatment.

Introduction

If a submarine becomes disabled and sinks how the crew gets back to the surface is dependent on a number of factors. These include the internal pressure of the submarine, the internal atmosphere of the submarine, the weather conditions and the state of readiness of the rescue forces.

There are two methods of leaving a disabled submarine, escape and rescue. Escape is where the survivors leave the submarine through an escape hatch and make a buoyant ascent to the surface. Escape may be using the single escape tower (SET) hooded free ascent method or by rush, or compartment, escape. SET escape, which reduces the time each individual is under increased

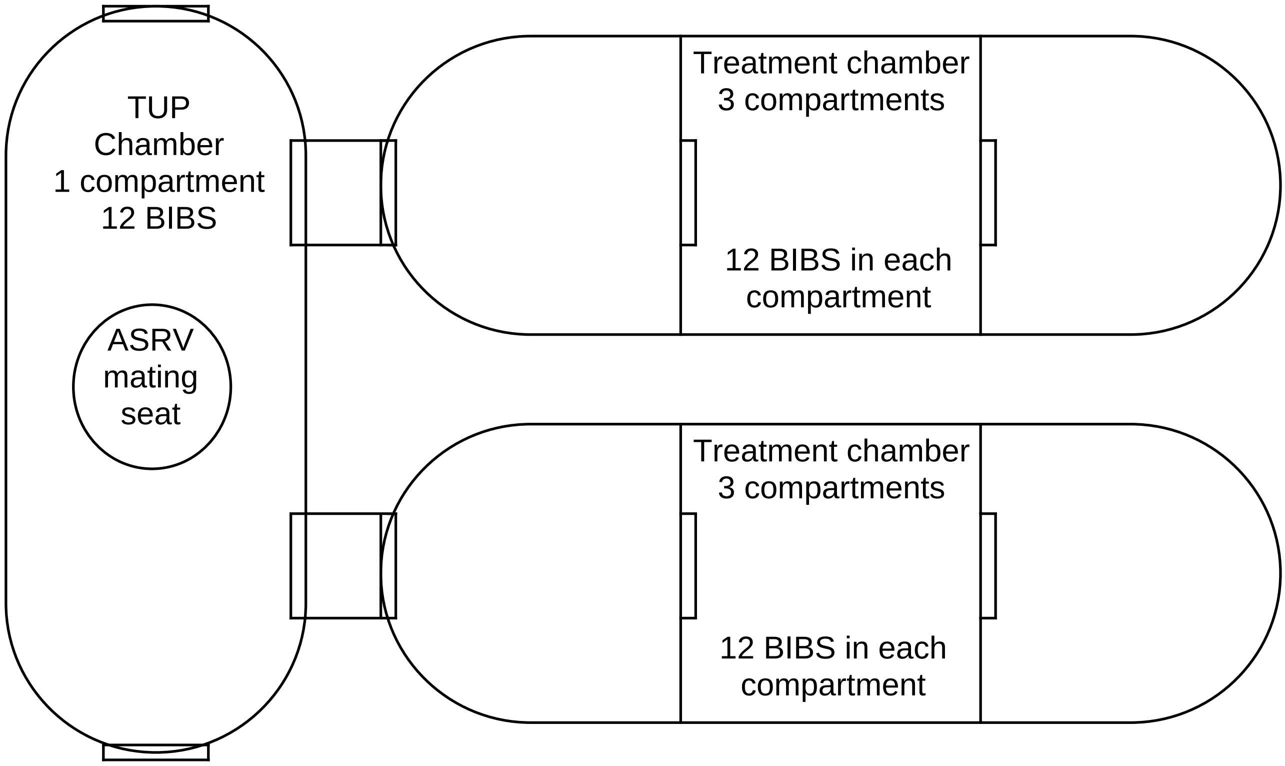

Figure 1. Schematic diagram of chamber complex.

pressure, is the preferred method having been carried out, as an exercise, successfully from a depth of 180 m. Rush escape is potentially survivable from depths of 60 m, but due to the length of time under pressure, because the compartment has to be flooded to outside pressure before the first member of the crew can escape, personnel can be expected to have a high casualty rate from anything but the shallowest of depths. Rescue involves the use of a submersible to transport the survivors to the surface where subsequent decompression can be undertaken. Rescue is limited primarily by the operating depth of the rescue vehicle.

Escape would be favoured if there were falling oxygen levels within the submarine or intolerable atmospheric constraints. Rescue would be the preferred option if there was no surface support for escapees or in the presence of severe surface conditions.

The RAN in association with the Australian Submarine Corporation has developed the Submarine Escape and Rescue Service (SERS) which comprises a rescue submersible, a chamber complex and an Extension of Life Support pod delivery system, a method of replenishing a disabled submarine. It consists of pressure proof cylinders small enough to pass through the escape tower. The pods contain oxygen candles, soda lime, food, water, medical supplies etc. They can be delivered to the submarine by a ROV (remotely operated vehicle) or a diver and "posted" through the escape tower to be received by the survivors.

The chamber complex (Fig 1) consists of a transfer under pressure (TUP) chamber to which the submersible mates. From there the survivors transfer to two treatment chambers each of which has three compartments. Each treatment compartment and the TUP chamber has 12 built-in breathing system (BIBS) outlets which can be used for oxygen or oxy-helium mixtures. As the two treatment chambers can accommodate 36 patients each the TUP chamber will not be used as a treatment chamber but as a method of access.

In the event of a submarine accident the SERS plus the SUBSUNK (missing submarine) medical supplies will be transported to the accident site by a ship of opportunity (any available suitable ship). Figure 2 is a diagram of the layout of the whole system on board such a vessel. While the majority of the hardware will be identical for both the escape and rescue scenarios the illnesses expected in survivors and the management of casualties will be different because of the different pressure exposures.

The Australian Submarine Rescue Vehicle (ASRV) is capable of carrying 8 people (Fig 3). One or two crew and 6-7 survivors. It is estimated that each leaving surface to leaving surface cycle will take up to three hours. This means it could take up to 10 cycles, or 30 hours, to rescue

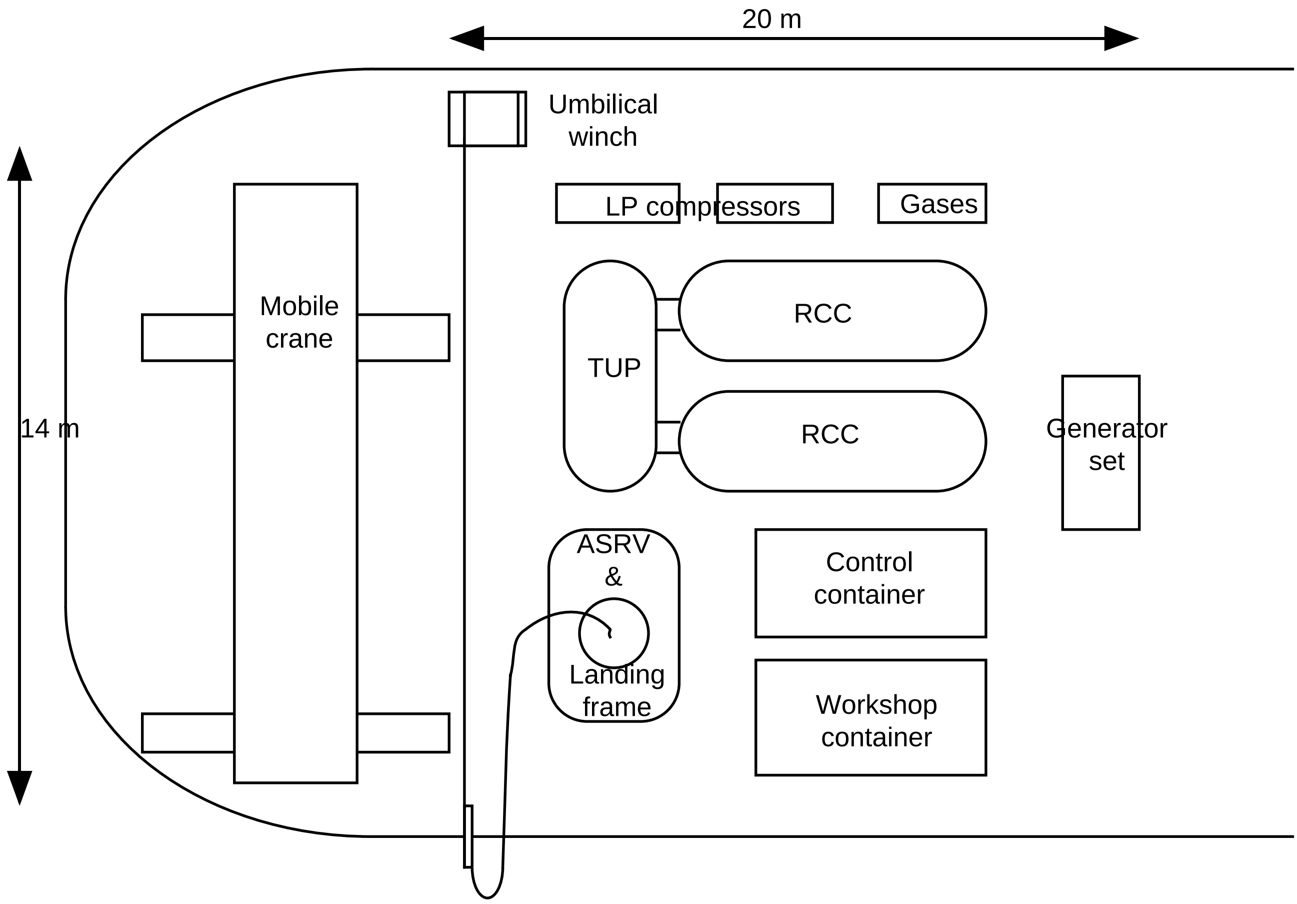

Figure 2. Diagram of deck layout on ship of opportunity.

the entire crew of 55. Over this 30 hour period it is possible the internal pressure within the disabled submarine could continue to rise. The ASRV is capable of performing transfer-under-pressure operations from a submarine with an internal pressure of up to 5 bar (40 m) and from depths down to the crush depth of the submarine.

SUBSUNK medical stores

The SUBSUNK medical stores have been packed in a manner designed for use in a "disorganised" emergency setting.

A dressings and triage kit contains large scissors for the removal of the Submarine Escape Immersion Suit (SEIS), thermometers, dressings and splints. A field medical report will be secured to each survivor at the triage point. Blankets and towels are packed in separate identifiable containers.

Items required for airway control, i.e. laryngoscopes, endotracheal tubes, cricothyrotomy kits, Guedel airways and suction catheters, are located in the red chest packed with the resuscitation medical officer's kit. There are oxygen therapy sets available for 64 people. Oxygen is administered using a constant flow, non-rebreathing system with a reservoir bag. All the equipment required to administer oxygen, reducer, tubing, flow meter, non-rebreathing mask, bag etc., to 4 people is packed in a plastic bag. Sixteen of these bags are in the chests labelled oxygen sets. Oxygen is supplied on a pallet of G sized cylinders (48 litre water capacity) which are distributed as required.

There are four medical officer kits, containing drugs and diagnostic equipment, for use in independent locations. One of these is the Resuscitation MO's kit containing airway management equipment. Another is the High Dependency kit. The other two are MOs' kits for delayed management or low priority areas. The intravenous fluids have been organised into units; each unit containing a one litre bag of Hartmann's solution, a giving set, an arm board and two cannulae. Tourniquets, sticking plaster (micropore) and skin sterilising swabs (alcowipes) are in the medical officers kits.

A separate surgical kit contains surgical supplies required for suturing and items required for the insertion of a chest drain. A trocar, Heimlich valve and sterile kit are located in the container labelled "chest drainage kit". Urinary catheterisation trays containing all required items come in individual prepacked sterile trays. All medical items are packed individually so can be distributed to the areas where they are needed.

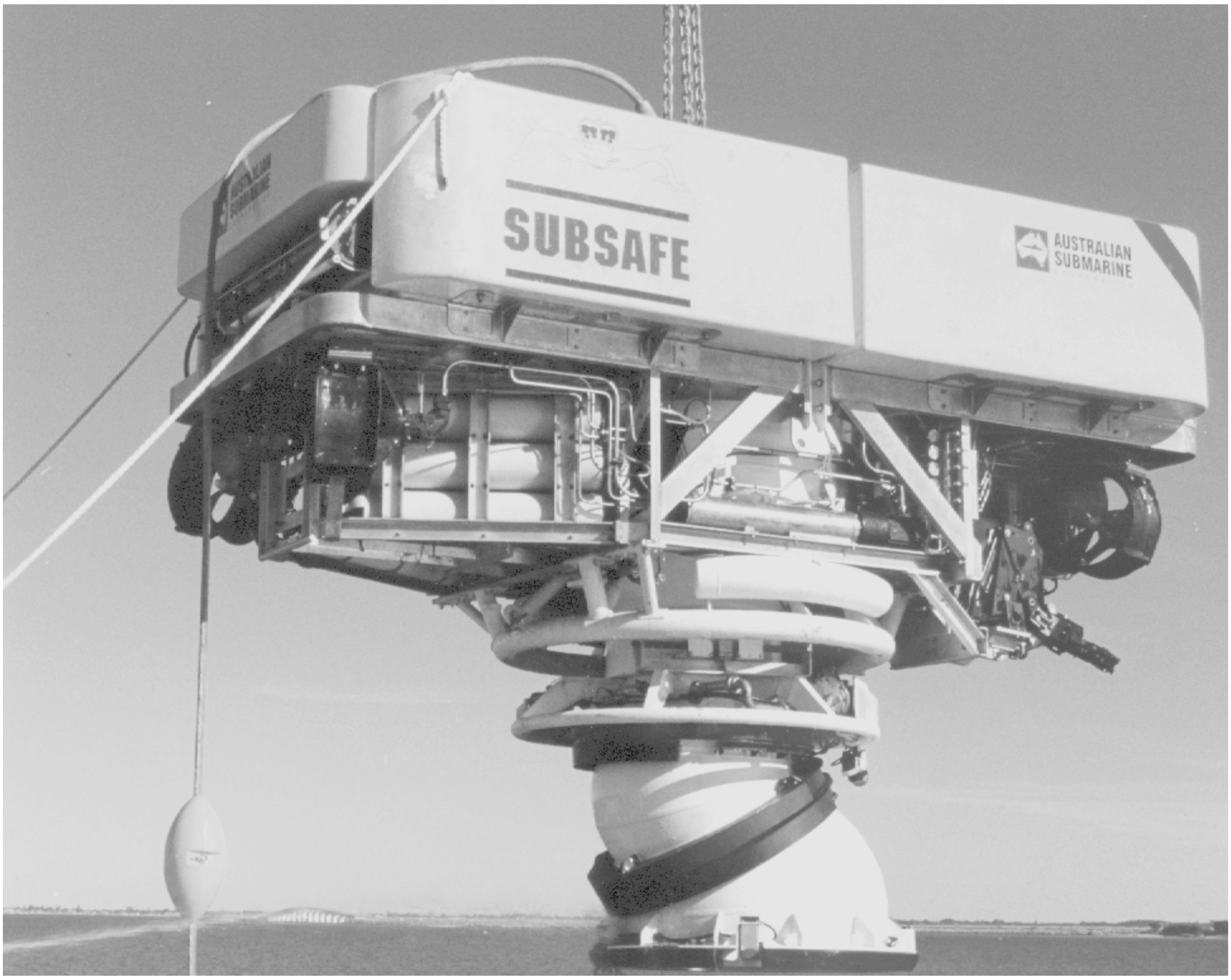

Figure 3. Australian Submarine Rescue Vessel. Photograph courtesy of Royal Australian Navy Photographic Unit.

Expected medical conditions

Survivors will have a range of medical problems depending on the cause of the submarine sinking, the time the submarine has been at depth, the internal pressure of the submarine, the condition of the atmosphere inside the submarine and, for escapees, surface conditions.

Medical problems may include:

TRAUMA

This will include fractures and lacerations which may not prevent successful tower escape.

BURNS

A fire on the submarine can lead to it becoming disabled and some survivors may have burns.

TOXIC GAS EFFECTS

A fire may produce toxic gases that can lead to hypoxia as well as toxic effects. These can include CO poisoning, low partial pressures of oxygen and increased percentage of carbon dioxide. Salt water in the battery compartment can cause liberation of chlorine gas, a potent toxin, leading to acute bronchospasm, pulmonary oedema and eye irritation. The lung effects may lead to an increased incidence of arterial gas embolism.

HYPOXIA

Most people remain conscious breathing an oxygen partial pressure of 0.12 bar or greater. Below 0.16 bar progressive symptoms of hypoxia develop, increased breathing rate, laboured respiration, clouded thought processes, decreased awareness of surroundings and finally unconsciousness. As the internal pressure of the submarine rises, the percentage of atmospheric oxygen needed to maintain an adequate partial pressure falls.

HYPEROXIA

Oxygen can be toxic. Partial pressures above 2 bar can lead to central nervous system toxicity with grand mal seizures. Breathing oxygen at lower pressures, above approximately 0.5 bar gradually leads to symptoms of pulmonary oxygen toxicity. The rapidity of onset of the relative symptoms increases as the partial pressure of oxygen is increased. Symptoms of pulmonary oxygen toxicity include chest tightness, cough, chest pain, shortness of breath and a fall in vital capacity. The severity of oxygen toxicity symptoms is important in selecting a decompression schedule.

ATMOSPHERE CONTAMINATION
Toxic gases arise from many sources and include products of incomplete combustion (carbon monoxide, phosgene), salt water contamination of the battery (chlorine), chemical spills and products of respiration (carbon dioxide). The biologic effects of toxic atmospheric contaminants are usually proportional to their partial pressure.

COLD
A sunken submarine quickly cools to the surrounding water temperature and at depth the submarine internal temperature may only be 5°C. Survivors on the surface in exposed conditions are also in danger of hypothermia.

PRESSURE
Most events which lead to a disabled submarine (DISSUB) will involve some internal pressure increase above 1 bar. This may occur with flooding, high pressure air leaks, salvage air and the use of emergency air breathing systems. If this increase in pressure is maintained for a sufficiently long period of time a decompression obligation will result.

DECOMPRESSION ILLNESS
This includes arterial gas embolism and decompression sickness. The risk of the latter will increase as the internal pressure in the submarine increases and the former increases with conditions that increase gas trapping such as the effects of irritant gases.

NEAR DROWNING.
Some escapees will be suffering the effects of salt water aspiration and drowning. These survivors will require varying degrees of respiratory support.

ESCAPE SCENARIO

Survivor movements

Survivors are brought to the rescue ship in inflatables, lifted onto the ship (kept horizontal) and transported to the triage area. Triage is performed into four groups.

SERIOUSLY ILL
These require immediate resuscitation and/or recompression.

LESS SERIOUSLY ILL
These form the second priority group.

MINOR PROBLEMS
These only need delayed treatment or even no treatment.

DEAD
These require to be placed where their bodies will not interfere with the treatment of the living.

The survivors are then transported to the appropriate treatment area according to their assigned priority. All survivors will be given 100% oxygen using a rebreathing circuit and intravenous fluids.

Treatment protocols

During a SUBSUNK event the decisions must be made about who should be treated, how they should be treated and how urgently they should be treated. All patients need to be resuscitated before being placed in the RCC.

Treatment groups

IMMEDIATE
This includes those suffering severe neurological DCI, those with rapidly progressive symptoms and signs and those with severe cardio-pulmonary DCI (“chokes”). Those who have a presentation and history consistent with arterial gas embolism (AGE) require early recompression. Even those who have apparently made a spontaneous recovery from AGE frequently deteriorate and early recompression is indicated.

DELAYED
In this situation where there are mass casualties and limited resources it is important to ensure that there is a recompression chamber available for those who require urgent treatment. Those with lesser symptoms such as joint pain or tiredness or minor paraesthesia which are stable may be given delayed treatment.

Treatment tables

The treatment table of choice for all survivors is an USN Table 6.

This table is as effective as those that involve deep air excursions and has the advantage that it is shorter. Any patients who do not respond quickly or significantly will be given an extended Table 6. Even those patients who apparently deteriorate further during the first 2 periods at 2.8 bar (18 m) on 100% oxygen will be given an extended Table 6, rather than having their treatment table changed.

Experience has shown that many of these patients will stabilise as the treatment progresses and then improve and those who do not may die. Whether this latter group would improve on any other treatment table is debatable and there is no clear evidence to support the suggestion.

The SERS recompression chambers are capable of supplying heliox (helium-oxygen mixtures) and it is possible to conduct a treatment using a table such as a COMEX 30 or RNZN 1A. These will allow the patient to be compressed to 4 bar (30 m) breathing 50/50 heliox. This offers a possible treatment for those who continue to deteriorate at 2.8 bar (18 m) on oxygen. However this will commit the RCC to a treatment which is longer and may preclude treating others simultaneously. Therefore the overall needs of all patients must be assessed before employing these treatment tables. These tables may well be used for survivors who escape last.

If the first 6-10 survivors all have serious DCI, requiring immediate recompression, it indicates that all survivors will require treatment, especially those who escape last. A Table 6 may not be logistically possible. The recommended treatment in this situation is 60 minutes at 18 m with a 30 minute ascent to the surface breathing oxygen throughout (18:60:30). There is evidence to indicate that this may be effective treatment for a number of survivors and will certainly prevent most deteriorating further. Those patients who remain symptomatic can receive follow up treatments.

Saturation therapy has been considered in the past but is only mentioned here to exclude its use except in extreme circumstances (i.e. failure of oxygen supply to the RCC). This therapy is labour intensive, long, requires considerable logistic support and is difficult to support when there is only one patient. There is the added disadvantage that medical support is difficult to provide to any patients that deteriorate due to conditions other than DCI. The SUBSUNK scenario involves multiple patients, small compartment recompression chambers, limited personnel and logistic support, seasickness and psychological trauma, let alone any other forms of trauma. Saturation therapy is inappropriate treatment except in extreme circumstances.

RESCUE SCENARIO

Survivor movements

After the ASRV has been successfully mated with the TUP chamber, it and RCCs will be pressurised and equalisation achieved. One doctor and one medic will be in the TUP to assist the survivors down the ladder to examine and treat them. The survivors will clean themselves and change into dry RCC approved clothing. Any medical procedures will be conducted in the TUP, time permitting. During this time the ASRV pilot will refill the variable ballast bags and prepare the ASRV for its next cycle.

After the ASRV has separated and the patients transferred into one of the RCCs the TUP is vented to the surface, cleaned and restocked.

Using the TUP as a large transfer lock, fresh medical attendants and ASRV pilots can be blown down (pressurised). When all the survivors are in the system one of the RCC locks would be used if further assistance was required.

Suggested management protocols

If a disabled submarine is pressurised the hazard of DCI in the survivors becomes an important component of how to conduct the rescue. The medical recommendations must address safe decompression and need to be tailored to the available assets.[1] Decompression of survivors from a pressurised disabled submarine falls into several categories.

<u>0-1.5 bar</u>

Saturated survivors rescued from an environment of 1.5 bar or less can be decompressed immediately to 1 bar.[1] They should be observed for symptoms and signs of DCI for 48 hours before any commercial flight.

<u>1.5-1.75 bar</u>

Survivors rescued from 1.5-1.75 bar are at a low, but definite, risk for DCI. They can be decompressed directly to the surface, but, if circumstances dictate, this should be done with a chamber close by in case recompression is necessary.[1]

<u>1.75-2.8 bar</u>

Survivors from depths up to 18 m (2.8 bar) will require an air saturation decompression.[1]

<u>2.8-5 bar</u>

Survivors rescued from these depths are the most difficult to handle for several reasons. Air saturation tables are limited to relatively shallow depths because of oxygen toxicity and survivors at these depths are likely to have developed significant pulmonary oxygen toxicity. In usual occupational diving operations the limiting factor for nitrox mixtures is nitrogen narcosis, restricting the depths for normoxic mixtures to less that 50 m (6 bar). On the North Sea oilfields heliox mixtures are used below 50 m, however, switching to heliox for decompression after an air saturation can cause isobaric gas exchange supersaturation and DCI.

No tables have been developed for the decompression of divers saturated on air from these depths. The USN Time Constrained Decompression Tables[1] are statistically derived, highly informed, but unconfirmed, estimates of the risks associated with decompression from an air saturation. The tables provide several alternative schedules for decompression on air from various depths. The most lengthy (conservative) schedule for each depth is associated with a 1% or less predicted bends incidence. Other schedules have faster overall decompression times at a cost of a higher incidence of DCI, in some cases nearly 80%.

USN Treatment table 7 is an oxygen/air table usually reserved for cases of unresolved or life threatening DCI. It involves a minimum stay of 12 hours at 18 m (2.8 bar) and then a slow decompression back to the surface. The probability of DCI occurring in an individual breathing air throughout a Table 7 has been estimated at 0.2 %; an important consideration for both the medical attendants and the survivors.

In the absence of tested decompression schedules it is planned that survivors from depths between 18-40 m (2.8-5 bar) will commence decompression at a rate of 1 m/hour and continue in accordance with table 7 from 18 m to the surface. The chamber atmosphere will initially be air. It is planned to let the survivors breathe down the oxygen content to maintain a partial pressure of oxygen no greater than 0.5 bar. Oxygen will be added as necessary to maintain this level.

Patients will begin breathing oxygen as soon as possible after reaching 18 m. Oxygen breathing will be limited by pulmonary oxygen toxicity and the medical officer will be required to assess each patient's clinical condition individually. The medical attendants will breathe chamber atmosphere throughout. This decompression schedule will take over 60 hours from 5 bar, the maximum working pressure for the ASRV. Any cases of DCI which occur during these decompressions will be treated with the usual saturation practices.

It is estimated a minimum of five ASRV cycles will be required to bring out half the crew of the disabled submarine. If the internal pressure in the submarine remains constant, once the first 3 compartment complex is full decompression can begin. If however the internal pressure is rising, it is planned to hold each group of survivors in a separate compartment until the maximum pressure is known. Then it will be decided whether earlier rescuees will perform a downward excursion to the depth of the later survivors, or the later rescuees perform an upward excursion based on predicted safe limits.[1] The upward excursion limits are based on limited testing, so, for safety reasons, we will aim to restrict any upward excursion to 50% of the predicted safe limit for that depth. Decompression will then begin. The transfer under pressure (TUP) section will be used for the supply of food and sanitation purposes.

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LCDR Robyn Margaret Walker, MB BS, Dip DHM, RAN, is the Officer in Charge, Submarine and Underwater Medicine Unit, HMAS PENGUIN, Middle Head Road, Mosman, New South Wales 2088, Australia. Phone + 61-02-9960-0333. Fax + 61-02-9960-4435.

NORMOBARIC OXYGENATION IN DIVE ACCIDENTS: A CHALLENGE FOR THE DEVELOPERS OF OXYGEN DELIVERY SYSTEMS

Jürg Wendling

Key Words

Accident, equipment, oxygen, rescue, transport, treatment.

Introduction

The value of immediate normobaric oxygenation (NBO) in the treatment of diving accidents is clear. The main treatment for decompression illness (DCI) is hyperbaric oxygen therapy (HBO). DAN Europe statistics[1] showed that 85% of the DCI cases treated with HBO had complete relief of symptoms. The two main factors influencing the final outcome are immediate treatment with NBO and liquids and the delay before recompression therapy.

In the US DAN statistics[2] about 70% of the patients with minor neurological symptoms or pain as pre-recompression symptoms were still symptomatic after treatment when the delay was more than 12 hours, while the percentage of residual symptoms was only 20% for a delay between 4 and 12 hours and about 10% for a delay less than 4 hours. The median delay before HBO treatment was 7 hours for AGE, 26 hours for DCS I and 20 hours for DCS II. Only 33% of DCI cases were given oxygen as first aid therapy during transport and only 6% of DCI cases got oxygen and fluids. In transit oxygen treatment increased the symptom relief rate before recompression by a factor of 2 to 8.

From the DAN Europe statistics we see an even more striking effect. While 99% of the no-oxygen group remained symptomatic, 55% of the oxygen group showed improvement and 12% had complete relief of symptoms by the time they arrived at a hyperbaric facility. The relief rate after HBO treatment was 70% for the no-oxygen and 96% for the oxygen group. These figures show that oxygen first aid therapy is not just an additive to the overall treatment, but an important contribution with a significant effect on the final outcome. Considering that the majority of divers who got oxygen did not really breathe 100%, because of inappropriate oxygen administration devices, and that many of them did not get oxygen during the whole transport time, the difference in outcome could even be greater.

Oxygen delivery systems

Why is the use of the NBO in first aid treatment still very uncommon in the diving population? Many divers are not aware of the first aid possibilities and do not know the techniques of oxygen therapy.

There are two systems for oxygen administration, open and closed. With open systems the exhausted gas is extruded to atmosphere. With the next inspiration the patient again fills his lungs with gas from the system. Open systems can be constant flow or on-demand. Most of the available oxygen systems do not assure 100% inspired oxygen concentration and in many cases the small cylinders only allow short times on oxygen.[3] The great disadvantage of open systems is that they consume large amounts of oxygen, 600 to 900 litres per hour. For a transport time of 2 hours one needs a 10 litre oxygen cylinder (Australian D size cylinders are 9.5 l water capacity).

The most commonly used constant flow oxygen delivery system has a loose fitting mask, designed to allow entrainment of air with each breath. The expired air mixes with the oxygen in the mask, dilutes it and then escapes between the mask and the patient's face. The flow rate is usually between 2 and 10 litres per minute (lpm). It was designed to raise inspired oxygen to around 40%, which is too low for diving casualties but useful to prevent hypoxia.

For a constant flow system to deliver 100% inspired oxygen a close fitting mask, to prevent air entrainment, and a reservoir bag, larger than the inspired volume to store the oxygen delivered during expiration, must be provided. A non-return valve must be used between the reservoir and the patient so that the oxygen in the reservoir is not diluted with expired nitrogen. The oxygen supply must be equal to, or more than, the minute volume, which is 10 to 20 lpm if the patient is to receive 100% oxygen. The Laerdal resuscitation mask, self-inflating bag and reservoir bag with a flow of about 15 lpm is an example.

On-demand systems are similar to a scuba regulator. Oxygen only flows when the patient breathes in so 100% oxygen can be achieved, but is used at the patient's minute volume.

In 1989 we assessed the frequently used oxygen delivery systems for their ability to assure inspiratory 100% oxygen, the maximum duration of the oxygen supply and acceptance of the systems by divers for long term use, which means comfort of the mouthpiece or mask etc. We found that none of the available systems met the optimum conditions for NBO and we therefore proposed the use of closed systems but there was nothing on the market at that time.[4]

Closed systems

With the help of a Siemens engineer I assembled a new device (Fig 1). Soon after the first experiments, this rebreather system, with a closed circuit, was tested.[5] As this type of gas supply is widely used in anaesthesia, the question was not whether it would work but whether such a sophisticated apparatus could be used by divers. When oxygen inflow is higher than uptake excess gas will escape through the relief valve. With an inflow that is too low, the rebreather bag will lose its volume and finally collapse (Fig 2). There is absolutely no danger for the diver, because, as he or she is awake, he can take off the mask and breathe air if the bag collapses.

The danger of CO_2 intoxication was also checked. Even if the colour change in the absorber is not noticed by the diver, the spontaneous increase in tidal volume will alert

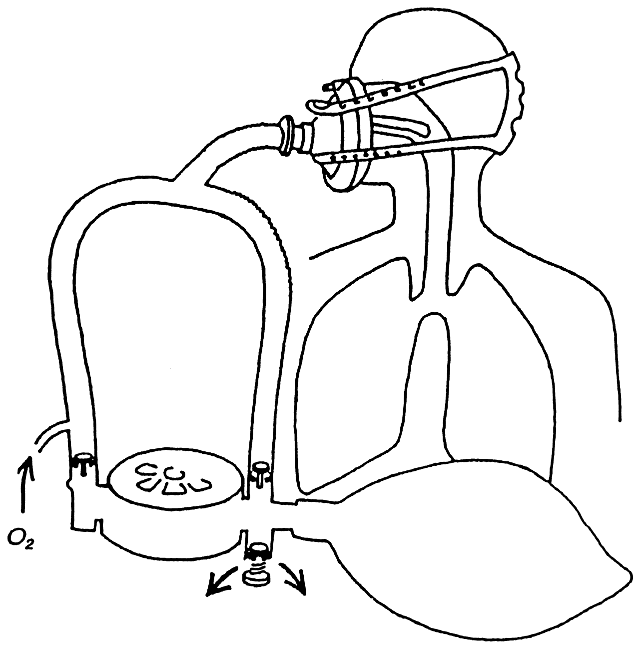
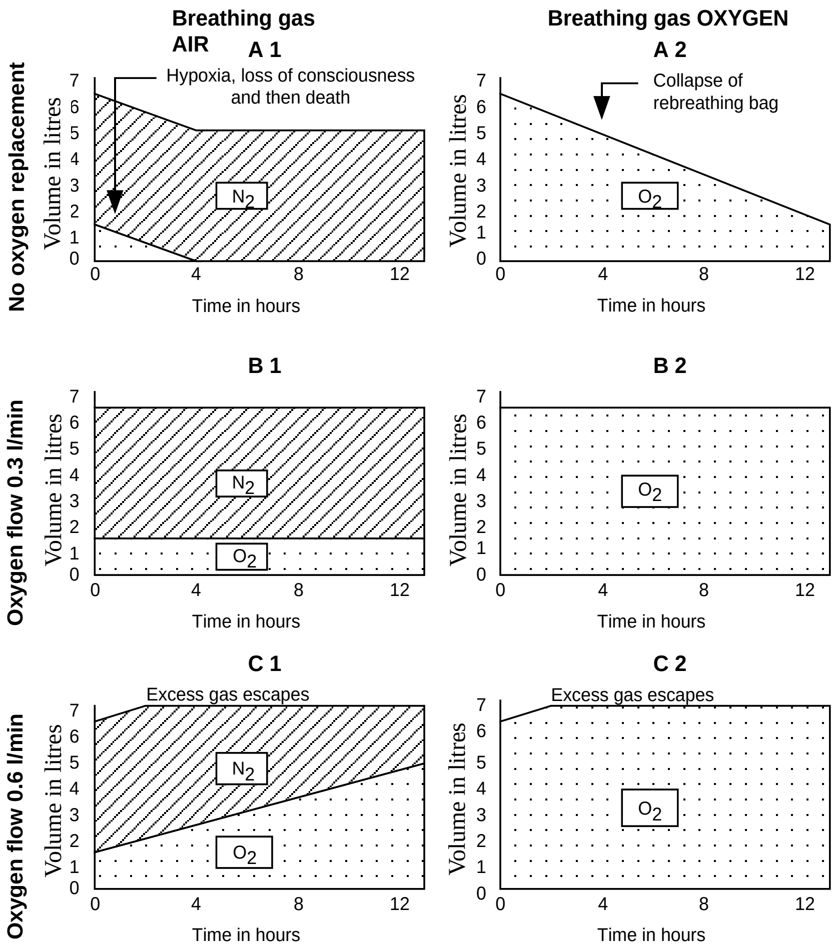


Figure 1. Diagram of closed circuit oxygen system for field first aid (Wenoll system).



A 1 Air closed circuit without oxygen substitution After 2 minutes the gas is hypoxic and will induce unconsciousness and death. Note that there is no ventilatory stimulation due to CO_2 absorption.

A 2 Oxygen closed circuit without O_2 subsitution. The total volume of the system will diminish gradually, so that the rebreathing bag will collaps after a few minutes. There is no danger to life as the gas remains 100 % O_2.

B 1 and B 2
Closed circuit systems with replacement of O_2. Both maintain volume and constant O_2 concentration.

C 1 Air closed circuit system with abundant O_2 supply. O_2 concentration increases while part of the gas mixture escapes to atmosphere.

C 2 Oxygen closed circuit system with abundant O_2 supply. Excess O_2 escapes to atmosphere.

Figure 2. Changes in total volume and oxygen concentration in closed systems with various oxygen inflows. Comparison of a closed circuit air system (left) and pure oxygen circuit (right).

him, or her, and induce interruption of the circuit a long time before the dangerous state of CO_2 intoxication can develop.

Elimination of nitrogen is the main goal of NBO therapy. When a closed oxygen system full of oxygen is attached to the patient who has breathed right out (full expiration) the system still contains some 30% of nitrogen after the first few breaths. This must be washed out in order to get a pure oxygen atmosphere. This can be achieved by a flushing phase, using an inflow of oxygen of 2 lpm for about 10 minutes. After about 10 minutes the N_2 is less than 3% (Table 1). Then the system is closed by reducing oxygen inflow to about 0.5 lpm. Fig 3 shows the Wenoll system in use.

Is a closed oxygen system safe for normal divers?

After six years of experience, carefully testing and improving some details, we can answer the question.[6] Closed systems are now widely used by divers in middle Europe, by Swiss police divers and soon by the Dutch Navy.

TABLE 1

ELIMINATION OF LUNG NITROGEN FROM A CLOSED CIRCUIT (SYSTEM FILLED WITH OXYGEN) USING AN OXYGEN FLOW OF 2 lpm

Time in minutes	Added oxygen	Expired gas Vol	Expired gas Nitrogen %	Expired gas Nitrogen Vol	Nitrogen in circuit %	Nitrogen in circuit Vol
Start					31%	2.00 l
1	+2.00 l	-1.5 l	31%	0.46 l	24%	1.54 l
2	+2.00 l	-1.5 l	24%	0.36 l	18%	1.18 l
3	+2.00 l	-1.5 l	18%	0.27 l	14%	0.91 l
4	+2.00 l	-1.5 l	14%	0.21 l	11%	0.70 l
5	+2.00 l	-1.5 l	11%	0.16 l	8%	0.54 l
6	+2.00 l	-1.5 l	8%	0.12 l	6%	0.41 l
7	+2.00 l	-1.5 l	6%	0.10 l	5%	0.32 l
8	+2.00 l	-1.5 l	5%	0.07 l	4%	0.25 l
9	+2.00 l	-1.5 l	4%	0.06 l	3%	0.19 l
10	+2.00 l	-1.5 l	3%	0.04 l	2%	0.15 l

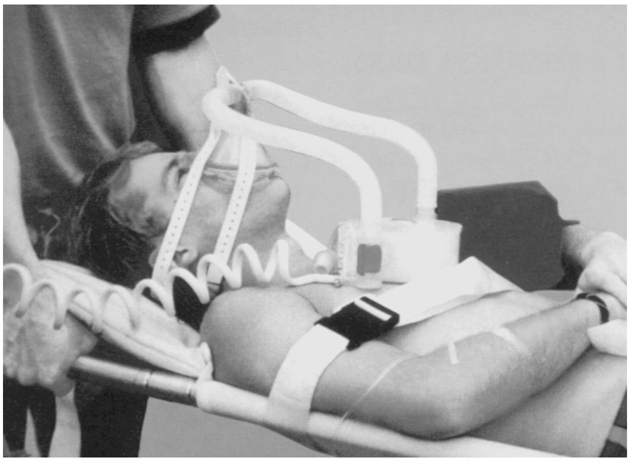


Figure 3. Closed circuit oxygen system (Wenoll system) for normobaric oxygen for divers in use .

For a treatment of less than 5 hours, the system can be turned on with a flow of about 1.3 litres and nitrogen elimination, high oxygen concentrations in the circuit and normal CO_2 levels will be maintained.

If transport will take longer, the system must be used as a closed circuit with flushing at intervals. The oxygen flow is set to 2 lpm for the first 10 minutes, then reduced to 0.5 lpm for 20 minutes. At the end of the 20 minutes another 10 minutes at 2 lpm is followed by another 20 minutes at 0.5 lpm. After these two cycles a 10 minute flush is followed by 50 minutes at 0.5 lpm three times, taking the patient to the 4 hour mark when the absorber has to be changed. With these settings a 2 litre oxygen cylinder at 200 bar will allow the whole five flush cycle to be repeated as the oxygen supply will be sufficient for up to 8 hours (Australian C size cylinders are 2.84 l water capacity and pressurised to 163 bar).

If CPR is needed, the system can easily be connected to a tracheal tube or a resuscitation mask and controlled ventilation with 100% oxygen performed. Another special use is closed circuit therapy in hypothermia, used by coastal life guards or alpine rescue teams, which however requires some adaptations to the equipment.

Conclusion

Although some open systems can be very useful for NBO they all have the disadvantage of a limited capacity due to high oxygen consumption (600-900 litres per hour). Closed-circuit rebreather systems are a new approach to the problem. They use less than 50 litres of oxygen per hour, which allows continuous NBO treatment for many hours using small oxygen cylinders. This argument might not be very important in my home country (Switzerland). However in the world's most favoured diving places transport time is so significant that the use of closed oxygen systems should be promoted as the standard procedure in first aid treatment of diving accidents in order to reduce residual symptoms and invalidity.

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Dr. med. Jürg Wendling, General Surgeon and Hand Surgeon FMH, is a diving and hyperbaric medicine specialist, Director of DAN Europe Suisse, Committee member of the European Committee for Hyperbaric Medicine, Swiss Delegate to EDTC. His address is Faubourg du Lac 67, CH- 2502 Bienne, Switzerland. Phone + 41-32-322-3838. Fax + 41-32-322-3839.

The closed circuit oxygen rebreathing system presented in the article is produced by EMS Elektromechanische Systeme GmbH, Waldstrasse 2, D - 91096 Möhrendorf, Germany. Phone + 49 9131 440 420. Fax +49 9131 47468

The Wenoll system sells for DM 350. A complete set with light weight box, 2 l oxygen cylinder, reduction valve with flowmeter is DM 1,100. Highly resistant special boxes (Pelikan type) with more space for first aid equipment are also available.

TECHNICAL ASPECTS OF DIVING IN ANTARCTICA

David Taylor

Abstract

Diving in Antarctica presents the diver with problems related to the extreme environment, logistical and medical support, physiological stress, physical discomfort and danger. This paper describes the peculiar technical difficulties encountered by diving in such an environment and the ways in which equipment and diving procedures need to be modified in order to ensure the success of the program and minimise risk.

Key Words

Environment, equipment, marine animals, thermal problems.

Introduction

Australian National Antarctic Research Expeditions (ANARE) have undertaken diving programs in Antarctica over a period of many years. The programs have collected scientific data on human physiology, marine biology and ecology. Antarctica is one of the coldest continents on earth and requires divers to undertake special training and modify their usual equipment and diving protocols. The logistical problems of an Antarctic diving program are extensive and as much a challenge to the diver as the environment itself.

The environment

Most ANARE diving programs have been undertaken at Davis Station, Antarctica. Davis (68°35'S, 77°58'E) is a permanently occupied Australian research station and is situated on the edge of the Vestfold Hills, Princess Elizabeth Land, 4,700 km across the Southern Ocean from Perth. The hills are of moderate relief and are penetrated by many deep fjords which extend inland to the ice plateau.

The weather at Davis is relatively mild. The Vestfold Hills are interposed between the station and the ice plateau and this land mass breaks up the catabatic winds and modifies the local climate. Consequently, Davis enjoys a low average wind speed of 20 km/hr and clear, still days. The mean temperature ranges from 0°C in summer to -18°C in winter. The continent is very dry with only 5-12 cm of precipitation per year and has a low level of humidity. Daylight hours vary from 0 hours per day in the winter to 24 hours per day during the summer.

The ambient temperature has the most influence on sea and ice conditions. The sea begins to freeze in March after the short summer season. Fast sea-ice is present from March/April until December/January and may extend several hundred kilometres off-shore and reach a thickness of 1.4 to 2.0 m in the late winter.[1-4] Increasing temperatures, winds and ocean swells cause this fast ice to "breakout" in the spring although it may remain in the fjords for much longer.

Salinity depresses the freezing point of sea water to approximately -1.8°C and after the fast ice has formed the sea is relatively insulated from the winter extremes above. Consequently, water temperature varies little, from 0°C to -2.0°C throughout the year.[1-6] Diving visibility is excellent and typically greater than 100 m.[3,5] It is at its maximum during winter and spring when the fast ice cover reduces turbulence and sediment suspension and low light intensities depress phytoplankton (algal) growth. Light under the ice may be limited at certain times of the year by short hours of daylight, the low angle of incident light and ice thickness. Algal bloom may first appear in September and may greatly decrease visibility from December onwards.[2,5]

The seas around Davis are prone to the usual ocean currents and tides. These are modified by fast ice cover which nullifies the effects of wind and minimises tidal fluctuations. However, the sea remains a dynamic force beneath the ice and dangerous currents may be present especially near the estuaries and narrow inlets of some fjords.

Dangers

Environmental hazards above the ice present major difficulties in Antarctic diving. Hypothermia may be seen among divers, attendants and support staff as a result of exposure to low temperatures, wind and wet clothing.[4] Frostbite is not uncommon and results from freezing of water within skin cells following intense, cold-induced vasoconstriction. It affects the exposed areas especially the cheeks, ears, nose and fingertips.

Hypothermia may also be a problem below the waterline.[1,4] Sullivan and Vrana[1] demonstrated a slowly progressive central hypothermia in Antarctic divers. This hypothermia is likely to be a major cause of physiological depletion in divers and motor and mental deterioration may affect their performance, comfort and safety.[2,4] Peripheral hypothermia results in digital discomfort, facial pain and the loss of peri-oral muscle control if the face is directly exposed to water. Continued underwater exposure results in localised cooling with the hands and feet exhibiting the most rapid rate of heat loss. These cool rapidly because they have the greatest skin surface area to mass ratio, little subcutaneous fat and relatively little insulation to allow dexterity.[2]

Ultraviolet (UV) radiation may be intense in Antarctica. The spatial and temporal variation of stratospheric ozone above Antarctica is of regional and global significance to the amount of UV radiation that reaches the ground.[7] Divers and their attendants are at particular risk from UV injury because of their exposure to direct radiation and that reflected from ice, snow and the water. Protection of the skin from sunburn and the eyes from snow-blindness is of great importance, particularly during the long hours of sunshine in the summer.

Marine animals are potentially dangerous to Antarctic divers.[2] The Leopard seal is a four metre, toothy, aggressive predator which feeds on krill, penguins and other seals. There have been no reported incidents of these animals injuring divers but harassment has occurred which necessitated the abandonment of the dive. ANARE diving regulations forbid diving activity within 400 m of a Leopard seal.[2] Non-breeding male Elephant seals "haul out" at Davis in summer. They are approximately 3.5 m in length, although may reach six metres and 3-4 tonnes in full fat when fully grown. There is a documented incident of an Elephant seal biting a diver on the shoulder and it is recommended that great care be taken if diving in the vicinity of breeding males in violent rut. An underwater encounter could be most embarrassing! Killer whales have a reputation as being ruthless and ferocious killers who feed on seals, walrus and penguins. Their exact threat to humans is uncertain and they should be considered as an unpredictable and potentially serious hazard.

Antarctic diving, especially under-ice, has its own peculiar dangers. Solo diving is often undertaken with a fully-suited "buddy" waiting at the surface. This arrangement ensures at least one diver free from hypothermia and exhaustion at any one time. As few divers are available it also avoids the need for multiple dives thus minimising the risk of decompression sickness (DCS). Tides and currents may cause difficulties as in any marine environment and may even cause diver entrapment by moving ice floes or closing up tide cracks in the ice through which the diver entered. Under-ice gloom may contribute to diver disorientation and claustrophobia but should be avoided with the use of adequate illumination.

Antarctic divers are at risk of dysbaric and non-dysbaric diving illnesses as well as illnesses unrelated to diving.[6] Divers are potentially more at risk from DCS in Antarctica. The water is very cold, and often dark, and the underwater work is made even heavier by the use of cumbersome suits.[8] Diver exhaustion is a potential problem and may result from hypothermia, heavy underwater work, cumbersome suits, the demands of the diving program and insomnia during the long hours of summer daylight.

Communications are particularly important in Antarctic diving programs. The interpersonal communications of those in the diving team must be good with an adequate designation of personal responsibilities and responsible leadership. Communication between the dive team in the "field" and Davis Station needs to be fail safe in the case of emergency. Radio schedules, spare radios and batteries are prerequisites.

Equipment

The recreational scuba regulator is prone to malfunction in Antarctic diving conditions.[2,5] The usual cause is ice crystal formation within the regulator mechanism which results in jamming or "freeze up". There are several factors which may precipitate first stage freeze-up. Firstly, adiabatic (without loss or gain of heat) expansion of air from the scuba cylinder results in cooling of the air as it expands from high to low pressure. This causes moisture in the air or water in the regulator mechanism to freeze. Secondly, the delivery of wet air to the regulator from the cylinder makes freeze up more likely. This is not usually a problem in Antarctica as the air delivered into the compressor is usually very dry. Thirdly, as modern first stages are metallic and very compact, they may become supercooled in the very cold atmosphere even before the first breath is drawn. This problem may be overcome by keeping the regulator in the relatively warm diving shelter until immediately before the dive. Ice crystals once generated may plug orifices or interfere with the movement of first stage components. Fortunately, first stage freeze up nearly always causes malfunction in an open or free-flow position.[2,5]

Second stage freeze-up is caused by moisture in the exhaled breath or water in the chamber forming ice around the demand lever. It is more likely to occur if the second stage is purged or allowed to free flow, conditions which rapidly decrease the regulator temperature. Unlike the first stage, second stage freeze up may result in no air getting to the diver. It is recommended that regulators be dried completely after the post-dive rinse and that no water be allowed to enter the second stage before immersion.

Ice formation on the external surfaces of the first and second stage assemblies is also possible. Usually ice forms around the large first stage spring which is surrounded by water in most regulators. This results in jamming of the spring with loss of depth compensation, restricted breathing or free-flow. Free-flow produces an increase in intermediate air pressure which in turn may cause free-flow of the down-stream second stage demand valve and second stage freeze up. ANARE uses the Sherwood Magnum Blizzard regulator which has been specifically designed for under-ice diving. This regulator has compressed air surrounding the first stage main spring which provides a form of insulation and reduces the incidence of freeze up in this assembly.[2] Other cold water regulators are insulated by 50% glycerol surrounding the first stage.[3]

The likelihood of regulator freeze up may be minimised by avoiding rapid flows of air from the scuba cylinder. Lengthy purging or inflation of the buoyancy compensator (BC) or dry suit, free-flow and the use of the octopus assembly is avoided where possible. Water must not be allowed to enter the regulator between dives and its exposure to extreme cold prior to use is discouraged. Inhalation from the regulator should be avoided until it is well below the water surface and gentle exhalation whilst descending through the surface layer of ice slush is recommended.[3] This avoids the use of the supercooled stages in the very cold atmosphere. The attachment of a small "pony" cylinder to the main scuba cylinder is highly recommended. This small unit has its own regulator and is a completely separate air supply which may be utilised in the event of main regulator freeze up.

A bank of large cylinders may be used to provide a surface air supply with air being delivered via an umbilical hose. This has the advantage of eliminating the scuba first stage, provides a very large reservoir of air and an effective safety line to the diver. These air banks have the disadvantage of being extremely heavy and require either helicopter or sled transport.

The Kirby-Morgan helmet, or "band mask", is a device which encloses the diver's entire face and has been used extensively on ANARE expeditions. It has the advantage of incorporating the second stage into the relatively warm air within the mask, prevents very cold water from contacting the face and allows the diver to communicate with the surface by an intercom system. However, the helmet is cumbersome and time-consuming to don, provides substantial water drag, restricts head movements and requires a considerable amount of familiarisation training.

Communication with surface attendants is essential in under-ice diving especially if the diver is diving alone. In this situation there can be no immediate reliance upon a buddy diver in the event of emergency. All under-ice divers must be attached to a life-line. The diving attendant should hold the life-line reasonably taut at all times and should be able to communicate with the diver through a predetermined sequence of tugs.[2] The life-line also allows the diver to find the entrance hole and the rescue diver to find the diver, if necessary. The wires of the Kirby-Morgan helmet intercom system run with the life-line. This intercom is an ideal system but, like many things in Antarctica, is prone to malfunction.

Ten mm wet suits are sufficient but cumbersome in Antarctic conditions. The dry suit has become popular as, when worn with the appropriate underwear, it provides excellent insulation from cold and wind and avoids the cold discomfort of changing out of a wet suit. The Poseidon Unisuit, used on ANARE expeditions, is built from closed cell foam neoprene with nylon lining both sides and is donned through an access sealed by a waterproof zipper. The suit is inflated by an inlet valve connected to the diver's air supply and exhausted by a second valve adjacent to the diver's shoulder. Thus, two valve manipulation allows for complete buoyancy control.

Drysuits, because they use air as insulation, require more weight to get the wearer below the surface and have more buoyancy problems than wet suits. It is essential to have training in how to dive wearing a dry suit in order to learn how to control the problems of shifting air inside the suit. One technique is to use a buoyancy compensator (BC) for buoyancy control and only add sufficient air to the dry suit to fill the underwear at the surface.

If a dry suit is worn an additional BC is theoretically unnecessary. However, some divers elect to wear a BC and dry suit. The BC may then be used for all buoyancy control or as a back up in the event of dry suit failure.

In the last seven years dry suits have gone from being rarities in Australia to being almost the standard suit in southern waters. The situation in April 1996 is that the majority of divers undertaking dives over 30 m are wearing drysuits. In the Scottish Sub-Aqua Club Survey in 1995 83% of the respondents dived in dry suits in conditions similar to those in Tasmania and Victoria.[9] The deciding factor is the vast improvement over the wet suit in keeping the diver warm. Without the misery of incipient hypothermia the diver can concentrate on enjoying the dive and is in a better state to cope with emergencies.

The dry suit has several disadvantages. Donning the suit can be time-consuming and hard work although this is minimised if detergent is used to lubricate the tight seals at the neck and wrists. The suits are bulky, cause considerable water drag and may exhaust the diver if considerable swimming is required. Dangerous over-inflation of the suit may be caused by inflation or exhaust valve freeze up or malfunction and may require the diver to vent excess air through a wrist seal. As with regulators, supercooling of suit valves prior to the dive and prolonged use of the inflation valve predisposes to valve freeze up. Thigh and ankle weights are often required to maintain the diver in the head-up position and to prevent air migration to the foot area if diver becomes head-down. If sufficient air does migrate to the foot area the diver may rapidly become inverted and his fins "pop" off. With or without fins, the diver may not be able to right himself and may lose buoyancy control as suit air migrates away from the exhaust valve. The dry suit must be sized correctly. This will limit the volume of air in the event of over inflation, avoid "suit squeeze" from folds of excess suit material and popping of the fins if the suit legs are too long. While air has been used traditionally for dry suit inflation, the use of argon gas to significantly reduce heat loss during a dive has been recommended.[3]

A major disadvantage is that if the suit is damaged and water gets in thermal protection is lost and, unless the diver is using a buoyancy compensator, the diver rapidly becomes negatively buoyant.

Hot water suits, which allow hot water from the surface to flow over the diver's bodies, are an efficient method of keeping divers warm. They are used in similar temperatures in deep water off shore in the oil industry, but have not been used in ANARE diving because of the logistic problems involved with transporting the heaters.

Pollock[5] has reported the use of dive computers in Antarctica. He examined the use of the Beauchat Aladin and Orca Edge models and found that primary computer functions operated normally despite marked shortening of battery life.

Diving gloves require modifications for cold water conditions. Ideally, a neoprene mitten glove is worn to allow the fingers to warm each other. However, this arrangement causes loss of dexterity and most gloves are a compromise with separate compartments for the thumb and index finger. The addition of hot water into the gloves immediately prior to the dive prolongs the time before digital discomfort ensues.[2]

Emergency equipment must be adequate and well maintained. First-aid equipment and oxygen must be available at the dive site and a recompression facility is advisable on station. ANARE transports a recompression chamber to Davis for each diving program although the logistics of transport and the time involved in training and commissioning of this chamber are considerable.

Logistics

Each member of the diving team must be psychologically and physically fit, and skilled and trained in special ice-diving techniques. The divers must have considerable experience in deep diving, penetration diving, diving in circumstances of poor visibility, night diving and must be skilled in first-aid and rescue techniques.[2] ANARE runs a diver training course in Australia and Antarctica which familiarises divers with the equipment and techniques which will be used.

Equipment assembly, maintenance and transport to Antarctica is a exhaustive process. Attention must be given to the adequacy of spare parts and contingency plans devised in the event of unforeseen circumstances. In Antarctica an equipment storage and maintenance facility needs to be established in a warm and convenient location with easy access to transport, washing and air compression facilities.

Dive site selection and camp movement may be undertaken by helicopter or over-ice vehicles. Helicopters are usually used during the summer when over-ice transport may be limited by melting and cracking of the sea-ice. Camp facilities include a fibreglass "apple" hut, tents, heating and cooking equipment, radio gear, rescue equipment, bedding, spare clothing as well as the diving equipment. Food and fuel for several days is carried in the event of a blizzard and isolation in the "field".

Conclusion

The dangers, difficulties and frustrations of diving in Antarctica are considerable. For every hour spent underwater there are hundreds of hours of planning, preparation and training. The technical aspects of this type of diving differ in many respects from diving in temperate or tropical waters and are directly related to the environmental temperatures. Most of the difficulties encountered usually involve maintenance or malfunction of the specialised equipment which needs to be used. Despite the cold and wet, the isolation and the sacrifices involved, Antarctic diving provides unparalleled experiences for those who make the effort.

Acknowledgment

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Dr David Taylor, MD, FACEM, was Medical Officer, Davis Station, Antarctica in 1989. His position when this paper was presented (April 1996) was Acting Director of Emergency Medicine, Ballarat Base Hospital, Ballarat, Victoria 3350, Australia.

Dr Taylor's address is Apartment A-2, "The St James", 5237 Fifth Avenue, Pittsburg, Pennsylvania 15232, U.S.A.

PAIN PERCEPTION DURING SCUBA DIVING

Karsten Kroener

Key Words

Equipment, investigations, pain.

Introduction

It is a common experience during scuba diving that small injuries like scrapes and cuts from sharp stones, shells or wrecks seem to be unnoticed until after the dive. It seems that the threshold for pain is higher during scuba diving than it is when on land. We have no explanation for this phenomenon, and to be absolutely honest, we do not even know if it is true. A study was therefore designed to find out if this experience is real and to explore different explanations for this phenomenon.

It is know that nitrogen is a narcotic gas, and as the content of nitrogen is increased in the tissues during diving, this could offer a possible explanation. Another fact is that nerve conduction from the nociceptors in peripheral tissues is lowered by cooling of the tissues.[1-3] Cooling of the skin might thus be an explanation of an increased pain threshold. Another explanation might be that during a dive one is concentrating and ignores pain.

Pain physiology

In 1979, the International Association for the Study of Pain defined pain as *an individual experience of a potential or an actual tissue damage, unpleasant sensory experience, or experienced as such.*

This is a very broad definition. In daily life we often use a very simple classification such as acute or chronic pain. This does not work very well in the orthopaedic clinic, so in our clinic and in research, we use another classification.

Nociceptive pain is an acute pain which is caused by damage to tissues, either actual or potential damage. This is a type of pain one experiences when one cuts or bruises oneself and when one breaks a leg.

Neurogenic pain is caused by a prior damage to one's neural tissues and gives rise to phantom limb pain, trigeminal neuralgias, reflex sympathetic dystrophies and so on.

Another group is the chronic pains. Chronic pain syndromes, such as chronic low back pain etc., are a very difficult group to treat.

Finally there is psychogenic pain, a group of pain syndromes associated with psychic disturbances.

When a painful stimulus is applied to peripheral tissues a number of nociceptors are engaged (mecano-receptors, thermo-receptors or chemo-receptors) and impulses are conducted along two types of nerves to the posterior horns of the medulla. First through thick myelinated fibres which give a very sharp and distinct pain and later by thin nerve fibres, without myelin, which give a duller and more lasting pain. This conduction can be modulated by other non-painful sensory input, the so-called gate control.

When one damages the nociceptors in the periphery there is also an inflammatory reaction with an outflow of vasoactive agents, such as histamine, prostaglandins etc.

The pain impulses are conducted through the posterior columns of the medulla to the brain where they enter different pain centres. Most importantly, one in the cortex which is responsible for the localisation of pain. But also in the cortex there is a descending pain inhibition centre from which signals are sent down to the spinal cord to further filter pain signals. Others centres are in the limbic system, responsible for the emotional reaction to pain, the basal ganglia which are responsible for the tremor or dizziness which are seen in pain and the hypothalamus, responsible for the discomfort and nausea which often occurs with pain.

Methods

In order to measure pain levels and thresholds we, at the Danish Pain Research Centre, normally use an electronic pressure algometer. This electronic device measures pain by sustaining a known pressure, which can be changed if desired, to an extremity. Knowing how much pressure is being applied we can define how much pain the patient has. By increasing the pressure we can find the pain threshold which is defined as the point where the patient decides that the pain is intolerable and wishes to be released. We can refine this by using the patient's reaction. This is done by using a visual analogue scale on which the patient can mark his or her pain perception.

In order to make our measurements under water, we had to develop apparatus to test pain by putting a known pressure on a finger and skin temperature. For that pressure the test person can, using a visual analogue scale, tell the investigator how much pain he feels. The pressure can be increased until the pain is so high as to be intolerable, what we call the "pain threshold". The next step was to compare this very simple and cheap apparatus with the laboratory equipment. We did that in 14 volunteers and Table 1 shows a very good correlation between the two machines, although the units of measurement are different on the two machines.

After an initial pilot study we made some small changes and did a pool test in 14 volunteers using our home made pressure algometer (Fig 1). We also measured the skin temperature at the tip of the finger in these patients to find out whether the temperature was altering nerve conduction.

Results

Figure 2 shows the results in our 14 volunteers. There are significantly higher pain thresholds during diving. The 14 volunteers were measured just before they went into the

TABLE I

PAIN PERCEPTION LABORATORY TESTS

	Diving algometer		**"Sometic" electronic**
	Pain detected	**Pain unbearable**	**Pain unbearable**
Units	(Newtons)	(Newtons)	(kPa)
1st test	25.2	40.5	308.3
2nd test	25.2	40.9	288.9
3rd test	23.7	40.6	291.1

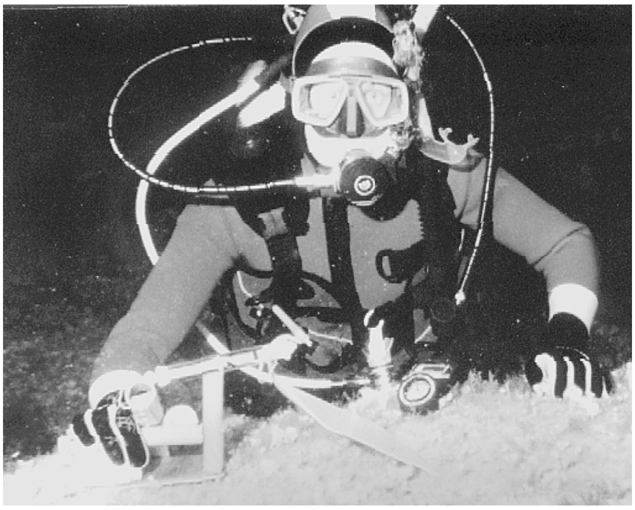
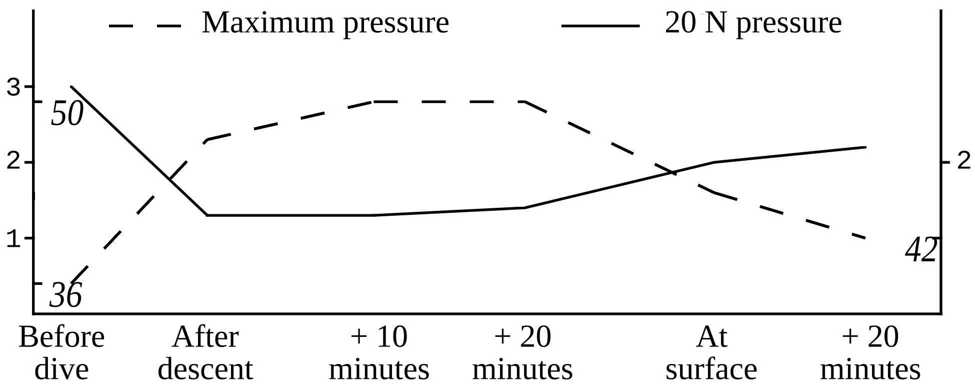


Figure 1. Diver underwater with right index finger in the "home made" algometer.



Outer scale (1, 2, 3) pain on the visual analogue scale (see text)

Inner scale (*36,42, 50*) pressures in N required to reach the pain threshold (unbearable pain)

Figure 2. Showing rise in pain threshold and decrease in pain perception in 14 divers while underwater.

pool. They went to 4 m and immediately after the descent we did another test. The test was repeated after 10 minutes, after further 10 minutes, after they had reached the surface and then 20 minutes later. The pain threshold is higher during the dive and comes back to almost normal after a while on land. When we pressed with 20 Newtons less pain was felt and underwater the pain scores were significantly reduced.

Further studies are necessary in order to find an explanation for this phenomenon. We are planning to go on with this study at different depths and different temperatures. Also, a test in a pressure chamber has been planned.

Audience participation

Unknown speaker

Why call unbearable pain the "pain threshold"? Surely a pain threshold is when pain is first felt.

Karsten Kroener

Perhaps we should have called it the "pain tolerance limit" but we chose "pain threshold".

Terry Brown, Alabama

There was a single case study in Undersea and Hyperbaric Medicine about the use of hyperbaric oxygen (HBO) in reflex sympathetic dystrophy, which is a tremendously difficult disorder to treat. I also know of a person with a chronic low back pain who was treated with HBO for decompression illness and his back pain got better. I wonder if you could comment about the use of HBO just for pain.

Karsten Kroener

These syndromes are very difficult to treat. These patients have tried practically every type of treatment. I would welcome the opportunity to try HBO, especially for the reflex sympathetic dystrophies, a very difficult group to treat. But I have no experience myself.

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Dr Karsten Kroener is an orthopaedic surgeon at the Danish Pain Research Centre, University of Aarhus, Bygn 1C, Aarhus Kommunehospital, DK-8000 Aarhus C, Denmark. Fax +45-8949-3344.

ARTICLES OF INTEREST REPRINTED FROM OTHER JOURNALS

THE IMPORTANCE OF DEEP SAFETY STOPS: RETHINKING ASCENT PATTERNS FROM DECOMPRESSION DIVES

Richard Pyle

Key Words

Bubbles, deep diving, mixed gas, tables, technical diving.

Before I begin, let me make something perfectly clear. I am an ichthyologist. For the purposes of this commentary, that means two things. First, that I have spent a *lot* of time underwater. Second, although I am a biologist and understand quite a bit about animal physiology, I am not an expert in decompression physiology. Keep these two things in mind when you read what I have to say.

Back before the concept of "technical diving" existed, I used to do more dives to depths of 54-66 m (180-220 ft) than I care to remember. Because of the tremendous sample size of dives, I eventually began to notice a few patterns. Quite frequently after these dives, I would feel some level of fatigue or malaise. It was clear that these post-dive symptoms had more to do with inert-gas loading than with physical exertion or thermal exposure, because the symptoms would generally be much more severe after spending less than an hour in the water for a 60 m (200 ft) dive than they would after spending 4 to 6 hours at much shallower depths.

The interesting thing was that these symptoms were not terribly consistent. Sometimes I hardly felt any symptoms at all. At other times I would be so sleepy after a dive that I would find it difficult to stay awake on the drive home. I tried to correlate the severity of symptoms with a wide variety of factors, such as the magnitude of the exposure, the amount of extra time I spent on the 3 m (10 ft) decompression stop, the strength of the current, the clarity of the water, water temperature, how much sleep I had the night before, level of dehydration, etc; but none of these obvious factors seemed to have anything to do with it. Finally I figured out what it was. On dives when I collected fish, I had hardly any post-dive fatigue. On dives when I did not catch anything, the symptoms would tend to be quite severe. I was actually quite amazed by how consistent this correlation was.

The problem, though, was that it did not make any sense. Why would these symptoms be less when catching fish? In fact, I would expect *more* severe symptoms after fish-collecting dives because my level of exertion, while on the bottom, during those dives tended to be greater (chasing fish is not always easy). There was one other difference, though. Most fishes have a gas-filled internal organ called a swim bladder which is basically a fish buoyancy compensator. If a fish is brought straight to the surface from 60 m (200 ft), its swim bladder would expand to about seven times its original size and crush the other organs. Because I generally wanted to keep the fishes I collected alive, I would need to stop at some point during the ascent and temporarily insert a hypodermic needle into their swim bladders, venting off the excess gas. Typically, the depth at which I needed to do this was much deeper than my first required decompression stop. For example, on an average 60 m (200 ft) dive, my first decompression stop would usually be somewhere in the neighbourhood of 15 m (50 ft), but the depth I needed to stop for the fish would be around 37.5 m (125 ft). So, whenever I collected fish, my ascent profile would include an extra 2-3 minute stop much deeper than my first "required" decompression stop. Unfortunately, this did not make any sense either. When you think only in terms of dissolved gas tensions in blood and tissues (as virtually all decompression algorithms in use today do), you would expect more decompression problems with the included deep stops because more time is spent at a greater depth.

As someone who tends to have more faith in what *actually* happens in the real world than what *should* happen according to the theoretical world, I decided to start including the deep stops on all of my decompression dives, whether or not I collected fish. Guess what? My symptoms of fatigue virtually disappeared altogether! It was nothing short of amazing! I actually started getting some work done during the afternoons and evenings of days when I did a morning deep dive. I started telling people about my amazing discovery, but was invariably met with scepticism, and sometimes stern lectures from "experts" about how this must be wrong. "Obviously," they would tell me, "you should get out of deep water as quickly as possible to minimise additional gas loading." Not being a person who enjoys confrontation, I kept quiet about my practise of including these "deep decompression stops". As the years passed, I became more and more convinced of the value of these deep stops for reducing the probability of DCI. In all cases where I had some sort of post-dive symptoms, ranging from fatigue to shoulder pain to quadriplegia in one case, it was on a dive where I omitted the deep decompression stops.

As a scientist by profession, I feel a need to understand mechanisms underlying observed phenomena. Consequently, I was always bothered by the apparent paradox of my decompression profiles. Then I saw a presentation by Dr David Yount at the 1989 meeting of the American Academy of Underwater Sciences (AAUS). For those of you who do not know who he is, Dr Yount is a professor of physics at the University of Hawaii, and one of the creators of the "Varying-Permeability Model" (VPM) of decompression calculation.[1] This model takes into account the presence of "micronuclei" (gas-phase bubbles in blood and tissues) and factors that cause these bubbles to grow or shrink during decompression. The upshot is that the VPM calls for initial decompression stops that are much deeper than those suggested by neo-Haldanian ("compartment-based") decompression models. It finally started to make sense to me.

Since you already know I am not an expert in diving physiology, let me explain what I believe is going on in terms that educated divers should be able to understand. First, most readers should be aware that intravascular bubbles are routinely detected after the majority of dives, even "no-decompression" dives. The bubbles are there. They just do not always lead to DCI symptoms. Now, most deep decompression dives conducted by "technical" divers (as opposed to commercial or military divers) are very much sub-saturation dives. In other words, they have relatively short bottom-times (I would consider 2 hours at 90 m (300 ft) a "short" bottom time in this context). Depending on the depth and duration of the dive, and the mixtures used, there is usually a relatively long ascent "stretch" (or "pull") between the bottom and the first decompression stop as calculated by any theoretical compartment-based model. The shorter the bottom time, the greater this ascent stretch is. Conventional mentality holds that you should "get the hell out of deep water" as quickly as possible to minimise additional gas loading. Many people even believe that you should use faster ascent rates during the deeper portions of the ascent. The point is, divers are routinely making ascents with relatively dramatic drops in ambient pressure in relatively short periods of time, just so they can "get the hell out of deep water".

This, I believe, is where the problem is. Maybe it has to do with the time required for blood to pass all the way through a typical diver's circulatory system. Perhaps it has to do with tiny bubbles being formed as blood passes through valves in the heart, and growing large due to gas diffusion from the surrounding blood. Whatever the physiological basis, I believe that bubbles are being formed and/or are encouraged to grow in size during the initial non-stop ascent from depth. I have learned a lot about bubble physics over the last year, more than I want to relate here. I will leave that for someone who really understands the subject. For now, suffice it to say that whether or not a bubble will shrink or grow depends on many complex factors, including the size of the bubble at any given moment. Smaller bubbles are more apt to shrink during decompression; larger bubbles are more apt to grow and possibly lead to DCI. Thus, to minimise the probability of DCI, it is important to keep the size of the bubbles small. Relatively rapid ascents from deep water to the first required decompression stop *do not* help to keep bubbles small! By slowing the initial ascent to the first decompression stop, (e.g., by the inclusion of one or more deep decompression stops), perhaps the bubbles are kept small enough that they continue to shrink during the remainder of the decompression stops.

If there is any truth to this, I suspect that the enormous variability in incidence of DCI has more to do with the pattern of ascent from the bottom to the first decompression stop, than it has to do with the remainder of the decompression profile. DCI is an extraordinarily complex phenomenon, more complex than even the most advanced diving physiologists have been able to elucidate. The unfortunate thing is that we will likely never understand it entirely, largely because our bodies are incredibly chaotic environments, and that level of chaos will hinder any attempts to make predictions about how to avoid DCI. But I think that we, as sub-saturation decompression divers, can significantly reduce the probability of getting bent if we alter the way we make our initial ascent from depth.

Some of you may now be thinking "But he said he's not an expert in diving physiology. Why should I believe him?" If you are thinking this, then good, that is exactly what I want you to think because you should not trust just me. So before you make your mind up read Bruce Weinke's article in issue 3 of *DeepTech*.[2] It covers some pretty sophisticated stuff, but you should keep re-reading it until you *do* understand it. Unfortunately you can no longer call *aquaCorps*, which has gone out of business. So you cannot order audio tape number 9 ("Bubble Decompression Strategies") from the tek.95 conference in order to hear Eric Maiken explain a few things about gas physics that you probably did not know before. Nor the audio tape from the "Understanding Trimix Tables" session at the recent tek.96 conference with Andre Galerne (arguably the "father of trimix") talking about how the incidence of DCI was reduced dramatically when they included an extra deep decompression stop over and above what was required by the tables. On the same tape Jean-Pierre Imbert of COMEX (the French commercial diving operation which conducts some of the world's deepest dives) talks about a whole new way of looking at decompression profiles which includes initial stops that are much deeper than most tables call for. However, you can get your hands on a copy of issue 6 of *DeepTech* and read Eric Maiken's article.[3] Why not find out what George Irvine meant when he said he includes "three or four short deep stops into the plan prior to using the first stop recommended by each of the [decompression] programs" in issue 4 of *DeepTech* ?[4] If that is not enough, then check out Dr. Peter Bennett's editorial where he talks about basically the same thing in the context of recreational diving.[5] If you really want to read an eye-opening article, see if you can find the report on the habits of diving fishermen in the Torres Strait by LeMessurier and Hills.[6] The list goes on and on. The point is, I am not the only one advocating deep decompression stops.

Are you still sceptical? Let me ask you this. Do you believe that so-called "safety stops" after so-called "no-decompression" dives are useful in reducing probability of DCI? If not, then you should take a look at the statistics compiled by Diver's Alert Network. If so, then you are already doing "deep stops" on your "no-decompression" dives. If it makes you feel better, then call the extra deep decompression stops "deep safety stops" which you do before you ascend to your first "required" decompression stop. Think about it this way. Your first "required" decompression stop is functionally equivalent to the surface on a dive that is *taken to the absolute maximum limit* of the "no-decompression" bottom time. Would you not think that "safety stops" on "no-decompression" dives would be *most* important after a dive made all the way to the "no-decompression" limit?

Some of you may be thinking, "I already make safety stops on my decompression dives. I always stop 3 or 6 m (10 or 20 ft) deeper than my first required stop." While this is a step in the right direction, it is *not* what I am talking about here. "Why not?", you ask, "I do my safety stops on no-decompression dives at 6 m (20 ft). Why should I not do my deep safety stops 6 m (20 ft) below my first required ceiling?" I will tell you why not, because the deep safety stops seem to have to do with preventing bubble growth and bubble growth is in part a function of a change in ambient pressure, *not* a function of linear depth. Suppose that, after a dive to 22.5 m (75 ft), you make a safety stop at 6 m (20 ft). Well, the ambient pressure at sea level is 1 bar (ATA). The ambient pressure at 22.5 m (75 ft) is about 3.3 bar (ATA). The ambient pressure at your 6 m (20 ft) safety stop is 1.6 bar (ATA). This represents roughly one half the total ambient pressure of the bottom. Now, suppose you are on a dive to 60 m (200 ft) where the ambient pressure is about 7 bar and your first required decompression stop is 10 m (33 ft or 2 bar). However half the ambient pressure of the bottom would be 3.5 bar or 25 m (about 83 ft). Thus, on this dive you would want to make your deep safety stop at about 25 m (83 ft) to have roughly the same relative effect on ambient pressure.

But of course, the physics and physiology are much more complex than this. It may be that half of the ambient pressure of the bottom is not the ideal depth for a safety-stop. In fact, I can tell you with near certainty that it is not. From what I understand of bubble-based decompression models, initial decompression stops should be a function of absolute ambient pressure changes, rather than proportional ambient pressure changes, and thus should be even deeper than half of the bottom ambient pressure for most of our decompression dives. Unfortunately, I seriously doubt that decompression computers will begin incorporating bubble-based decompression algorithms, at least not in their complete form. Until then, we decompression divers need a simpler method, a rule of thumb to follow that does not require the processing power of an electronic computer.

Perhaps the ideal method would be simply to slow down the ascent rate during the deep portion of the ascent. Unfortunately, this is rather difficult to do, especially in open water. Instead, I think you should include one or more discrete, short-duration stops to break up those long ascents. Whether or not it is physiologically correct, you should think of them as pit-stops to allow your body to "catch up" with the changing ambient pressure.

Here is my method for incorporating deep safety stops:

1 Calculate a decompression profile for the dive you wish to do, using whatever software you normally use.

2 Take the distance between the bottom portion of the dive (at the time you begin your ascent) and the first "required" decompression stop, and find the midpoint. This depth will be your first deep safety stop, and the stop should be about 2-3 minutes in duration.

3 Re-calculate the decompression profile by including the deep safety stop in the profile (most software will allow for multi-level profile calculations).

4 If the distance between your first deep safety stop and your first "required" stop is greater than 9 m (30 ft), then add a second deep safety stop at the midpoint between the first deep safety stop and the first required stop.

5 Repeat as necessary until there is less than 9 m (30 ft) between your last deep safety stop and the first required safety stop.

For example, suppose you want to do a trimix dive to 90 m (300 ft), and your desktop software says that your first "required" decompression stop is 30 m (100 ft). You should recalculate the profile by adding short (2 minute) stops at 60 m (200 ft), 45 m (150 ft), and 37.5 m (125 ft). Of course, since your computer software assumes that you are still on-gassing during these stops, the rest of the calculated decompression time will be slightly longer than it would have been if you did not include the stops. However, in my experience and apparently in the experience of many others, the reduction in probability of DCI will far outweigh the costs of doing the extra hang time. In fact, I would be willing to wager that the advantages of deep safety stops are so large that you could actually reduce the total decompression time (by doing shorter shallow stops) and *still* have a lower probability of getting bent, but until someone can provide more evidence to support that contention, you should definitely play it safe and do the extra decompression time.

One final point. As anyone who reads my posts on the internet diving forums already knows, I am a *strong* advocate of personal responsibility in diving. If you choose to follow my suggestions and include deep safety stops on your decompression dives, then that is fine. If you decide to continue following your computer-generated decompression profiles, that is fine too. But whatever you do, ***you are completely and entirely responsible for***

whatever happens to you underwater! You are a terrestrial mammal. You have no business going underwater in the first place. If you cannot accept the responsibility, then stay out of the water. If you get bent after a dive on which you have included deep safety stops by my suggested method, then it was your own fault for being stupid enough to listen to decompression advice from an ichthyologist.

Acknowledgment

I would like to thank Eric Maiken for explaining bubble physics to me and for adding some theoretical foundation to my silly ideas.

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Richard L Pyle works in the Ichthyology Collection of the Bishop Museum in Honolulu, and is at present working on his Ph.D. in the Zoology Department of the University of Hawaii. His interest in exploring deep coral reefs has led him from deep air diving to open circuit trimix diving, and more recently closed-circuit mixed-gas diving using Cis-Lunar rebreathers.

His address is Ichthyology Collection, BP Bishop Museum, PO Box 19000-A, Honolulu, Hawaii 96817-0916, USA. Phone +1-808-848-4115. Fax +1-808-841-8968. E-mail deepreef@bishop.bishop.hawaii.org .

WHEN THINGS GO WRONG

Brian Cumming

Key Words

Accidents, deaths, decompression illness, equipment, incidents, safety, trauma.

Most of the 315 UK sports diving incidents that occurred in the 12 months to the end of September 1996 could have involved any one of us. Sure, there were a number of really stupid ones that I hope most people would have avoided, but it is all too easy to adopt a self-righteous attitude towards the mishaps of others. Who, if we are honest, can claim an error-free diving career?

The 1996 incidents represent a 10 per cent reduction on the number recorded in the previous year, which itself was 9 per cent down on 1994. We cannot be sure that this indicates increasing safety, but it is clearly a trend in the right direction.

Data for the BSAC's annual report comes from its own incident reporting scheme, the Coastguard, Royal National Lifeboat Institution, British Hyperbaric Association (BHA), through the Institute of Naval Medicine (INM), newspapers and other independent sources.

We also receive information on overseas incidents but only record and publish those relating to BSAC (British Sub-Aqua Club) members and do not count them in the statistical analyses.

TABLE 1

INCIDENTS BY MAJOR CATEGORY

Boat or surface*	98
Decompression illness*	77
Injury	30
Overseas	29
Ascents	22
Technique	22
Equipment	19
Deaths*	16
Miscellaneous	2
Total	315

These figures were obtained from a coloured bar graph, which did not translate well into black and white, by measurement of the bar heights and the numbers scale height.
* These figures were obtained from the text.

The spread of incidents throughout the year is typical, most incidents occurring in spring/summer, with a big step up at Easter. Of those incidents where the depth is known, most are at the surface, including divers, boating incidents and those occurring out of the water.

TABLE 2

INCIDENTS BY MONTH

Month	Year	Incidents
October	1995	11
November	1995	10
December	1995	6
January	1996	4
February	1996	7
March	1996	11
April	1996	40
May	1996	33
June	1996	42
July	1996	42
August	1996	48
September	1996	22
Total		276

The in-water incidents occurred predominantly in the 21-30 m range. My guess is that this is not an especially dangerous range but simply where most dives are conducted.

Only ten incidents occurred in the "barmy range" of over 50m (air divers), almost half the number recorded last year. Let us hope this trend (if that is what it is) continues.

TABLE 3

DEPTH RANGE OF INCIDENTS

Depth	Incidents
Unknown	53
Surface*	98
1-10 m	6
11-20 m	28
21-30 m	45
31-40 m	32
41-50 m	9
Over 50 m	9
Total	280

These figures were obtained from a coloured bar graph, which did not translate well into black and white, by measurement of the bar heights and the numbers scale height.

* This figure was obtained from the text.

We categorise incidents under a number of broad headings:

FATALITIES numbered 16, around the average that history prepares us to expect, and each brings great sadness to all involved. Seven were BSAC members, again a typical number.

When did the fatalities occur? Our information indicates that people are perhaps pushing themselves too hard at the beginning of the season, when the water is still cold, and without giving themselves a chance to work up to diving fitness and competence. Build up slowly, give yourself time to regain diving fitness after a winter's lay off.

TABLE 4

UK DIVING DEATHS

Month		Deaths
March	1996	2
April	1996	4
May	1996	4
June	1996	1
July	1996	2
August	1996	2
September	1996	1
Total*		16

These figures were obtained from a coloured bar graph, which did not translate well into black and white, by measurement of the bar heights and the numbers scale height.

* This figure was obtained from the text.

Among half the fatalities there is too little information to determine what caused the problem. Of course, these are the only cases in which the casualty's opinion is unobtainable.

Three deaths involved individuals with prior medical conditions. Where these were known the individuals were clearly taking a risk, but this was not so in all cases. In one incident a diver had a check-up, was given a clean bill of health but suffered a fatal heart attack while diving two weeks later.

Three cases involved divers apparently diving alone. This is particularly relevant in view of the current discussion about solo diving. It cannot be claimed that these divers would all have survived had they been diving with a buddy, but the 20% of fatalities involving solo divers is out of proportion with the number of solo dives conducted.

The report records a number of incidents where divers became unconscious underwater and were safely recovered to the surface by attentive buddies. It is almost certain that these would have added to the fatalities had the divers been alone. As it is, because the outcome was positive they could easily pass unnoticed as relatively minor incidents.

DECOMPRESSION ILLNESS (DCI) is the second biggest category, with 77 incidents recorded. In 40% of cases there is too little information to determine the prime cause, and almost a quarter seem inexplicable; in other words, the dive profile would not have been expected to cause a problem.

These could be cases of patent foramen ovale (holes in the heart) or just reflect that no table or computer guarantees freedom from problems. But I suspect that in many cases the truth is simply stretched. A BHA representative told me that as chamber operators spend time with patients they often admit to features of the dive that relate to the problem but were omitted or distorted in reporting the incident. Few of us like admitting our mistakes.

The next group, just under a quarter, involves cases of DCI where some clear "rule" of safe diving practice has been broken; rapid ascents, missed stops or incorrect repeat dives.

> *After an initial dive to 18 m which included 12 minutes of training stops, a diver re-entered the water alone to free a stuck anchor. The work caused exertion and the diver surfaced rapidly from 15 m, out of breath. At the surface the diver was distressed. Recompression treatment resolved the problem.*

> *A diver received a spinal bend causing loss of function of the left leg. The incident involved a dive to 62 m, the rescue of an unconscious diver and a rapid ascent. A full recovery is reported.*

> *Two divers completed a dive to 30 m for a bottom time of 35 minutes after experiencing difficulty recovering the shot. The computer of one cleared, but the other still required 5 minutes of stops when they surfaced because of low air and being overdue. One complained of "pins and needles" in his hands and was put on oxygen. He was treated for two hours in a recompression chamber.*

In a revealing breakdown of DCI incidents by type, by far the biggest category involves serious cases of neurological DCI, backing up a comment made to me by the BHA that divers are not taking DCI seriously enough. Twenty-five per cent of cases treated result in unresolved problems for the casualty.

TABLE 5

DECOMPRESSION ILLNESS BY TYPE

Type	Number
Neurological DCI	122
Pain and limb DCI	25
Omitted decompression	18
Deaths	15
Unclassified	15
Skin DCI	4
Pulmonary barotrauma	3
Total	202

These figures were obtained from a coloured bar graph, which did not translate well into black and white, by measurement of the bar heights and the numbers scale height. The bar graph obviously covers more than last year when there were 77 cases of DCI.

ILLNESS AND INJURY, here the biggest single group comes under the heading of "bad luck", where it is difficult to see how the problem could have been foreseen or avoided.

> *Dekitting, a diver was lowering a combined 15 l and pony cylinder to the ground when a clip on his BC broke allowing the set to fall on to his big toe. A double fracture was diagnosed.*

> *Two fully kitted divers were walking towards the entry point for a dive, their route included a series of steps blocked by a group of young children. In trying to negotiate this obstacle one of the divers fell and broke his leg.*

> *During a training session in a pool with a maximum depth of 4 m, a trainee experienced difficulty clearing during a descent. He ascended a little, the ear cleared and the session continued. Six days later, undergoing a diving medical, it was discovered that this diver had a perforated eardrum.*

The other group of any significance involved a number of similar incidents where divers were injured by buddies rolling or jumping into the water on top of them. They were stuck on the head and arms, often by the buddy's cylinder. These incidents are potentially serious and totally avoidable.

BOATING/SURFACE INCIDENTS numbered 98, and the major cause forming the biggest single group is lack of, or poor, servicing, leading to engine failure and divers stranded at sea. If the failure occurs while divers are down, lost divers are likely to be the result.

Seven divers in three groups were diving at the same time, each group with an SMB (surface marker buoy). The engine of the diveboat stalled twice, and by the time it was restarted the second time the cox had lost sight of the SMBs. After a search, the Coastguard was contacted and an inshore lifeboat launched. All divers were eventually found and returned safely to shore.

There are many such cases, and the fact that no lives were lost is down to good luck and the skill of the rescue services.

The next big group involves carelessness from boat-handlers:

Two RIBs were waiting for the last pair of divers to surface when a third boat appeared. The divers deployed a delayed SMB and ascended. One surfaced and the second was just below the surface when the third boat drove over the top of the second diver's bubbles, despite shouted warnings.

Two divers had completed a dive to 30m and were using a lifting bag as a delayed SMB to make their ascent. When they were at 18 m a RIB pulling a shot weight towed the shotline through them, hitting one with the weight. The SMB was ripped out of their hands and they descended to the seabed.

During an ascent from a wreck, at the final stop, a diver was caught by a fishing hook and dragged towards the surface. Every so often the line went slack and the diver sank again. The diver's buddy finally managed to cut this diver free, but a rapid ascent was made to just below the surface, where buoyancy control was re-established.

Another group comes under the heading of poor planning:

Four pairs of divers dived in a cove from the shore. Three pairs returned but the fourth was carried west by the current. A yacht was asked to pick them up.

A car ferry had to take avoiding action for a diver who surfaced in a main shipping lane.

Two divers apparently drifted off a shotline to a wreck and were picked up 2.5 miles from the site by another charter boat. They had no surface detection aids available.

This last issue comes up repeatedly and is easy to resolve. Flares, large inflatable "sausage buoys" and flags are all effective in increasing your visibility to searchers. I find it astonishing that anyone commits themselves to the deep without such a device.

FAST ASCENTS have been conducted by divers after they have lost their weight belts; been unable to control drysuit buoyancy; or been dragged up by delayed SMBs and lifting bags.

Two divers were filling a lifting bag at 32 m to help recover a shot. The regulator being used free-flowed, the bag became buoyant and although the diver who had been filling it moved back, it carried him to the surface.

One of a pair of divers tied a delayed SMB line to a wreck and released the buoy in preparation for their ascent. The line did not seem to run freely. It was detached from the wreck but became entangled with fishing line. The line jammed, catching the diver's thumb. Once the line was detached, the diver was pulled rapidly upwards, because the buoy had not reached the surface. The divers were attached to each other by a buddy-line so both were carried to the surface. Their computers indicated that five minutes of stops had been missed.

Two divers ascending from a no-stop dive to 35 m intended to conduct a safety stop of 3 minutes at 6 m. However, one was unable to release air from his drysuit wrist dump and ascended buoyantly to the surface. His buddy went with him. The thermal under-suit is thought to have become tucked up and so prevented the effective dumping of air.

After a 24 minute dive to a maximum of 39 m, a dive trio commenced their ascent. One of them lost control of his buoyancy, because of unfamiliarity with a new drysuit dump-valve, and ascended directly to the surface, missing all planned stops.

Two trainee divers were swimming close to the sea bed in 15 m when the weight belt of one of them became detached, dropped to the bottom and was lost in the silt. This diver alerted the instructor, who tried to assist. Despite dumping air, and with the trainee upside down and finning downwards, they made a buoyant ascent.

Most of these incidents could have been avoided with more care, attention or practice with the equipment.

TECHNIQUE covers a category of incidents in which poor planning features strongly:

Two Coastguard teams were tasked to search for two overdue divers. No dive plan had been logged. It turned out that they had been stuck in road traffic.

Two divers stayed too long at depth, were unable to relocate the shotline for ascent (it had been removed) and had trouble using a delayed SMB. Stops were correctly conducted at 6 m, but at the 3 m stop one diver was almost out of air and used the alternative air source of the other. When they surfaced they had missed 3 minutes of stops, though they had some air left.

EQUIPMENT is the final category and it is dominated by two issues, poor or missing servicing and regulator free-flows, most commonly due to cold water:

A diver's regulator mouthpiece "came apart" underwater. She swam 7 m to her buddy and snatched his regulator, displacing his mask. The buddy used his octopus and adjusted his mask. The defective regulator was then found to be serviceable and the dive continued for a further 30 minutes.

One of a pair of divers experienced a violent free-flow from their regulator as they descended. A second regulator attached to a second cylinder was used, and as the pair were unable to stop the free-flow the first cylinder was turned off. Subsequent examination indicated that this regulator had not received a recommended upgrade, and a mechanical failure had occurred.

Four minutes into a dive, at 17 m, the regulator of one of a pair of divers started to free-flow. Attempts to rectify this underwater failed and the diver made a rapid ascent. Icing of the .first stage was found to have caused the problem.

This latter incident was at an inland site in March. The message is clear: ensure that all servicing is correctly carried out and take precautions against regulator free-flow when operating in cold water.

We all place ourselves at higher than normal risk every time we dive. and things do regularly go wrong. Usually we can correct the situation, but every so often the toast lands jam side down.

I believe we tend to transfer our everyday experience of risk management to the diving situation without realising that the "incident pit" slope is very much steeper because we are in an alien environment.

Boat engine failures are not the same as car engine failures, arriving late at a planned stop is not the same as arriving late for a meeting and in the real world we have an inexhaustible supply of air.

We allow ourselves to be lulled into a false sense of security, allow too small a margin for error or problems, and when things start to go wrong they often develop too fast to cope with. But we could cut the incidents by 50 per cent through:

Thorough and timely equipment servicing;
More care over dive planning;
Building up slowly;
Taking more care with boat handling;
Ensuring we stay within the recommended limits for safe dive profiles.

Brian Cumming is the British Sub-Aqua Club Safety and Incidents Adviser.

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5TH ANNUAL SCIENTIFIC MEETING ON DIVING AND HYPERBARIC MEDICINE

Holiday Inn, Coogee Beach, New South Wales
August 29th and 30th 1997
will be hosted by
the Hyperbaric Medicine Unit, Prince of Wales Hospital,
on behalf of
the Hyperbaric Technicians and Nurses Association (HTNA) in conjunction with
the Australian and New Zealand Hyperbaric Medicine Group (ANZHMG) and
the Submarine and Underwater Medicine Unit (SUMU) Royal Australian Navy

Friday August 29th will be devoted to hyperbaric medicine. Saturday August 30th will focus on diving related subjects. Drs Carl Edmonds and Des Gorman are among an impressive list of speakers.

For further details contact
John Kershler or
Michael Talty, Conference Co-ordinator
Department of Diving and Hyperbaric Medicine
Prince of Wales Hospital
High Street, Randwick, New South Wales 2036

Phone (02)-9382-3881
Fax (02)-9382-3882

MEDICAL ADVICE TO THE SCOTTISH SUB-AQUA CLUB

James Douglas

Key Words

Asthma, diabetes, diving medicals, standards.

Recently the Medical Officers of the BSAC, Sub-Aqua Association and SSAC have formalised existing practice to co-operate closely on medical standards and policies. We have formed a UK sport diving medical advisory committee and have introduced a medical form which can be used by any club supported by the BSAC Medical Referee System. This is a common sense development which I believe the SSAC will gain substantially by.

I will continue to advise the NDO on broad medical strategies and developments as they arise, eg dive computers or Nitrox. I will also continue to deal with the majority of Scottish Medical Referee work for the Club as I am the local person. I have attended many diving medical meetings over the years and I am a member of the relevant American, Australian and European Diving Medical Associations. The United Kingdom has a world-wide lead in the subject of medical advice to sport diving clubs. We have a tradition of "professional amateurism". The life boat service, mountain rescue and SSAC are obvious examples where professional standards are obtained by amateurs on a voluntary basis. Similarly a number of UK doctors who are sport divers have been putting an enormous amount of time and effort into rational assessment of risk to promote safe diving.

The study of diving medicine originated with the Royal Navy and has been further developed by the off-shore oil industry. Different medical standards should be applied to occupational and voluntary activity. In sport diving we have the advantage that dives can be put off and there is a range of diving situations. Society encourages people to take whatever level of personal risk they wish in sporting activity providing they understand what they are doing and do not put others at risk. I see a big difference between an established diver who develops heart trouble but wishes to take an informed risk, and an adolescent who has asthma but wishes to take up diving without a true insight into personal risk. We encourage people to take up the diving but advise them against taking proven risks and certainly not putting buddy divers into hazardous situations.

Two examples illustrate the reasons for establishing a UK standard. Asthma and diabetes have been traditional bars to sport diving. However, people have been diving with these conditions despite what doctors have said. The Medical Committee over the past few years has been trying to question such dogmas and make real assessments of risk by gathering diving incident information. Doctors who run recompression chambers have been pooling information on the symptoms and treatment of decompression illness in order to detect trends. Improvements in the medical care of asthma and diabetes have also helped. The number of people with asthma in the United Kingdom is steadily increasing. So more people with asthma are wanting to dive. Modern inhaler drugs and self recording monitors have revolutionised the treatment and quality of life for asthmatics. A well controlled asthmatic who is stable on treatment is probably not at the substantial risk of burst lung that was once thought. However unstable and exercise induced asthma could put the diver at substantial risk. We are now allowing carefully selected asthmatics to dive.

A similar process has happened with insulin dependent diabetics. The BSAC had a fatal accident a few years ago involving an insulin dependent diabetic and medical standards were questioned closely. Diabetics were banned from diving but they continued to lobby and protest their "innocence" to the medical committee. Again, improvements in diabetic treatment and monitoring have substantially reduced the chances of a diabetic coma occurring during a dive. The BSAC has a register of diabetic divers and the Medical Committee is attempting to produce hard evidence as to whether the risks of diabetic diving are real or imagined. This contrasts strongly with the rest of the world where asthmatics and diabetics continue to be completely banned from sport diving. However, we have an excellent record of diving safety in this country and the low level of "medical incidents" caused by illness rather than decompression sickness is not something that we would wish to lose. It is important to understand that I am not advocating an "anything goes" policy for medical standards and that epilepsy and drugs acting on the Central Nervous System will have to remain complete bars to sport diving.

The Medical Committee and Medical Referee System is working to maintain sport diving safety by continually reviewing medical standards and accumulating information on which to base the medical standards. Diseases, treatments and diving are all continuously changing so the whole process requires systematic review.

Dr James Douglas is the Honorary Medical Adviser to the Scottish Sub-Aqua Club. His address is Tweeddale Medical Practice, High Street, Fort William, Scotland PH33 6EU, United Kingdom. Phone +44-1397-703-136. Fax +44-1397-700-139. E-mail jd@lochaber.almac.co.uk .

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