The world as it is

ANZHMG statement on the administration of mild hyperbaric oxygen therapy

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Key words
Mild hyperbaric therapy, hyperbaric oxygen therapy, hyperbaric facilities, medical conditions and problems, evidence, medical society, policy

Executive summary

(ANZHMG statement on the administration of mild hyperbaric oxygen therapy. *Diving and Hyperbaric Medicine*. 2010;40(2):78-82.)
'Mild' hyperbaric therapy (MHT) and hyperbaric oxygen therapy are easily confused. Essentially the difference lies in the effective oxygen dose. Oxygen is an extremely useful and efficacious drug in a wide range of medical conditions. MHT does not typically provide more available oxygen to the body than is possible with oxygen administration at one atmosphere (sea level), and there is no known therapeutic benefit of mild compression alone. There is, therefore, no documented, biologically plausible evidence for the use of MHT over delivery of oxygen by a simple facemask at one atmosphere of pressure. MHT is advocated for a wide range of clinical conditions, in particular for chronic neurological conditions and as part of a suite of 'wellbeing' therapies. The Australia and New Zealand Hyperbaric Medicine Group, a standing sub-committee of the South Pacific Underwater Medicine Society, is not aware of any reliable clinical evidence for therapeutic benefit from mild hyperbaric therapy and does not recommend the use of this modality for any medical purpose.

Introduction

Hyperbaric oxygen therapy (HBOT) is an established treatment for a number of health conditions. It is available at approximately 18 centres around Australia and New Zealand, including both public hospitals and private facilities. More recently, a number of centres have opened that offer an apparently similar therapy using low-pressure treatments. The term 'mild hyperbaric therapy' (MHT) is the one most often used to describe this form of treatment. For the purpose of this document, we suggest this term is more or less synonymous with 'mild hyperbaric oxygenation', 'low-pressure hyperbaric therapy' and related terms. These terms all signify a form of therapy that differs substantially from conventional HBOT. The purpose of this document is to clearly define the relative places of these two therapies within the context of medical practice in general.

The Australia and New Zealand Hyperbaric Medicine Group (ANZHMG), a standing sub-committee of the South Pacific Underwater Medicine Society, is the local specialist group of the medically qualified providers of HBOT. Because, at times, our activities are confused with those of 'alternative' practitioners, this statement is issued in order to allow third parties to accurately identify and characterise the form of therapy being offered to them.

Definitions

Whilst not universally accepted in the current confusion of terms in this area, the definitions below will serve as a practical and workable means by which to distinguish the practice of HBOT from the various forms taken under the umbrella term 'mild hyperbaric therapy'.

HYPERBARIC OXYGEN THERAPY (HBOT)

The Undersea and Hyperbaric Medical Society (UHMS) is the leading world body representing practitioners in this area and defines HBOT as: "*A treatment in which a patient breathes 100% oxygen while inside a treatment chamber at a pressure higher than sea level pressure (i.e., >1 atmosphere absolute or Ata)*".[1]

The treatment chamber referred to is an air-tight vessel variously called a hyperbaric chamber, recompression chamber or decompression chamber, depending on the clinical and historical context. Such chambers may be capable of compressing a single patient (a monoplace chamber) or multiple patients and attendants as required (a multiplace chamber) (Figures 1 and 2). These chambers typically operate at pressures above 202.6 kPa (2 Ata) for periods of 60 to 120 minutes for each session of treatment, with the patient breathing 100% oxygen.

MILD HYPERBARIC THERAPY (MHT)

There are many definitions and each individual practitioner or retailer tends to develop their own variant. One compromise definition that covers almost all of this activity is "*a*

Footnote: For a simple pressure conversion chart to assist with interpretation of different pressure measurements in this document, please refer to the appendix.

Figure 1
A monoplace chamber (Prince of Wales Hospital)

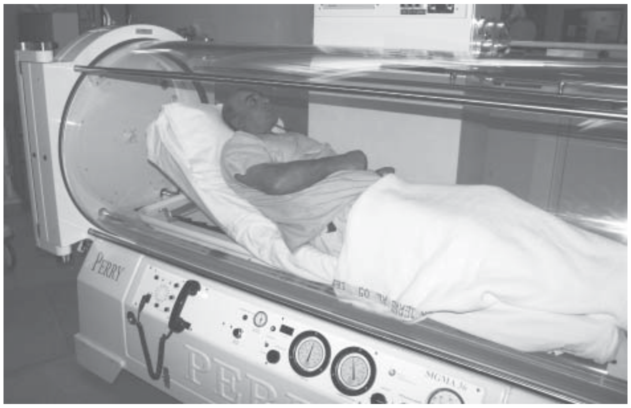

Figure 2
A chamber designed to treat multiple patients (The Karolinska Institute, Stockholm; photo by Peter Kronlund)

treatment, usually administered in an inflatable portable chamber, in which a patient breathes air or oxygen-enriched air at pressures between 1.2 and 1.5 Ata (slightly higher than sea level pressure)”.

MHT is often delivered in a ‘shop-front’ facility, usually under the supervision of a non-medical person, but the chambers can be hired or purchased for use at home. While any hyperbaric chamber is capable of delivering MHT, most MHT is delivered in vessels constructed specifically for this purpose. These chambers are usually built of pliable material and are easily transported and inflated at the point of treatment. One such vessel is illustrated in Figure 3.

What are the important differences between HBOT and MHT?

While constructed of different materials, the differences in the type of compression vessel are less important than the pressure that can safely be generated inside.

MHT implies low pressure therapy: almost always less than 151 kPa (1.5 Ata), while HBOT, although possible at any pressure above 101.3 kPa (1 Ata), is almost universally delivered at between 203 and 304 kPa (2.0–3.0 Ata).

The most important difference, however, is that during HBOT the patient breathes 100% oxygen in order to deliver greatly increased oxygen pressure to the target tissues in the body; far more oxygen than can be delivered in any other way. On the other hand, MHT is delivered with air, or air mixed with added oxygen at low pressures such that, although oxygen pressures are higher than breathing air alone at sea level pressure, they do not exceed the pressure of oxygen that can be given by the administration of 100% oxygen at 101.3 kPa (1 Ata). For example, in most Australian hospital-based hyperbaric facilities, the standard treatment for a chronic, non-healing foot ulcer in a diabetic patient involves breathing 100% oxygen at 243 kPa (2.4 Ata). Therefore, each breath taken contains oxygen at a partial pressure approaching 243 kPa (1,824 mmHg) and the arterial oxygen pressure will reach something around 203 kPa (1,500 mmHg).

In contrast, a typical MHT session will involve pressurisation to 131 kPa (1.3 Ata) breathing 30% oxygen for about one hour. Under these conditions, each breath has an inspired oxygen pressure of 40 kPa (296 mmHg) and the arterial pressure is likely to reach a more modest 30 kPa (230 mmHg). This is the same oxygen pressure that can be attained by breathing about 35% oxygen at sea level. To put it another way: this amount of oxygen can easily be achieved without the use of the chamber at all.

There are many well-proven effects of increased oxygen levels in the blood and tissues. The administration of oxygen outside a chamber is a very common and familiar treatment in any healthcare system. There is, however, very little evidence indeed that mild compression while breathing oxygen-enriched (to a modest degree) air is any more useful than oxygen alone in a slightly higher concentration at ambient pressure; as in the example above. The latter is certainly much cheaper and more widely available. The

Figure 3
An inflatable chamber suitable for the administration of MHT (photo by Bruce McKeeman)

Table 1
ANZHMG accepted indications for hyperbaric oxygen therapy; these indications are reviewed annually. At the time of writing, the ANZHMG proposes that, after review of the evidence, the indications below are appropriate.

Broad indication	**Specific indication**
Bubble injury	Decompression illness
	Arterial gas embolism (diving/iatrogenic/misadventure)
Acute ischaemic conditions	Compromised flaps/grafts
	Crush injury/compartment syndrome
	Reperfusion injuries
	Sudden sensorineural hearing loss
	Avascular necrosis
Infective conditions	Clostridial myonecrosis
	Necrotizing fasciitis non clostridial
	Myonecrosis necrotizing cellulitis
	Malignant otitis externa
	Refractory mycoses
	Refractory osteomyelitis
	Intracranial abscess
Radiation tissue injury	Osteoradionecrosis
	established
	prophylactic
	Soft tissue radiation injury
	established
	prophylactic
Problem wounds	Chronic ischaemic problem wounds
	Diabetic: ulcers/gangrene/post surgical
	Non-diabetic problem wounds:
	pyoderma gangrenosum
	refractory venous ulcers
	post-surgical problem wounds
Toxic gas poisoning	Carbon monoxide poisoning:
	moderate/severe
	delayed sequelae
Ocular ischaemic pathology	Cystoid macular oedema
	Retinal artery/vein occlusion
Miscellaneous	Thermal burns
	Bells palsy
	Frostbite
Adjuvant to radiotherapy	Adjunct to radiotherapy in treatment of solid tumours

proponents of MHT claim that in addition to the extra oxygen, the mild compression has some benefit in oxygen delivery that remains unexplained and unproven.

What are HBOT and MHT used for?

As suggested above, HBOT is a legitimate therapy prescribed and administered in a hospital or specialised clinic setting under the direction of a medical doctor. There is an increasing body of evidence to support the use of HBOT in a range of serious medical conditions. Those for which the ANZHMG believes there is sufficient evidence to justify routine clinical use are summarized in Table 1.

A useful publication on the evidence for the major indications for HBOT can be purchased from the UHMS web site (<www.uhms.org>).[1] Much information is freely available on the internet. For example, all the randomised trial evidence is summarised at <www.hboevidence.com>, and a detailed examination of many of the indications listed in Table 1 may be found in a doctoral thesis linked from the front page of the same site.[2–12]

The uses for which MHT has been advocated are much wider and this therapy is often offered along with a suite of 'natural' therapies, massage and lifestyle advice. It would be a very difficult task to locate all the claims made for MHT, but Table 2 lists some of those offered in a collection of several internet web site advertisements.

There is very little if any evidence that MHT (or indeed HBOT) has meaningful beneficial effects for the great majority of these indications. For many indications (see Table 2), there has simply been no objective investigation of potential benefit and any such claim is either entirely speculative or based on personal experience. For others, there is good evidence that HBOT and MHT do not positively affect these conditions. For the remainder, the clinical evidence is unclear.

The ANZHMG is not aware of convincing evidence for the effectiveness of MHT for any indication listed in Table 2 and, therefore, does not agree that MHT has any place as a therapeutic modality. Medical science is a process of

Table 2
Summary of proposed indications and evidence for mild hyperbaric therapy
(RCT = randomized controlled trial; Cochrane review = formal systematic analysis of all randomized trials)

Broad indication	Specific indication	Notes on evidence
Paediatric neurological disorders	Cerebral palsy	RCT evidence indicates no difference MHT versus HBOT Not tested against oxygen alone Wide agreement there is no therapeutic effect[2,3]
	Autism spectrum disorder	RCT evidence of more improvement in MHT group (but actual outcome measured was not different) Not tested against oxygen alone Benefit unlikely but possible[4,5]
	ADHD/ADD	No formal evidence
Injury healing	Surgical trauma	No formal evidence
	Traumatic brain injury	Acute – Cochrane review suggests no established benefit for HBOT[6] No formal evidence for MHT Chronic – RCT underway for HBOT
Nervous system dysfunction	Multiple sclerosis	Cochrane review shows no benefit for HBOT[7] No formal evidence MHT
	Parkinson's disease	No formal evidence
	Chronic fatigue syndrome	No formal evidence
	Stroke	Cochrane review suggests no benefit in acute stroke from HBOT[8]
	Altzheimer's disease	No formal evidence
	Optic neuritis	No formal evidence
	Headache and migraine	Cochrane review suggests benefit from HBOT and 100% oxygen at 1 ATA[9]
Infections	Sinusitis	No formal evidence
	Osteomyelitis	Some poor comparative evidence for HBOT, nil for MHT
	Human immunovirus (HIV)	Poor evidence from case series for HBOT
	Lyme disease	Poor evidence for HBOT only
Enhanced immunity	No specific claim	
Skin disorders	No specific claim	
Athletic performance	Enhanced performance	Conflicting evidence for HBOT
	Muscle stiffness	Cochrane review shows that HBOT does not improve post-exercise stiffness[10]
	Improved strength	Low-grade evidence is conflicting for HBOT
	Improved recovery	
	Strengthened heart and lungs	Not tested
Arthritis	(type not specified)	No evidence
Cancer	Basal cell carcinoma	No formal evidence
	Various unspecified	HBOT may enhance radiotherapy[11]
Wellbeing	Relieving tension and stress	No formal evidence for any claims
	Improving cognitive function	
	Detoxifying the blood	
	Retard aging	
	Improving sleep pattern	
	Improving digestion	

hypothesis testing and modification of our understanding. The use of HBOT for many of these indications is under active investigation and it is likely that some individual indications will be shown to be appropriate at some future date whilst others will not.

Conclusion

Oxygen is a very useful and efficacious drug in a wide range of medical conditions. MHT does not typically provide more available oxygen to the body than oxygen administration at one atmosphere, and there is no known therapeutic benefit of mild compression alone. It is therefore difficult to understand how MHT might have therapeutic benefits.

MHT is advocated for a wide range of clinical conditions, in particular for chronic neurological conditions and as part of a suite of 'wellbeing' therapies.

The ANZHMG is not aware of any reliable clinical evidence for therapeutic benefit from mild hyperbaric therapy and does not recommend its use for any medical purpose.

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Appendix
Pressure conversion chart; note the term 'atmospheres absolute' is used to emphasise the use of total pressures including the air pressure at sea level: thus 1 Ata = 760 mmHg = 101.3 kPa = sea level pressure

Atmospheres (Ata)	Kilopascals (kPa)	mmHg	Metres' seawater (msw)
1.0	101	760	10.07
1.2	121	912	12.08
1.4	141	1604	14.10
1.6	162	1216	16.11
1.8	183	1368	18.13
2.0	203	1520	20.14
2.2	223	1672	22.15
2.4	243	1824	24.17
2.6	263	1976	26.18
2.8	284	2128	28.20
3.0	304	2280	30.21

Health risk management in the Tasmanian abalone diving industry

David Smart

Key words
Occupational diving, occupational health, risk management, health, diving industry, abalone

Abstract

(Smart D. Health risk management in the Tasmanian abalone diving industry. *Diving and Hyperbaric Medicine*. 2010;40(2):83-7.)
Risk management is a systematic process applied to all aspects of diving operations. The process aims to reduce accidents and adverse outcomes to a minimum. Risk results from a combination of probability and consequence, and where this combination has major or extreme impact, the risk should not be tolerated. Over the four years 2001–2004, the incidence of decompression illness amongst abalone divers in Tasmania was 1.4 cases per 100 divers per year. Risk management in diving encompasses medical fitness, education and training, dive planning, equipment and maintenance, emergency procedures and equipment, and continual vigilance to remedy new risks as they are identified. There is still much to achieve

Introduction

Contrary to popular belief, diving is a remarkably safe occupation and this level of safety is improving with enhanced levels of training of participants in the activity. In figures derived from amalgamated data from the professional and recreational industries, serious incidents occur approximately 1:10,000 to 1:20,000 dives, and the death rates have been estimated at 1:95,000 to 1:200,000 dives.[1] Between 10 and 20 divers die each year in Australia, and this compares with a national annual death toll due to road trauma of nearly 3,000.[2,3] In the year to 30 June 2003, there were 262 cases of decompression illness treated in Australia and 17 (6.5%) of these were in Tasmania.[4]

Over the four years 2001–2004, 56 divers were treated for decompression illness (DCI) at Royal Hobart Hospital. Of these 56, 16 were recreational scuba divers (all with training), 17 were recreational 'hookah' surface-supplied breathing apparatus divers (10 untrained, five trained and two unknown), 12 were employed divers from the aquaculture industry, seven were professional abalone divers and four others. Thus, abalone divers make up 12.5% of all divers treated. The Tasmanian Government restricts the total number of abalone licences to 125. Based on this restriction, the incidence of DCI is, therefore, 1.4 cases per 100 divers per year. The relative incidence for other groups is unknown, because the total numbers of divers and dives are unknown, and have not been studied formally. It is not possible to completely eliminate risk from diving; we are dealing with a biological animal (the diver) in a hostile and frequently changing environment.

Risk management

Risk management is a systematic approach to improving safety and reducing adverse incidents, and the principles can be applied to almost any process or activity.[5] Risk management is covered by Australian and New Zealand Standard 4360.[6] The process of risk management identifies the risks specific to an industry and assesses their potential impact; the risks are then mitigated. As part of the process, systems are needed to ensure that previously treated risks do not return, and that further risks are monitored.

Risk is a product of probability and consequence. Probability is the chance that an adverse event will occur. Consequence is the impact of the adverse event on the diver. The higher the probability and the worse the consequence, the greater the health risk to the diver. Risk management aims to reduce adverse health events from diving to as low as possible whilst maintaining productivity. In particular, divers should aim to completely prevent events that have catastrophic short- or long-term consequences.

This report provides a medical perspective of risk management in abalone diving, focusing on how risk management principles may be applied to improve diving safety and maintain health of divers. By applying the basic principles of risk management to diving practice, the majority of abalone divers should be able to complete a 30–40 year career in the industry and retire from diving in good health without disability.

A medical perspective of risk management in diving

Based on the experience of diver morbidity treated at the Royal Hobart Hospital (RHH), a medical perspective is provided below under eight broad headings.

1. MEDICAL FITNESS TO DIVE

There is no doubt that occupational divers need to maintain optimum physical health. It is a physically demanding occupation in a potentially hostile environment. Annual medical assessment of fitness is required under Australian Standard 2299.1.[7] Unfortunately, based on the author's observations, only a fraction of abalone divers comply with the AS2299.1 recommendation for annual diving medical assessments. An equally important principle is that divers take responsibility for their own day-to-day fitness to dive. It goes without saying that many long-term health issues result from individual choices regarding consumption of alcohol, tobacco and other drugs. In abalone divers, long-term health problems from ear and sinus barotrauma are commonly encountered by diving physicians. Time spent in the short term recovering from such conditions is well spent, rather than 'soldiering on', thus causing permanent hearing impairment or sinus injury.

Divers are encouraged to seek early advice from a diving medicine specialist if they experience health problems after diving. The most common clinical syndrome of DCI resembles a bout of influenza: tiredness and lethergy, inability to concentrate, headache and non-specific migratory muscle and joint pains. Occasionally there may be nausea and vomiting. Musculoskeletal pains are common and may be restricted to one joint, most frequently the shoulder, or develop in multiple joints. Skin rashes occur on rare occasions. Other non-neurological symptoms include chest pain, shortness of breath and abdominal pain. Neurological syndromes can range from minor paraesthesiae, numbness and slight unsteadiness, through to paraplegia, hemiplegia, severe cognitive deficits and even loss of consciousness and seizures. Any of these symptoms and signs may be worsened by ascent to altitude (>300 m) after diving; a significant issue in Tasmania (see below).

Early treatment of diving-related illness results in faster and more complete recovery. It is recognised that earlier treatment of DCI results in better outcomes for the diver. For serious neurological DCI, recompression treatment is even more time-critical. In Tasmania, there is a 24-hour diving emergency contact via the Ambulance Tasmania 000 number. The diving medicine specialist is contacted once the alarm is raised, and provides input at the earliest stage to management and transport of the diving casualty. In the majority of cases, divers are treated in the hyperbaric chamber within four hours of an emergency call. Early treatment also prevents long-term sequelae of diving, such as bone necrosis.

2. EDUCATION AND TRAINING

Industry-specific education and training is an essential process supporting diving safety. Well-trained divers have the skills and knowledge to recognise and prevent hazards, and respond to emergencies. In Tasmania, all abalone divers undergo training in accordance with the Tasmanian Abalone Industry Code of Practice, and this code outlines many risk management procedures.[8] This training constitutes a minimum entry platform from which to launch an abalone-diving career. From a medical perspective, additional training beyond the basic minimum is always an advantage, as is the revision of skills, particularly in the area of diver rescue and management of emergencies. Because diving accidents are infrequent, divers and their tenders are at risk of deskilling if emergency procedures are not revised and practised regularly. The divers' tender is an integral part of the diving team, and has great responsibility in supporting the diver. The current code of practice requires that tenders possess an up-to-date first-aid certificate that includes an oxygen therapy course. However, there is no clear process by which currency in first-aid skills is monitored. In addition, there does not appear to be any requirement for rescue training for divers or tenders, or training regarding the specific aspects of administration of 100% oxygen to the injured diver. In many situations, the tender is alone on board the dive boat. Whilst the probability of needing to rescue an incapacitated or unconscious diver from the water is low, the consequence of a delay in rescue, or rescue in a vertical position could be catastrophic. It is doubtful whether, currently within the industry, rescue drills and oxygen administration are practised regularly.

3. DIVE PLANNING AND EMERGENCY PROCEDURES

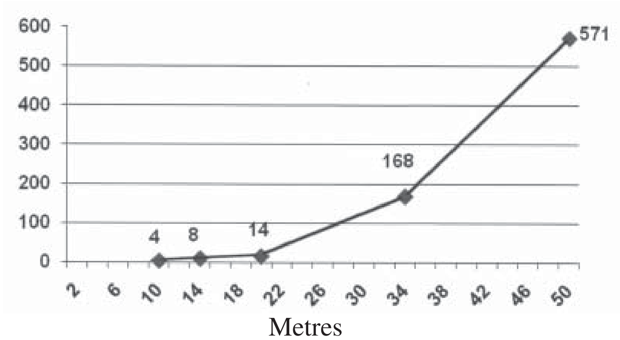
Planning of the dive is an essential part of risk management. There are several areas that have impacted on the health of Tasmanian abalone divers in recent years. One of the most common problems experienced by abalone divers requiring recompression at RHH is failure of the surface air supply, resulting from compressor malfunction or severance of air hoses (usually due to boat propellers). This forces the diver to undertake an emergency ascent to the dive boat, leading to DCI. At present, emergency bail-out air cylinders with regulators and contents gauges are mandated only for dives deeper than 15 metres' seawater (msw).[8] It is the author's opinion that bail-out air supply should be required during all abalone diving, regardless of depth. In an out-of-air situation, this simple risk-management procedure allows the diver to undertake a controlled ascent, thus preventing a potentially fatal rapid ascent in a state of extreme stress. Gas embolism with neurological deficit has resulted from depths as shallow as 2 msw.

The planning process must also consider the remoteness of the dive location, since greater degrees of self-sufficiency will be required for remote locations. Divers should be in peak physical health when diving in remote areas. Emergency equipment, procedures and links to emergency assistance and recompression facilities must be checked and tested prior to departure. Supplies of oxygen must be sufficient to provide continuous treatment of an injured diver for the full return distance from the most remote site, with a 50% reserve. Emergency contact numbers should be checked. Remote diving also mandates greater conservatism in diving practice to reduce the risk of accidents.

4. DIVE PROFILES

Deep diving poses an independent health hazard for all divers (Figure 1). Where possible, abalone divers should maintain

Figure 1
Risk of decompression sickness per 10,000 dives versus depth of dive for controlled dives in hyperbaric chambers.[9]



depths shallower than 20 msw. The no-decompression line is not an equal risk line and risk increases as divers descend deeper than 20 msw. The data in Figure 1 are based on 25,164 chamber dives at the no-decompression limit; and the risk of decompression sickness increased significantly with depth.[9] Deeper diving has also been associated with higher risk of dysbaric osteonecrosis. The effect of depth is compounded by repetitive dives and short surface intervals, due to greater nitrogen loads in the 'fast' tissues such as the brain and circulation, and higher bubble loads in the body. Hookah diving at depths greater than 20 msw creates potential problems of adequate air volume delivery, because of the increased ambient pressure.

Strategies to reduce risk in the dive-planning phase include:

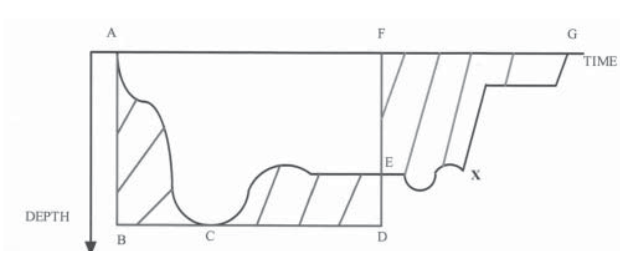
- *Table limits*: Ensure that the tables or the computer schedules are adhered to, and keep inside table limits. US Navy tables dived to the limit have a predicted 5.6% decompression illness rate, whilst that of the DCIEM tables is approximately 0.5%.[10–12] The DCIEM tables are now backed by thousands of hours of human diving data, measuring decompression stress using Doppler ultrasound, and are used by most professional diving operations in Australia, including the Royal Australian Navy, and all hyperbaric facilities.
- *Ascent rates*: In many studies, rapid decompression is associated with greater bubble formation.
- *Surface intervals*: Plan for surface intervals of at least two hours. This allows significant off-gassing of nitrogen from the body, because of its exponential removal from tissues. Repetitive dives at closer intervals have been shown to increase the risk of DCI, as demonstrated with dives on the *HMAS Swan* in Western Australia.[13]
- *Dive computers*: Computers have become very useful tools to assist recreational and professional divers.[14] The advantages of computers are that they travel with the diver and are able to precisely monitor multi-level dive profiles. Many Tasmanian abalone divers now use a computer to track their dives. Computers provide immediate feedback on ascent rates using alarms, and also guidance on repetitive dive schedules. Computers have limitations, in that the models under which they operate have not been researched as thoroughly as 'square dive profiles' (e.g., DCIEM tables).

With multi-level diving, computers provide credit for time not spent at the deepest depth, permitting longer dives. This is demonstrated in Figure 2. The areas enclosed by ABCDE represent a safety margin created by not following a precise square dive profile. In this dive profile, the computer allows extra dive time EXG by the credit given for not spending time at maximum depth, ABCDE. Hence, if the computer is dived to the limit, there is no safety factor left in the dive time. If something goes wrong at point X (e.g., a rapid ascent), then the diver is placed at greater risk than they would be with a dive time limit based on a square dive profile for the deepest point of the dive.

In hyperbaric chamber tests with repetitive diving, dive computers appear to operate less conservatively than dive tables.[15] Divers also need a backup plan using easily accessible, printed dive tables should their computer fail. It goes without saying that the same computer should be used for the same diver, every dive, day after day, so that it accurately tracks all of the diver's in-water activities. The situation is potentially more risky if decompression diving is undertaken because this deliberately exceeds the no-stop limits determined by the tables. Dive computer algorithms are largely untested in terms of risk for decompression diving. Decompression diving carries an exponential increase in risk, and an advanced knowledge of dive tables is needed. Decompression procedures are referred to in the code of practice but lack sufficient detail to be workable. The author has observed that diving for longer than recommended table limits still occurs without the use of appropriate decompression schedules. This is associated with an excessive degree of risk and is not recommended.

- *Bounce diving*: Multiple ascents at rates exceeding 18 msw per minute pose an independent risk factor for DCI. When limits for bounce diving were placed upon Tasmania's aquaculture industry, there was a significant reduction in decompression illness.[5,16]
- *Ascent to altitude after diving*: Based on the diving exposures regularly undertaken by abalone divers, flying

Figure 2
Hypothetical dive profile showing square dive limits ABCDF versus multi-level computer dive ABCEXG



after abalone diving should be avoided for a period of 48 hours. Ascent to altitudes less than 2,400 m after diving should also be limited in accordance with the Australian Standard 2299.1 (2007) (Table 1).[7] Because of the extreme nature of abalone diving, ascent to altitudes greater than 300 m should be avoided for 12 hours. This is of serious practical importance in Tasmania where many of the roads traverse hills or mountainous regions (Figure 3). There are limited data on the safety of ascents to altitudes of 300–2,400 m, and a conservative approach is advised.

- *Nitrox diving*: Nitrox diving using oxygen concentrations greater than air (e.g., 32% or 40%), may reduce the risk of DCI, but only if dived using air tables. When dived to the limits of the equivalent air depths, it is unlikely to be safer. In practice, given the cost and logistic issues of remote area diving, it is unlikely to be useful in the abalone industry.

Table 1
Recommended time intervals after diving before ascent to altitude (Australian Standard 2299.1)[7]

Altitude (m)	Time after last dive (h) Category of dive 1	2	3
0–150	Nil	Nil	2
150–600	Nil	2	12
600–2,400	12	24	48
>2,400	24	48	72

Category 1: Single dive to 50% of no-decompression limits, with no decompression or repetitive dives in previous few days.
Category 2: Routine no-decompression diving; single decompression dives
Category 3: Multiple decompression dives; extreme exposures; omitted decompression

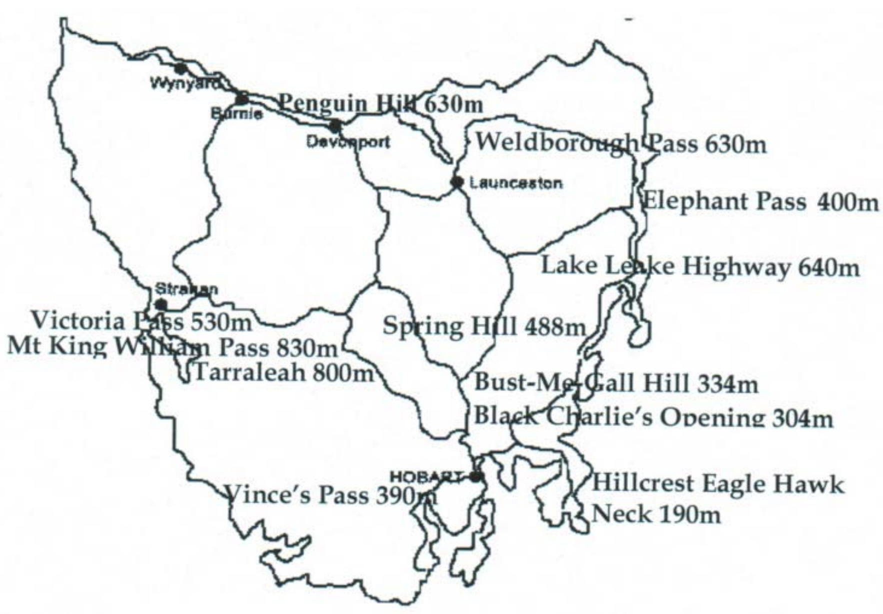
5. DIVING EQUIPMENT AND MAINTENANCE

The Tasmanian Abalone Industry Code of Practice outlines recommended maintenance schedules, but not in accordance with AS 2299.1, and there are no recommendations regarding frequency of maintenance. Unfortunately the code of practice does not even refer to the Australian Standard 2299.1, instead referring simply to “Australian Standards”.[8] In the author’s opinion, this is a major omission and constitutes a significant area of risk for the industry. Australian Standard 2299.1 (2007) is the default reference for all professional diving operations, and abalone divers should be fully conversant with its contents. The need to carry functioning, well-maintained bail-out cylinders while diving, and rescue/oxygen equipment in the boat is emphasised again.

6. EMERGENCY EQUIPMENT

Administration of 100% oxygen is essential for all diving accidents. Abalone diving is frequently undertaken in remote areas, considerable distances away from assistance. The average diver breathes up to 15 litres per minute when receiving 100% oxygen. The Australian D-sized oxygen cylinder contains approximately 1,400 litres, providing just over 90 minutes’ endurance at this rate. In remote-area diving risk assessment, quantities of oxygen should be carried to ensure an injured diver can receive 100% oxygen until rescued, allowing for a worst-case scenario. Sufficient oxygen should be carried for all diving, because an episode of gas embolism is a possibility from any depth.

Figure 3
Maximum elevations on roads from dived areas of Tasmania



7. TRANSPORT OF THE INJURED DIVER

The goals of pre-hospital management are to provide treatment with 100% oxygen and to transport the diver to a hyperbaric chamber for recompression as quickly as possible without causing deterioration in their condition. The mode of transport of patients with serious diving illness needs to take into account factors such as the distance to the nearest chamber, available resources such as transportable recompression chambers, aircraft and helicopters, road ambulance and access to the sick diver. For road transport, detailed knowledge of road routes from the dive locations to the chamber is also required, because even hills higher than 300 m may result in worsening of the diver's condition (Figure 3). Air transport should not be used unless the aircraft can be pressurised to sea level. The choice of systems depends on the severity of the injury and consideration of local resources and geography. Once a call is made for emergency assistance, this is best left to medical specialists and paramedics directly involved in the incident to determine what is needed.

8. RECORDING OF INCIDENTS AND 'NEAR MISSES'

Industry-wide anonymous incident reporting has proven useful in identifying risks in other diving industries, and allows a systematic approach to remedying any problems identified. The opportunity exists for the Tasmanian abalone industry to set up an incident-reporting system to assist with risk management.

Summary

Risk management is a systematic process applied to all aspects of diving operations. The process aims to reduce accidents and adverse outcomes to a minimum. Risk results from a combination of probability and consequence, and where this combination has major or extreme impact, the risk should not be tolerated. Risk management in diving encompasses medical fitness, education and training, dive planning, equipment and maintenance, emergency procedures and equipment, and continual vigilance to remedy new risks as they are identified. There is still much to achieve in the Tasmanian abalone diving industry in all these areas.

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