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SPUMS

Surf Life Saving Australia

Decompression illness in children

Decompression modelling 101

Asthma in 100 British divers

More from DIMS

A lucky technical diver

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PURPOSES OF THE SOCIETY

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

OFFICE HOLDERS

President	Dr Robyn Walker	16 Moriarty Road, Chatswood,
E-mail <Robyn.Walker@defence.gov.au>		New South Wales 2067
Past President	Dr Guy Williams	P.O.Box 190, Red Hill South,
E-mail <guyw@imap.cc>		Victoria 3937
Secretary	Dr Cathy Meehan	McLeod Street Medical, 67 McLeod Street, Cairns
E-mail <cmeehan@ozemail.com.au>		Queensland 4870
Treasurer	Dr Andrew Patterson	28A Roland Avenue, Wahroonga,
E-mail <a.j.patterson@exemail.com.au>		New South Wales 2076
Editor	Dr Mike Davis	SPUMS Journal, C/o Office 137, 2nd Floor,
E-mail <spumsj@cdhb.govt.nz>		Christchurch Hospital, Private Bag 4710, Christchurch, NZ
Education Officer	Dr Chris Acott	30 Park Avenue, Rosslyn Park
E-mail <cacott@optus.net.au>		South Australia 5072
Public Officer	Dr Guy Williams	P.O.Box 190, Red Hill South
E-mail <guyw@imap.cc>		Victoria 3937
Chairman ANZHMG	Dr David Smart	Department of Diving and Hyperbaric Medicine
E-mail <david.smart@dhhs.tas.gov.au>		Royal Hobart Hospital, Hobart, Tasmania 7000
Committee Members	Dr Simon Mitchell	45 Opanuku Road, Henderson Valley,
E-mail <dr.m@xtra.co.nz>		Auckland, New Zealand
	Dr Douglas Walker	P.O.Box 120, Narrabeen,
E-mail <dougwalker@ausdoctors.net>		New South Wales 2102
	Christine Lee	P.O.Box 862, Geelong,
E-mail <clee@picknowl.com.au		Victoria 3220

ADMINISTRATION

Membership	Steve Goble	C/o ANZ College of Anaesthetists
E-mail <stevegoble@bigpond.com>		630 St Kilda Rd, Melbourne, Victoria 3004
Journal	Sarah Webb	C/o Office 137, 2nd Floor,
E-mail <spumsj@cdhb.govt.nz>		Christchurch Hospital, Private Bag 4710, Christchurch, NZ
		Phone: +64-3-364-0045, Fax: +64-3-364-0187
North American Representative	Jeffrey Bertsch	E-mail <jeffbertsch@earthlink.net>
European Representative	Henrik Staunstrup	E-mail <hst@mail1.stofanet.dk>

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Membership is open to all medical practitioners.
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Membership application forms can be downloaded from the Society's web site at <http://www.SPUMS.org.au>

Further information on the Society may be obtained by writing to:
SPUMS Membership,
C/o Australian and New Zealand College of Anaesthetists,
630 St Kilda Road, Melbourne, Victoria 3004, Australia
or e-mail <stevegoble@bigpond.com>

The Society's financial year is January to December, the same as the Journal year.
The 2006 subscription will be Full Members A$132.00 and Associate Members A$66.00, including GST.
There will be an additional surcharge of $8.00 for journal postage for all members living outside Australia.

The Editor’s offering

Once again I am touching on issues far broader than those contained in the pages of this journal. There is little that has not already been said about the devastating Indian Ocean tsunami, but on behalf of the Society I would like to send our thoughts and best wishes, as they rebuild their lives, to all those who have lost family and friends or whose health and/or livelihood have been shattered by this event. It is a reminder to us again, as if we needed any, of the power of Nature. Despite a half-century of sea-swimming, snorkelling and scuba diving, I always have a momentary feeling of trepidation as I take that ‘giant stride’ off the boat into a realm that is not mine, but which I have been so privileged to enjoy. Never lose respect for the ocean.

Some members, including our President, have been heavily involved in relief efforts. The direct impact of this for the Society is that the establishment of the new Society web site has been delayed, since Robyn Walker was the person working closely with the site developers. It is hoped that this will come on line before the next issue, when a detailed explanation of the changes made to it will appear in the Journal. These changes are radical, and will considerably enhance services to members in the future.

A second impact has been on registration numbers for the ASM in the Maldives in April. Please read Robyn’s message on page four, and consider coming to the meeting. Even though this issue of the Journal is only reaching you a few weeks beforehand, there is still time to register. Following the poor attendances at meetings in the past two years, if this one goes the same way, the new Executive Committee will have some serious thinking to do regarding the direction of the Society.

The contentious issues of asthma, children in diving and technical diving all appear again in this issue. The Hawaiian hyperbaric unit is currently producing a series of retrospective clinical reports on their considerable 20-year experience in managing decompression illness, and Richard Smerz’s paper is the first paediatric series that I am aware of in the English-speaking literature. As such, it is both concerning, in that children and adolescents, some of whom should not be diving in the first place, are placed in potentially dangerous situations, and reassuring in that outcomes from aggressive hyperbaric treatment have largely been excellent.

In the last issue, it was reported that the external respiratory work of breathing from a scuba regulator during exercise at normal ambient pressure impaired pulmonary function in asthmatics.[1] I drew attention to the difficulty of relating such physiological data to actual ‘risk’ for asthmatics who dive. Adding further fuel to this debate, Peter Glanvill, a West-Country general practitioner working with the Plymouth group in the United Kingdom, has followed 100 asthmatic scuba divers over several years’ diving during which they accumulated over 12,000 dives. Except for one diver with a separate pathology (decompression sickness in the presence of a large patent foramen ovale), no important diving morbidity related to their asthma was reported by this group. This is despite a fair number reporting exercise as a trigger for their asthma and/or wheezing underwater. It is likely that the findings from this survey will be misused by some in the diving world as a licence to say that asthmatics are at no greater risk in scuba diving than non-asthmatics. However, it is important to remember the considerable limitations of such self-selected survey data and not to extrapolate from or misrepresent Glanvill’s interesting observations.

Technical diving is rapidly gaining popularity. Last weekend at the Poor Knights’ Islands, six out of a boat of about 18 divers were ‘teckies’, three on closed-circuit systems and three with multi-cylinder, open-circuit rigs. They disappeared well below my buddy and I as we dived to over 30 msw on the colourful drop-offs in excellent diving conditions. Barbara Trytko and Simon Mitchell’s classic report of a severely injured deep technical diver illustrates the clinical problems one may face in treating these divers if they get into trouble. However, such injuries are not isolated to deep mixed-gas diving. During the same weekend as I have just described, and the preceding one, two severely injured, unconscious scuba-air divers who probably experienced out-of-air, uncontrolled ascents from relatively shallow water were treated by the Auckland unit. Perhaps the main message is the need for modern hyperbaric units to have a full intensive-care capability where both equipment and staff are concerned – Trytko’s care of Diver X undoubtedly contributed to his good outcome. The problem, as always, is who pays to ensure these facilities are available; the mothballed spanking new chamber in the Royal Brisbane Hospital may be a message for the future, as recompression chambers are expensive to keep operational.

Surf life saving has been part of Peter Fenner’s life for decades both as an active participant and as a doctor. Whilst we will have more from him in forthcoming issues relating to his main expertise in marine stingers, I was delighted to be able to cajole him into putting his talk at the ASM on one of Australia’s sentinel organisations, Surf Life Saving Australia (SLSA), into publishable form. As well as a wide-ranging discussion, he provides data not previously published. The action shot of an Australian lifesaver diving into the water encapsulates for me all that SLSA and similar organisations around the world are about. SLSA will celebrate its centennial year in 2007.

Mike Davis

Reference

1 Gotshall RW, Fedorczak LJ, Rasmussen JJ. Severity of exercise-induced bronchoconstriction during compressed-air breathing via scuba. *SPUMS J*. 2004; 34: 178-82.

Front cover photo courtesy of SLSA and Harvie Allison

Editorial

Decompression illness in children

Christopher J Acott

Smerz's article[1] in this issue highlights several controversial topics related to children: the risks associated with scuba diving; informed parental consent; 'medical fitness' of asthmatics to dive; psychological 'fitness', what treatment pressure is needed and whether there is a need for alternative treatment tables for children and their susceptibility to pulmonary oxygen toxicity.

The physiological, physical and psychological problems/risks associated with children scuba diving have been documented and discussed previously.[2-4] The risks are inconclusive due to a lack of substantive data; however, it is disturbing that in this small series a 15-year-old was left with neurological sequelae (lack of bladder control) which may lead to immense psychological and emotional trauma in later years. Although statistically a rare occurrence, I suggest this fact would be of little comfort to the patient or parents.

Smerz's case histories illustrate that little was discussed with the parents prior to the children scuba diving, and that truly informed consent could not have been made. Twenty-seven per cent of children were known asthmatics; indeed, one had a previous neurological event on a dive. Would parents allow their asthmatic children to dive after the physical laws governing gas compression and expansion and the possibility of pulmonary barotrauma or cerebral arterial gas embolism were explained to them? In addition, one adolescent was diagnosed as suffering from Attention deficit hyperactivity disorder (ADHD) and another from an anxiety disorder. Whether medicated or not, adolescents diagnosed with ADHD, the triad of inattention, impulsivity and hyperactivity, or suffering from an anxiety disorder are psychologically unsuitable for diving.[5]

Both Walker's and DAN's data show that the risk of dysbaric disease or injury is the greatest in the less experienced divers, and this was verified by Smerz's data, which also showed that the mistakes made by children are similar to those reported by adults.[6,7]

By 1939 recompression had become the accepted method of treatment for decompression illness but there was disagreement concerning its application and today this controversy persists.[8] The treatment tables used in these cases are unique to Hawaii. Previous published data by Overlock et al showed a decrease in 'failure rate' of these deeper treatment tables (1.6%) when compared with standard practice of the minimum pressure oxygen treatment tables (US Navy treatment table 6 (USN T6) or Royal Navy table 62 – 4.8%).[9] Smerz again claims a better resolution rate. However, the numbers were small in both reports and are not significant. At a pressure of 777 kPa breathing a nitrox mixture containing 282 kPa of oxygen would subject the patient and attendant to a narcotic pressure of nitrogen of 495 kPa which would cloud judgement and interpretation of signs and symptoms. Under these conditions accurate self-assessment or assessment by an attendant is doubtful and at best would be extremely crude. It would be interesting to see data on their attendant decompression illness rate.

The evidence level of clinical efficacy for these tables at best would be Class 2B with a level of evidence of C, while for USN T6 it would be Class 2A with a level of evidence of B.[10] Many hyperbaric units would be unable to deliver the treatment pressures used in Hawaii in any case. Perhaps the most important aspect of all recompression regimes is the time spent breathing hyperbaric oxygen. However, even in the use of hyperbaric oxygen there is no agreement concerning what partial pressure should be used.[11] A workshop on all the treatment tables, how or why they work and the data substantiating them is needed, although outcome data have been and still are antedoctal and are based on different variables and largely from retrospective studies such as this one.

Twenty-three per cent of Smerz's patients developed pulmonary oxygen toxicity during treatment. Individual variation to oxygen toxicity has been known for many years but Ambriz et al suggested that children might be more susceptible to pulmonary oxygen toxicity based on physiological arguments and two case histories.[12] Therefore, they suggested modified treatment tables for children. Smerz refutes this showing that there was no difference statistically in the incidence of pulmonary toxicity between adults and children treated in the Hawaiian recompression chamber. More data are needed.

In Australasia a diving medical is required before participation in recreational scuba diving. At a diving medical for a child or adolescent I insist that the parents are present and explain to them:

- the unknown risks associated with scuba and why
- the lack of data regarding children due to relatively few children having participated in scuba diving in the past 40 years
- the physical, psychological and physiological changes that occur in childhood and adolescence and how and why these may impact on diving
- the morbidity associated with scuba diving, but explain that serious complications are rare and why various medical conditions may lead to morbidity or death
- data show that inexperienced divers (< 20 dives) are prone to injure themselves
- equipment requirements will change as the child matures, and the costs involved
- 'water skills' are an important part of safety and that these should be attained before diving.

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illness in children and adolescents in Hawaii, 1983 – 2003. *SPUMS J*. 2005; 35: 5-10.
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Christopher J Acott
Hyperbaric Medicine Unit, Royal Adelaide Hospital, Adelaide, South Australia 5001.
Phone: *+61-(0)8-8222-5116*
Fax: *+61-(0)8-8232-4207*
E-mail: *<cacott@optusnet.com.au>*

Key words
Children, decompression illness, decompression sickness, medicals/diving, editorial

(Acott CJ. Decompression illness in children. *SPUMS J*. 2005; 35: 2-3.)

Dr Smerz replies:

Whilst I am pleased to observe the interest in our 'Hawaiian deep tables', I am surprised at the amount of focus they receive from Acott in his editorial. The paper is not an apology for their employment or their efficacy. I do not challenge the substance of his comments at this time as we anticipate publication of a more definitive exposé of our treatment tables in *Undersea and Hyperbaric Medicine* later this year, which may alter his currently expressed opinion regarding their efficacy. However, I am not certain that they are germane to the thrust of this article.

My purpose in specifically demonstrating the tables we employed, which admittedly are more aggressive than most, was to show that longer exposure times to increased partial pressures of oxygen did not result in an increased incidence of untoward effect. One might reasonably conclude that our tables ought to produce potentially higher rates of complications than those employed by most others. Were that the case, and it appears not, then those using less aggressive tables might still have reason to question the need for table modification. Our results, therefore, should provide some reassurance that adult treatment tables are not imposing undue harm and result in substantial recovery. Our most optimal outcome of complete resolution, obtained using the present and most commonly employed treatment tables, has been achieved in only 70% and 75% of cases treated, and has remained steady at this rate over some period of time.[1] To risk obtaining less adequate results by abandoning the current, time-established tables in favour of an unproven regimen with no substantiated reason to do so invites ethical concerns.

Because of the small size of our study group, care must be exercised when looking at percentages as they tend to artificially magnify a problem. That is why in epidemiological analyses, rates are generally preferred and present a view that is more meaningful. Twenty-three per cent of our cases (five patients), as Acott points out, developed signs of pulmonary oxygen toxicity. However, it is the total number of risk exposures to increased partial pressures of oxygen (62) which is the appropriate epidemiological denominator, and hence an incidence rate of 8%.

Finally, since Acott raises the question, our incidence rate for attendant decompression sickness during the time frame 1983–2003 was 0.1% (3/2,854 exposures). We typically employ three attendants at different intervals throughout the treatment for the deep tables and two per treatment for the 283 kPa table. We decompress all attendants on oxygen using the RNPL decompression tables for tenders.

Reference

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SPUMS Annual Scientific Meeting
Maldives, April 2005

The earthquake and resulting tsunami of 26 December 2004 have etched unforgettable images on the minds of many people. Initial reports suggested that the Maldives had been significantly affected and that damage to the airfield and fresh-water supply to many islands had occurred.Since then SPUMS has had advice that the CocoPalm Resort suffered no damage. It is understood, however, that there has been a loss of sand from one of the beaches.

The resort is fully functional and whilst it may seem insensitive to some to continue with the Conference, the long-term viability of many tourist destinations may suffer if tourists stay away.

The 2005 ASM will proceed and I urge you to continue to support the Society and, more importantly, the people of the Maldives.

Look forward to seeing you there.

Robyn Walker, President, SPUMS
28 January 2005

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23 April - 1 May

CocoPalm Resort and Spa

Dunikolhu Island, Baa Atoll

The Maldives

Theme: Evolving Diving Practices

Principal Guest Speaker: Michael A Lang

Marine Sciences Program and Scientific Diving Officer
Smithsonian Institution, USA

Conference Convenor:
Dr Cathy Meehan

McLeod Street Medical, 67 McLeod Street,
Cairns, Queensland 4870, Australia
E-mail: <cmeehan@ozemail.com.au>

The correct dates for the 2005 SPUMS ASM are as above. Australian delegates will arrive back into Australia on 01 May. In previous editions of the Journal preliminary dates were published which have been changed for improved airline connections and premium diving conditions. We apologise for any confusion this has caused.

Original articles

Epidemiology and treatment of decompression illness in children and adolescents in Hawaii, 1983–2003

Richard Smerz

Key words
Children, adolescents, decompression illness, medical/diving, treatment, epidemiology

Abstract

(Smerz R. Epidemiology and treatment of decompression illness in children and adolescents in Hawaii, 1983–2003. *SPUMS J*. 2005; 35: 5-10.)
The advisability of children and adolescents engaging in scuba-diving activities remains a topic of debate. The advent of enhanced opportunities for divers of a younger age has intensified the controversy. Increased risks for physical injury and the psychological readiness of children and adolescents are at the heart of the debate. Recently, questions have arisen regarding the appropriateness of treating younger divers using the current medical management strategies employed to treat adult cases. This retrospective study reports on the 20-year experience at the University of Hawaii in treating child/adolescent cases. Twenty-two cases were evaluated and treated between 1983 and 2003. Six (27%) of these cases suffered an arterial gas embolism (AGE); the remainder had decompression sickness. Seventeen (77%) presented with moderately serious to severe injury. Nineteen (86%) were associated with lack of experience, and nine (41%) may have been related to poor judgement, and lack of self-control. Six cases (27%) suffered an AGE, three of whom had relevant histories of asthma. All cases were treated using treatment tables developed at the University of Hawaii for adult divers with twenty (90.9%) attaining complete resolution of symptoms. Five cases developed mild pulmonary oxygen toxicity resulting from treatment. The oxygen toxicity incidence rate of 8% was slightly higher than but not statistically different to that seen in our adult patients. Established adult treatment schedules appear to be safe and produce excellent outcomes when used to treat younger divers.

Introduction

Children and adolescents have been engaged in scuba diving since the 1960s, and interest has steadily grown since the mid-1980s with the advent of new dive programmes and diving opportunities designed for and marketed to divers of even younger ages.[1,2] Yet, there are questions about the appropriateness of this avocation for children and adolescents, based largely upon perceived concerns of enhanced risk for physical injury and their psychological readiness to undertake diving.[1–6] There have been a number of case histories and fatalities recorded over the years that suggest these concerns may be more than theoretical.[7–10]

More recently, questions regarding the appropriate medical management of diving injuries in children have also arisen.[6] Few published data are available to address these concerns. This study reports on our experience over the past twenty years in evaluating and treating diving injuries in children and adolescents in an attempt to answer some of the questions raised.

Methods

A retrospective review of 1,274 records of patients evaluated and/or treated for dysbarism, arterial gas embolism (AGE) and decompression sickness (DCS), at the Hyperbaric Treatment Center (HTC), University of Hawaii, John A Burns School of Medicine between 1983 and 2003 was conducted in 2004. The foci of this study were cases occurring in patients aged 17 years or younger. Based upon history of injury and presenting physical signs and symptoms, cases were categorised as either AGE or DCS, and the DCS cases were further classified as cerebral, spinal cord, or pain only. Diving-accident histories, including contributing operational diving factors and accident-related comorbid influences, medical histories, age, gender, certification level and diving experience, severity of injury, treatment schedules employed, outcomes per injury type, number of treatments per case, and complications of treatment were assessed and analysed.

Severity of injury was assessed as either mild, moderate, or severe, based upon the gravity of the injury effects upon the ability to conduct activities of daily living as determined at the initial evaluation irrespective of the site of injury. Severe injuries were defined as life threatening and/or had potential for profound residual impairment, i.e., coma, paraplegia, and/or complicated by life-threatening comorbidity. Moderate injuries were defined as those that resulted in a degree of impairment or loss of function sufficient to modify activities of daily living, i.e., motor weakness of a lower extremity, but maintenance of ability to ambulate. Mild cases were those where symptoms and findings were more subjective or would result in little significant impairment.

All cases had been treated using adult treatment schedules developed at the University of Hawaii. The specific tables employed in this study group were: 220 fsw (774 kPa) or 160 fsw (588 kPa) using mixed gases initially, then 100% oxygen; 60 fsw (283 kPa), which is a modified US Navy treatment table 6 (USN T6); and 47 fsw (242 kPa), our usual hyperbaric oxygen (HBO) table, the latter two of which tables employ only 100% oxygen.[11] Outcomes were defined as complete or partial resolution of symptoms.

Results

EPIDEMIOLOGY

Twenty-two patients met our case definition; 17 males and five females, ranging in age from 12 to 17 years (Table 1). There were six novice (in training) or resort course divers, 13 Open Water (OW) divers, two Advanced Open Water (AOW) divers, and one uncertified diver. Novice/resort course divers had undertaken two to eight lifetime dives, OW divers four to 20 lifetime dives, AOW divers 30 and 200 lifetime dives, and, astonishingly, the uncertified diver had undertaken 100 lifetime dives.

Three of the six AGE cases and three of the DCS cases had a pre-existent history of asthma, two of whom (Cases 1 and 6) were actively using non-steroidal medi-halers for control of symptoms at the time of injury. One asthmatic (Case 3), though not symptomatic or taking medication, had experienced an episode of altered consciousness, mental confusion and weakness (suggestive of an AGE) immediately upon surfacing from a dive three weeks prior to the occurrence of this second reported event and for which she did not seek treatment. Two of the DCS cases (Cases 12 and 16) were actively taking medications for behavioural disorders.

Operationally, during the incident dives, there were nine patients (41%) who experienced rapid or uncontrolled ascents, four (18%) who demonstrated panic, two (9%) who experienced an out-of-air (OOA) situation; two pushed the limits of the dive tables and one missed a required decompression stop (14%), two (9%) had buoyancy-control problems, one had an ear squeeze, another hit his head on the underside of the dive boat, and one was extremely cold in the water.

Three divers (14%) developed symptoms only after going to altitude or getting into a hot tub shortly upon completion of their dives. The uncertified diver (Case 7) developed symptoms after the third of four dives on the day of injury.

Treatment

There were six cases of AGE and 16 cases of DCS (six pain, five cerebral, five spinal cord; Table 2). Five cases were initially characterised as having severe life-threatening or debilitating symptoms (three AGE, two DCS), 12 cases were determined to have moderately serious symptoms (two AGE, 10 DCS). Five cases were defined as mild severity (one AGE, four DCS).

Two of the six AGE cases (33%) experienced significant pulmonary barotrauma during the incident dive, and two (33%), including one of the pulmonary barotrauma cases (Case 4), also suffered near drowning. Delays to treatment ranged from 20 minutes to 72 hours (mean 14.25 hours, median 5.5 hours).

All patients had been treated using the HTC treatment tables until either complete resolution of symptoms was attained or until no further change in condition was evident for at least two consecutive treatments. The number of treatments ranged from one to 22 (mean 2.8, median 1).

All but two cases (2 and 11), achieved complete recovery (Table 3). Case 2 was left with some left-leg weakness, while Case 11 was left with a gait abnormality, some sensory loss of both lower extremities, and a neurogenic bladder.

Five patients developed mild symptoms of pulmonary oxygen toxicity (incidence, 8%) during treatment.

Discussion

In the past twenty years, the HTC, which is the only facility in the State to treat decompression illness, has evaluated and treated only 22 divers aged 17 years or younger. This is an average of about one case per year in a state surrounded by the Pacific Ocean and which serves as a haven for all manner of water sports. The latest case was seen in 2000.

Between 1990 and 2000, the Professional Association of Dive Instructors' (PADI) statistics show that 70% of all certified divers are PADI divers, and approximately 15% of their certified divers are in our age group of interest. Hawaii has ranked third in the United States (US) in certifying new PADI divers. It would be reasonable to assume, therefore, that the percentage of divers aged 17 or less in Hawaii, including the transient tourist population, is close to 15%. Without reliable denominator data consisting of the total number of dives undertaken by those in our study group during this period of time (1983–2003), a true estimate of incidence of injury is not calculable. However, in terms of frequency of occurrence, dysbarism in this age group in Hawaii has not occurred in proportion to their representative percentage of the certified diving population, accounting for only 1.7% of our total case load, and 2.2% of all cases diagnosed. A more complete assessment of potential risk would also include fatalities associated with diving. In that regard, we have been fortunate to have not seen, nor are we aware of, any fatalities in this age group related to compressed-gas diving in Hawaii. Others have reported such occurrences in other regions of the globe.[7–10]

Divers Alert Network (DAN) located at Duke University, based upon their systematic collection of diving accident information from reporting sites throughout the US, have

Table 1
Epidemiology of cases of arterial gas embolism (6 cases) and decompression sickness (16 cases)
ADHD – Attention deficit/hyperactivity disorder; AOW – Advanced Open Water; deco – decompression; hx – history; OOA – out of air; Ops – operational; OW – Open Water; uncert - uncertified

Case	Age (gender)	Certification level (# dives)		Ops factors	Medical hx (pre-dive)
Arterial Gas Embolism					
1	12 (F)	Novice	(3)	Panic; rapid ascent	Asthma
2	13 (M)	OW	(15)	OOA; panic; rapid ascent	–
3	14 (F)	OW	(10)	–	Asthma; prior neuro event
4	14 (M)	Novice	(4)	Emergency ascent training; uncontrolled ascent	–
5	15 (M)	OW	(6)	Panic; rapid ascent	–
6	16 (M)	OW	(15)	Panic; rapid ascent	Asthma
Decompression Sickness					
7	13 (M)	Uncert	(100)	OOA; rapid ascent	–
8	13 (M)	OW	(4)	Pushed tables; rapid ascent	–
9	14 (F)	OW	(9)	Hot tub post dive	–
10	14 (M)	Resort	(8)	–	–
11	15 (M)	OW	(20)	Buoyancy problem; rapid ascent	–
12	15 (M)	Novice	(3)	Very cold in water	ADHD on meds
13	16 (M)	OW	(20)	–	–
14	16 (M)	OW	(20)	–	–
15	16 (M)	OW	(20)	Altitude post dive	–
16	16 (M)	OW	(8)	Ear squeeze	Anxiety on meds
17	16 (F)	AOW	(30)	Pushed tables; rapid ascent	–
18	16 (M)	Novice	(4)	Altitude post dive	–
19	17 (M)	Novice	(2)	–	Asthma
20	17 (F)	OW	(10)	–	Asthma
21	17 (M)	AOW	(200)	Head injury	–
22	17 (M)	OW	(15)	Missed deco stop	Asthma; migraines

Table 2
Treatment summary of arterial gas embolism cases and decompression sickness cases
Tx – Treatment; Comp – complications; POT – pulmonary oxygen toxicity

Case	Severity/type	Delay	Tx table (kPa)	(# txs)	Tx comp	Comorbid injury	Recovery
Arterial Gas Embolism							
1	Moderate	3 hrs	588	(1)	–	–	Complete
2	Severe	20 mins	774 242	(2) (10)	–	Pneumomediastinum/ pericardium	Partial
3	Severe	1.5 hrs	588 242	(1) (2)	–	–	Complete
4	Severe	5 hrs	774 588	(1) (1)	Mild POT	Pneumothorax/mediastinum; near drowning	Complete
5	Mild	1 hr	283	(1)	–	–	Complete
6	Moderate	2 hrs	774 283	(1) (2)	–	Near drowning	Complete
Decompression Sickness							
7	Moderate/pain	30 hrs	774	(1)	Mild POT	–	Complete
8	Mild/pain	8 hrs	283	(1)	–	–	Complete
9	Moderate/spinal	24 hrs	774 283	(2) (1)	–	–	Complete
10	Moderate/spinal	6 hrs	283	(1)	–	–	Complete
11	Severe/spinal	4 hrs	774 283 242	(1) (6) (15)	–	–	Partial
12	Mild/pain	1.75 hrs	283	(1)	–	–	Complete
13	Moderate/cerebral	1.5 hrs	774	(1)	–	–	Complete
14	Moderate/cerebral	1.5 hrs	774	(1)	–	–	Complete
15	Moderate/cerebral	8 hrs	283	(1)	–	–	Complete
16	Moderate/pain	72 hrs	283	(1)	–	–	Complete
17	Moderate/pain	14 hrs	774	(2)	–	–	Complete
18	Mild/pain	45 hrs	283	(1)	Mild POT	–	Complete
19	Moderate/spinal	18 hrs	774	(1)	Mild POT	–	Complete
20	Moderate/spinal	26 hrs	774	(1)	Mild POT	–	Complete
21	Mild/cerebral	10 hrs	774	(1)	–	–	Complete
22	Severe/cerebral	1 hr	774	(1)	–	–	Complete

Table 3
Treatment outcomes by severity and type of injury and incidence of pulmonary oxygen toxicity
AGE – arterial gas embolism; DCS – decompression sickness

Severity:	**Severe***	**Moderate**	**Mild**	**Total**	**O_2 toxicity**
AGE	3 (1)	2	1	6	1
DCS – pain	–	3	3	6	2
– cerebral	1	3	1	5	–
– spinal	1 (1)	4	–	5	2
Total DCS	–	–	–	16	–
Total divers	5	12	5	22	5

*only two children (in parenthesis) did not achieve full recovery

consistently reported over the years that the risk of dysbaric injury is greatest in the least experienced divers.[12]

Certification level does not necessarily correlate with experience and, more importantly, competency in diving. The total number of lifetime dives may be a better indicator. In our study population, 19 (86%) had 20 or fewer lifetime dives, reflective of their relative inexperience. Additionally, other indicators of inexperience may be inferred by the panic events and rapid ascents, the pushed tables and missed deco stops, and out-of-air situations seen in 9 (41%) of the cases.

These operational missteps may also have extended from faulty judgement, a loss of self-control, an inability to cope with a stressful circumstance or management of multiple tasks at once, and/or lack of emotional maturity. However, these same operational miscues were also prevalent at similar rates in our adult-diver injury cases. DAN reports these same findings in their data in which over 95% of cases were adults.[12] One might conclude, therefore, that their rate of occurrence in the children and adolescents of this study was typical and expected statistically. Although we do not have experience data on all of our adult cases, those we do have indicate that the percentage of our adult population who presented with 20 or fewer dives was substantially less than that of our study group.

This study underscores the absolute need to screen children and adolescents carefully in regards to their emotional and psychological maturity as well as their ability to comprehend the inherent risks associated with diving before undertaking this sport. A validated sense of responsibility, self-confidence and ability to deal with the stressors of diving should be in evidence prior to undertaking this avocation. These considerations are probably more important in young divers where there is likely to be less parental involvement or supervision than is required in the dive programmes designed for even younger divers, and where the environmental conditions are often more challenging, and an unwarranted sense of immortality is pre-eminent.[13]

Twenty-seven per cent of the study population suffered an AGE, a diving injury in which statistically 20% of cases result in fatality, hence not insignificant. It most often occurs secondary to pulmonary barotrauma, which in itself can be life threatening. Two patients sustained significant barotrauma. AGE was seen in 27% of our study group as compared with 11% in our adult-diver injury population. Hence the frequency of this injury in the study group was almost 2.5 times as great. Fifty per cent of the AGE cases in this study had a history of asthma, which probably led to the barotrauma that resulted in their injury.

Some diving physicians have relaxed their views over the years with respect to advising asthmatics against diving based upon concerns about pulmonary barotrauma and AGE. This has been predicated upon the fact that there are reportedly a substantial number of asthmatic divers who have never experienced such events.[14] Based upon the small sampling of cases in this study, there may be a need to be more circumspect about this matter with younger divers. Their lungs are less mature, the airways may be more sensitive and less compliant, are of smaller diameter, and may cause greater expiratory resistance and air trapping, thereby paving the way for a barotraumatic event with air embolisation. This study supports other recent work.[15–17]

Seventeen (77%) cases presented with moderate to severe symptoms. All patients were treated using the usual HTC treatment tables, which were developed at the University of Hawaii in the early 1980s and have been used ever since. They typically employ a deep spike to 220 fsw (774 kPa) or 160 fsw (588 kPa) using nitrox 65/35 and/or 50/50, followed by a gradual staged ascent to 60 fsw (283 kPa) where the patient is treated on 100% oxygen to the conclusion of the treatment schedule. The HTC also employs a treatment table commencing at 60 fsw (283 kPa) which is a modified USN T6 with oxygen treatment periods at 60, 45, 30 and 15 fsw. The 47 fsw (242 kPa) table is a two-hour HBO treatment table. Over the twenty years of their usage these tables have resulted in complete functional recovery in 92.9% of all cases treated,[11] which is about 20% better than that reported nationally by DAN for all reporting sites combined.[12] In this study group, 90.9% achieved complete functional recovery.

Compared with the USN T6, which runs 4.75 hours in duration and generates a unit pulmonary toxicity dose (UPTD) of 645, the HTC tables run from 5.25 hours for the 283 kPa table to 6.5 hours for the 774 kPa table and generate UPTDs of 791 to 904.[18] The study group amassed 62 treatment exposures from which five resulted in the development of mild pulmonary oxygen toxicity (incidence, 8%). This was a slightly higher, but not statistically significant, rate than was seen in our adult patients. Thus, concerns regarding the need to modify or reinvent a 'paediatric' set of treatment tables appear to be unwarranted.[4] Delay to treatment did not appear to affect outcomes.

Conclusions

Decompression accidents in this younger population were rare events but, when they did occur, significant injury was usual. Most were associated with poor judgement, lack of attention, loss of self-control, and inexperience. Children and adolescents may be at increased risk for suffering an AGE overall. It is clear that patients in this age group who have reactive airway disease are at greater risk of experiencing pulmonary barotrauma, which may result in arterial gas embolisation, and, therefore, should be advised that diving should not be undertaken. Treatment tables developed for adults produced excellent outcomes in the vast majority of cases, did not present an increased risk of untoward events, and should continue to be used in lieu of developing new and unproven treatment regimens.

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Richard Smerz, DO, MTMH, is Associate Clinical Professor, Undersea and Hyperbaric Medicine and Medical Director, Hyperbaric Treatment Center,
University of Hawaii, John A Burns School of Medicine,
347 North Kuakini Street,
Honolulu, Hawaii 96817, USA
***Phone:** +1-(808)-587-3425*
***Fax:** +1-(808)-587-3430*
***E-mail:** <rsmerz@htchawaii.com>*

Human error and violations in 1,000 diving incidents: a review of data from the Diving Incident Monitoring Study (DIMS)

Christopher J Acott

Key words
DIMS, scuba diving

Abstract

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Incident reporting is a method of identifying, classifying and analysing incidents/events in the context of contributing and associated factors including, but not limited to, human error. It is an established part of safety analysis and risk assessment in aviation, the nuclear-power industry and medicine (particularly anaesthesia). The incident-reporting technique was used to examine the types of human error and violations of safe diving practice that occurred in 1,000 recreational diving incidents reported to the Diving Incident Monitoring Study. Whilst errors can be classified, violations are not predictable and cannot be classified.
Human error: The 'psychological' classification of error was used. Error contributed to 87% of the incidents reported. 'Knowledge-based' (type 1) and 'rule-based' (type 2) errors predominated. Corrective strategies to minimise knowledge-based errors include improvement to educational programmes involving buoyancy-jacket use, air-supply management, ear-equalising techniques and coping with unexpected sea conditions. Rule-based errors can be minimised by the development of specific protocols and checklists. Failure to do an adequate pre-dive equipment check contributed to 15% of all incidents. 'Skill-based' (type 3) errors due to haste or inattention featured in 26% of incidents and can be minimised by overlearning a particular task. 'Technical' (type 4) errors are associated with inadequate training and featured in 12.5% of incidents.
Violations: There were 148 reports received that contained 201 violations; 65 (44%) of these incident reports involved morbidity. Twenty of these reports (containing 19 violations) involved untrained divers (no formal tuition or supervision), of which 15 (75%) described incidents that were the cause of the total morbidity in the untrained divers.

Introduction

Safety in diving is dependent upon an adequate understanding of the associated risks. Accident and fatality data are used as an index of safety and risk but are retrospective. Accidents are unpredictable,[1,2] such that the development of strategies to prevent future accidents through retrospective analyses of accidents is imprecise and difficult.[3]

Other limitations associated with accident and fatality data are:

- events are often reconstructed from a jigsaw of information that lacks substantiation of events by the victim;
- valuable information may be forgotten during the turmoil of the rescue and resuscitation, such that the recorded events may be an oversimplification of what happened;[1]
- events are often changed to suit the perception of what happened and are seen in the light of 'doing the right thing';[1,3]
- reports may be subject to investigator bias and report: 'what must have happened' rather than 'what did happen';
- only legal issues may be addressed.[4]

INCIDENT REPORTING

Errors are a part of everyday cognitive function, occur repeatedly, are usually trivial and are usually recognised and corrected before they cause harm.[1] It is easier to predict and prevent errors than accidents, because errors are methodological, taking on predictable forms that can be classified.[1,5] Because an accident is often the product of unlikely coincidences or errors occurring at an inopportune time when there is no 'system flexibility', it is reasonable to assume that error prevention will also prevent accidents.

Incident reporting is a method of identifying, classifying and analysing incidents/events in the context of contributing and associated factors including, but not limited to, human error.[3,6–8] This method is now established in aviation, the nuclear-power industry and medicine (particularly anaesthesia).[7,10–13] It is not a new concept, having been first used in the 1940s to improve military air safety, although the idea had its foundations much earlier in nineteenth-century Britain.[14]

Incident reporting is anonymous and has no interest in culpability or criticism. Therefore, it allows for accurate reporting without the fear of legal redress. It focuses on the process of error, regardless of outcome. Because of its unconstrained nature, the application of such a technique will also result in a description of recreational diving practices and demography.

The safety implications of the application of incident monitoring to recreational diving are obviously the identification of commonly occurring and dangerous errors, their contributing factors and the development of corrective strategies to address these.[6–8,12,14] Hence, if errors can be identified and their effects minimised or eliminated, there will be an inevitable decrease in the number of accidents and their consequences.

The main criticism of incident reporting is that only the incidents considered important are reported. Monitoring of incidents will, therefore, not identify the absolute incidence of error, but will show the relative incidence of errors or identify 'clusters' of errors.[1–3,7,8,11] Although often represented in a quantitative manner, the data obtained are qualitative and not quantitative.[14] It is, therefore, important when designing corrective strategies to address all errors and not just the ones reported frequently.

Accidents may also be caused by violations of acceptable safe practice even in a 'flexible' system. Accidents due to violations are difficult to decrease because no corrective strategies can be designed to prevent their occurrence. Identifying violations, however, may contribute to the design of quality-assurance procedures or impact on educational programmes.

Data from 1,000 incident reports to the Diving Incident Monitoring Study (DIMS) were examined for human errors and violations and analysed to suggest corrective strategies. Any incident may contain both a human error and a violation.[15–18]

Methods

The Diving Incident Monitoring Study (DIMS) commenced in 1989 with a pilot study and has since been refined.[8] A diving incident is defined as any error or unplanned event that could or did reduce the safety margin for a diver on a particular dive. The error may have been made by anybody associated with the dive and can occur at any stage during the dive.[8,19]

Table 1
Classification and characteristics of errors and how they are represented on the DIMS form

Type of error	Characteristic of error	DIMS factors
Knowledge-based (type 1)	Due to a lack of or inadequate knowledge	Inexperience Unfamiliar with diving conditions Error in judgement Failure to understand equipment Unfamiliar equipment
Rule-based (type 2)	Failure to apply a correct protocol or the application of an incorrect protocol	Failure to check equipment Poor dive planning Lack of/poor servicing of equipment Lack of a buddy check Inadequate supervision Poor communication Lack of post-dive maintenance
Skill-based or slips and lapses (type 3)	Failure to respond to a particular stimulus	Inattention Haste
Technical (type 4)	Could be 'knowledge-based' or 'rule-based' error	Insufficient training Poor technique Inadequate knowledge
Latent (type 5)	Interaction between the diver and buddy, the marine environment, equipment, physiological adaptation to immersion and increased ambient pressure	Anxiety Poor physical fitness Sea sickness Recent illness Drug or alcohol intake Fatigue
Violation, stupidity	Deliberate action contrary to protocol	Nil

The current DIMS form is available on the websites of SPUMS (<www.spums.org.au>) and the Divers Alert Network South East Asia Pacific, (<www.danseap.org>). Divers are encouraged to fill out one of these forms as soon as they have witnessed or have been involved in an incident. Anonymity is assured by the design of the questionnaire in that it does not record any identifying features. Once reported, the data are collected and analysed according to the psychological classification of errors (see below). Violations are noted and listed, and some are categorised as 'stupidity'.

Errors are classified as either 'active' or 'latent'.[2,3] Active errors are the immediate precursors to the accident or incident, while latent errors are the 'scene setters' or the 'shaping factors' that establish the scene in which active errors can occur.[2,3,7,22] Active errors can be further categorised into contextual, modal or psychological. The contextual classification of error describes how a series of actions are performed in a particular environment and hence is only relevant to that environment. The modal classification involves the manner in which the action is performed; the error is one of substitution, repetition, insertion or omission. This system is useful in collecting data from diverse environments and for calculating error probabilities. The psychological classification of error provides insight into the cognitive functions that cause the error and is represented on the DIMS form as the 'contributing factors' section. Although this is an oversimplification of events it is useful in the development of preventive strategies.[21] 'Psychological errors may also be subdivided into four 'active' categories as well as a 'latent' category:

- 'Knowledge-based' errors, type 1
- 'Rule-based' errors, type 2
- 'Skill-based' errors, type 3
- 'Technical' errors, type 4
- 'Latent' errors, type 5

A violation is defined as any action that is contrary to accepted 'safe diving practice' as defined by the recreational diving agencies.[15–18] A violation subcategory of 'stupidity' is defined as any action that involved no appreciation of risk or forethought, or lacked sensibility.[20]

Table 2
Contributing factors ranked by frequency of occurrence and categorised into types of error (see Table 1)

Contributing factor	Number (%)	Error
Error in judgement	249 (15.0)	1
Inexperience	224 (14.0)	1
Inattention	212 (13.0)	3
Poor dive planning	196 (12.0)	2
Failure to check equipment	193 (12.0)	2
Haste	143 (8.8)	3
Insufficient training	129 (7.9)	4
Anxiety	124 (7.6)	5
Failure to understand equipment	109 (6.7)	1
Unfamiliar with diving conditions	109 (6.7)	1
Poor communication	96 (5.9)	2
Poor physical fitness	83 (5.1)	5
Lack of a buddy check	64 (3.9)	2
Lack of servicing equipment	51 (3.1)	2
Failure to understand dive table	42 (2.6)	1
Inadequate supervision	40 (2.4)	2
Sea sickness	37 (2.3)	5
Poor servicing of equipment	34 (2.1)	2
Drug or alcohol intake	25 (1.5)	5
Feeling unwell	5 (0.3)	5

One thousand DIMS incident reports were examined by the author for data concerning human errors and violations. From these data corrective strategies are proposed. Violations were noted from the narrative reports. Table 1 lists the types of error, the characteristics of these errors and how each type is represented in the contributing factors section on the DIMS form.

Results

The results are tabulated for human error in Tables 2 and 3, and for violations in Tables 4 to 8. Twenty reports were obtained from untrained divers (the 'untrained' box was ticked on the DIMS form) and even though diving while untrained is a violation in itself, analysis involved separation of violation reports into trained and untrained divers for comparative purposes.

Table 3
Types of error identified in the first 1,000 DIMS reports and proposed corrective strategies (percentage of the total number of errors (1,618) reported, types 1 to 5, shown in parenthesis)

Type of error	Number	(%)	Corrective strategy
Knowledge-based (type 1)	498	(30.8)	Additional training and quality-assurance programmes
Rule-based (type 2)	458	(28.3)	Development of specific protocols or check lists
Skill-based (type 3)*	259	(16.0)	Overlearning of a task, reduce distraction
Technical (type 4)	129	(8.0)	As for type 1 or 2
Latent (type 5)	274	(16.9)	Education or 'change the system'
'Violations'	201		Quality-assurance and continuing education programmes?

*when present, skill-based errors were associated with morbidity or had the potential for causing harm in 75% of cases

Table 4
The 10 most common violations listed in order of frequency, including incidents with multiple violations (untrained divers in parenthesis). There were 201 violations, 19 in untrained divers

Violation	Number	
Diving without essential equipment	76	(15)
Continuing to dive with symptoms	19	(2)
Stupidity	14	(2)
Continuing to dive while breathing from an octopus, one out of air	10	
Dive leader/instructor ignorant of divers' ability (placing divers in danger)	9	
Diving with known faulty equipment	9	
Returning to surface alone without notifying buddy	9	
Diving with inadequate air supply	8	
Diver lying about his dive profile or medical fitness	6	
Dive leader or instructor not responding to a diver underwater	6	

HUMAN ERROR

The contributing factors in 1,000 incidents reported are listed according to error type in Table 2. At least one contributing factor was acknowledged in 869 (87%) reports. A total of 1,618 errors were reported. Table 3 lists the frequency with which each error type occurred and the proposed corrective strategies. The reporting of one type of error was not mutually exclusive of reporting other errors or violations.

VIOLATIONS

There were 148 reports received that contained 201 violations. Nineteen of these violations involved untrained divers (divers who had not undergone any educational or practical training programme in compressed-gas diving). The 10 most common violations are listed in order of their frequency in Table 4. Others included lack of a boatman during the dive, diving outside the recreational diving limits (i.e., greater than 50 metres sea water (msw) depth on air) and divers returning to the surface alone when out of air.

There were 21 reports which contained two violations and one which contained three. Interestingly, multiple violations did not involve untrained divers. Sixty-five (44%) of the violations by trained divers caused harm, in contrast to 15 (75%) of those by untrained divers. Morbidity associated with violations is listed in Table 5.

Diving without essential equipment for a particular type of diving activity was the most frequently reported violation in both trained and untrained divers. Table 6 lists the frequency with which this occurred with each piece of equipment. The incidence of diving without reference to a set of diving decompression tables or diving computer (23.6% of violations) was highlighted by these data and, not surprisingly, was associated with a majority of the reported cases of decompression illness (DCI) and represents 8.1% of the total morbidity reported to DIMS. The majority of the dives concerned were to depths greater than 15 msw.

Table 5
Violations associated with morbidity (untrained divers in parenthesis)

Violation	Number	
Diving without essential equipment	30	(7)
Continued to dive with symptoms suggestive of decompression sickness	15	
Diving outside the limits of recreational diving (> 50 msw on air)	4	
Diving while unwell or ill	2	
Stupidity	2	
Diving with known faulty equipment	1	
Dive instructor's poor advice after a dive – ignoring diver's symptoms	1	
Multiple violations	**Number**	
Diving without essential equipment plus continuing to dive with symptoms	3	(2)
Diving without essential equipment plus stupidity	0	(1)
Diving with known faulty equipment plus dive leader not responding to a diver	1	
Dive leader/instructor ignorant of diver's ability plus lack of equipment	1	
Dive leader not responding underwater plus lack of equipment	1	
Diving with inadequate air supply plus lack of equipment	1	

Violations subcategorised as 'stupidity' occurred frequently and are listed in Table 7. Unfortunately, dive instructors and divemasters featured prominently in this sub-category. The qualification of the divers and the number of violations, including stupidity, committed are listed in Table 8.

Table 6
Lack of essential equipment listed in order of frequency (untrained divers in parenthesis)

Lack of equipment	Number	
Dive tables and/or dive computer	43	(13)
Octopus regulator	7	
Depth gauge	5	
Watch or timing device	5	
'Bailout bottle' (using surface supply)	4	(2)
Reel line (wreck or cave penetration)	4	
BCD	2	
'Safety sausage' or surface-signalling device ('drift' diving)	2	
Torch (night diving)	2	
Knife (kelp diving)	1	
Contents gauge	1	

Table 7
Violations classified as stupidity
(untrained divers in parenthesis)

Violation	Number	
Diving with a speargun	3	
Diving without a boatman	3	
Diving in a boating lane	2	
Diving in a boating lane without a diving flag	1	
Diving where fishermen are burleying for sharks	1	
Playing with a shark	1	
Diver not checking entry site and colliding with diver in water	1	
Divemaster switching diver's air supply off in rough conditions on exit ladder	1	
Diving without a compressor attendant (hookah)	1	(2)

Discussion

ERRORS

In 50% of the incidents reported, a knowledge-based error was involved. The most common of these errors were with:

- buoyancy-jacket (BCD) use (especially buoyancy control at decompression stops or in the last 5 metres of an ascent)
- ear-equalisation techniques
- air-supply duration
- dive planning
- diving in a current
- coping with unexpectedly rough surface conditions, particularly at the exit.

Forty-six per cent of incidents reported involved rule-based errors. The aviation industry has addressed this type of error with comprehensive written check lists that pilots are compelled to use before and during flight. Nearly 15% of all incidents reported here involved divers who failed to do an adequate pre-dive equipment check, especially on their BCDs, primary and secondary regulators, and air supply. A comprehensive check list, which requires divers to tick boxes and to calculate the duration of their air supply prior to diving, would decrease the incidence of these errors.

Table 8
Diver qualifications, violations and stupidity
(more than 1 violation per incident in parenthesis)

Qualification	Number of incidents	(%)	Stupidity
Open water diver	43	(8)	6
Advanced diver	26	(6)	1
Divemaster	10	(0)	0
Dive instructor/leader	27	(6)	3
Dive student	3	(0)	0
Other/unknown	17	(2)	4

At least one skill-based error was identified in 259 (26%) reported incidents. Seventy-five per cent of these incidents were associated with morbidity or had the potential for causing harm. Commonly, these errors realated to improper use of a BCD's deflate and inflate buttons causing a consequent undesirable and rapid change in buoyancy.

Technical errors were identified in 13% of reported incidents. Techniques that the incident reporters thought to be inadequately taught were BCD use, ear equalisation, dive planning, the conduct of an adequate pre-dive check and shared-breathing ascents.

All types of error were reported in association with BCD use. Problems with BCDs are often associated with morbidity and mortality.[22–25] BCD use should be highlighted in training programmes and a thorough instructional programme should accompany the purchase or hiring of a particular BCD. Specific problems associated with BCD use, misuse and design have been reported in detail previously.[23]

Knowledge-based, rule-based and technical errors were made in the planning and conduct of dives to depths equal to or greater than 27 msw. Areas of particular concern were in the understanding of the decompression tables for determining any required decompression stops, and the calculation, checking and provision of any additional air supplies for these stops. These issues should be addressed by the recreational diver training organisations in their deep diving courses.

The frequency of problems associated with diving in a current, adverse surface conditions and ear-equalisation techniques is of concern as these are basic skills that should be acquired in basic training.

Medical fitness issues were emphasised in reported latent errors. Anxiety was the most frequently reported latent error and was a precursor to panic in many incidents. Poor physical fitness became evident with adverse environmental conditions, particularly swimming against a current. Medical fitness issues will not be discussed here. All incidents in which the reported diver was unwell prior to the initial dive resulted in morbidity (DCI, pulmonary and aural barotrauma). These data have both 'fitness-to-dive' and educational implications.

VIOLATIONS

The number of reports involving violations is disturbing. Unlike errors, violations are unpredictable and are not methodical or part of everyday cognitive function. No corrective strategies can be designed to prevent recurrence. If violations can be identified then educational and quality-assurance programmes may minimise them.

Nearly 40% of the violations occurred in incidents involving divers with only basic open water qualifications. However, of note was the high incidence (> 25%) of violations (including stupidity) involving dive instructors, dive leaders and divemasters (Table 8). These reported violations involved:

- placing a diver at risk by conducting a dive in a diving environment that exceeds his/her experience of a diver's ability due to ignorance;
- conducting a dive following a poor dive briefing;
- ignoring a diver underwater who is indicating that a problem exists with his/her air supply;
- dismissing a diver's symptoms post dive;
- sending an 'out-of-air' diver unaccompanied to the surface; and
- cave penetration knowing that the divers concerned had a depleted air supply or had faulty equipment but reassuring the divers that there was no need for concern.

Any violation involving dive instructors, dive leaders or divemasters could be addressed in part by targeted quality-assurance programmes.

Common causes of an out-of-air problem have been reported previously.[26] This paper, however, failed to address the continuation of a dive by an out-of-air diver by using a buddy's octopus regulator, which inevitably resulted in both divers having to do an emergency ascent when there was depletion of the donor's air supply. This violation could have been sub-categorised as 'stupidity' and disturbingly was frequently associated with dive instructors and dive leaders.

Diving without reference to a set of diving tables or a diving computer to depths greater than 15 msw was reported in both trained and untrained divers (56 reports received) and in many instances these dives were repetitive. Forty cases of DCI were recorded in these reports. Diving outside recommended recreational limits (Table 5) was a violation reported in five incidents (all involving trained divers); four of these resulted in DCI. These data have implications for educational programmes regarding decompression theory.

Specialised diving environments require additional essential equipment. However, a lack of:

- a guiding reel line in both cave and wreck diving in planned and unplanned penetrations;
- a boat watchout and surface-signalling devices in drift diving;
- a diving knife in kelp diving;
- a functioning torch in night diving; and
- a compressor attendant or a bailout bottle (in case of compressor failure) while using surface-supply (hookah) equipment

were all reported. These equipment violations can be addressed in part by specialised diving courses, thorough dive briefings and dive checks emphasising the requirement for additional equipment.

Continuing to dive with symptoms that developed after a previous dive was the second most common violation reported (Table 4). This was noted in cases of DCI, inner-ear, pulmonary and other aural barotrauma. Other violations reported, involving all qualifications, were diving without depth or content gauges, dive watch/timer, BCD or a functioning octopus regulator. Interestingly, these violations were not reported in untrained divers. Any violation categorised as stupidity (Table 7) deserves little discussion except to note that three (21%) of the 14 reported involved diving instructors (Table 8), which is of concern.

It is also of concern that untrained divers are still able to gain access to diving equipment, in particular a full air cylinder. In part, this may be due to the laxity of regulations governing 'air fills' in that divers must produce validation of their training before an air cylinder is filled.

In the context of human error and accidents these data compare favourably with similar data from surveys in anaesthesia practice, aviation and the nuclear-power industry, in that between 80 and 90% of serious incidents or accidents in systems where human beings interact with equipment are actually due to human error.[3,10,11,13] These data, however, compare unfavourably in the number of accidents caused by violations.

Conclusions

Errors associated with the use of a BCD and the adequacy of the air supply predominated. An instructional programme should accompany the purchase or hiring of a particular BCD and each dive should be preceded by a pre-dive air-supply check.

Knowledge-based errors could be eliminated by training programmes emphasising more thoroughly the problems of diving in a current, coping with rough surface conditions and ear-equalisation techniques. Additional training programmes are needed for divers who intend to perform dives to depths of 27 msw or greater. This is clearly recognised by the recreational diving industry with the provision of advanced and deep diving training courses and the depth limitations imposed on divers with varying levels of qualification and experience. Unfortunately, this approach is not routinely applied throughout the industry.

A significant improvement in safety could be obtained by reducing the frequency of 'rule-based' errors. A 'pre-dive' checklist should be developed which has to be read and each item checked before each dive. This pre-dive check should include an air-supply (depth and time) calculation. Such a check list on a waterproof card could be issued to all divers as part of their training package.

The violations of acceptable safe diving practice by diving instructors, dive leaders or experienced divers featuring in these reports are disturbing but should, at least in part, be addressed by quality-assurance and annual continuing educational programmes, such as those described by Nimb.[27] These programmes should be guided by analysis of incident reports (which would involve using the DIMS model of incident reporting).

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Chris Acott, MBBS, Dip DHM, FANZCA, is Physician in Charge Diving Medicine at the Hyperbaric Medicine Unit, Department of Anaesthesia and Intensive Care, Royal Adelaide Hospital, Adelaide, South Australia, and Coordinator of the Diving Incident Monitoring Study.

Address for correspondence:
Hyperbaric Medicine Unit, Royal Adelaide Hospital,
North Terrace,
Adelaide, SA 5001,
Australia.

Phone: *+61-(0)8-8222-5116*
Fax: *+61-(0)8-8232-4207*
E-mail: *<cacott@optusnet.com.au>*

Extreme breath-hold diving

In October 2004, a French freediver, Loic Leferme, achieved a new No Limits world freediving record with a 171 msw dive off Villefranche-sur-Mer, on the Cote d’Azur. Leferme took two minutes to descend to depth on a sled, and ascended using a lifting balloon. The dive took 3 min 40 sec.

In a recent talk, Carl Edmonds estimated the death rate amongst extreme breath-hold divers may be as high as one in 50. One suspects that, if something goes wrong on one of these dives, Dr Acott might put it firmly in his ‘stupidity’ category.

Nevertheless, the physiological changes occurring during these deep dives must be remarkable, but appear to have been little studied.

A longitudinal cohort study of UK divers with asthma: diving habits and asthma health issues

Peter Glanvill, Marguerite St Leger Dowse and Philip Bryson

Key words
Asthma, scuba diving, health surveillance

Abstract

(Glanvill P, St Leger Dowse M, Bryson P. A longitudinal cohort study of UK divers with asthma: diving habits and asthma health issues. *SPUMS J*. 2005; 35: 18-22.)
Few epidemiological studies have evaluated the safety issues relating to diving and asthma. This study followed a group of divers for a period of up to five years, observing the effect of asthma on their normal diving habits. Certified divers were recruited. Data gathered included demographics, diving history, and asthma history. Divers returned data annually. Diving practices considered to expose a diver to an increased risk of arterial gas embolism were evaluated. One hundred divers participated (68 male, 32 female), 30 being new to the sport at the start of the study. There were 12,697 dives reported during the study, with 43 respondents improving their diving grade. Twenty-eight had performed a free ascent, 37 had shared air at some time in their diving career, and 15 had performed both exercises. It is unknown if these activities were routine diving practice or emergency procedures. Twenty reported problems during diving activities, with 12 reporting wheezing underwater. One respondent reported two episodes of decompression illness, and a patent foramen ovale was subsequently confirmed. All 20 respondents reporting problems would have been excluded from diving using the UK guidelines, together with a further 40 who reported specific trigger factors. This study suggests that current UK guidelines with regard to diving and asthma, in this study group, are sufficiently restrictive.

Introduction

The subject of asthma and diving is a perennial topic of interest to diving physicians. There have been few studies to evaluate the impact of asthma on divers. In a survey of self-selected divers with asthma published in 1990 there was no evidence of an increased incidence of decompression illness (DCI) and no respondents reported significant problems with their diving, despite their diving practices often being contrary to the advice current at that time.[1] It was concluded that the standards applied to divers with asthma, wishing to dive in the UK, were reasonable. The work was criticised,[2] and as recently as 2002 it was observed "*there is little or no consensus on which, if any, asthmatics are safe to dive*".[3]

The aims of this study, therefore, were to follow a group of divers with asthma over a period of time and to observe their normal diving habits and histories to determine whether the United Kingdom Sport Diving Medical Committee (UKSDMC) guidelines are adequate. This paper details the results of that study.

Methods

The study was a longitudinal cohort study of UK divers with asthma. Recruitment of certified divers was made by direct contact during medical examinations for fitness to dive, by referral from other diving physicians, and via UK sport-diving magazines. Divers were asked to complete a questionnaire (based on the 1990 study)[1] annually for up to five years from the commencement of the study. The questionnaires were mailed annually to all participating divers with an accompanying explanatory letter and a stamped addressed envelope. Divers were included in the study if they had returned at least one of the five questionnaires. Contact was maintained where appropriate by telephone. Data requested included diving history (training organisation, diving grade, number of years' diving, total dives in diving career, annual number of dives and maximum depth dived), emergency diving practices (sharing air, free or emergency ascents), diving-related illness (decompression sickness, gas embolism, pneumothorax), and asthma history (age of onset, wheezing triggers and frequency, medication regime, and pre-dive medication management). No incentive was offered to participate in the project and respondents were free to withdraw at any time.

Data were processed by trained operators and entered into a Microsoft Access™ database. All the records were independently scrutinized and quality-assessment procedures followed with hard copy checked against data entry.

No statistical analyses were used in this study; the data are presented as recorded by the divers from fixed option responses. Some data were evaluated from free-form solicited text that related to defining any problems divers reported with asthma and diving, and are treated separately in the section 'Problems and additional information reported by solicited free text'.

A total of 100 respondents answered at least one questionnaire and were included in the study. All numbers can therefore be considered as percentages except where indicated in the text.

Definitions

'Still diving' should be read not as 'currently diving' but as an expression of enthusiasm to dive should the opportunity arise. 'No longer diving' should be read as including divers where no positive information is available, as well as those who have described reasons for ceasing to dive. Declarations of frequency of wheezing may not take into account the effect of prophylactic medication.

Results

AGE AND GENDER DISTRIBUTION

Between 1991 and 1995, 100 divers completed questionnaires suitable for analysis (68 male, 32 female). The median age of divers at the start of the study was 29.5 and the mean 30; ages ranged from 11 to 57.

DIVING HISTORY, GRADES AND PRACTICES

The number of dives reported by respondents over the study period was 12,697. At the start of the study they reported a previous history of 14,814 dives (Table 1:a). Thirty respondents were new to the sport at the start of the study and a further 19 had completed 20 dives or fewer. Experienced respondents, during the period of the study, averaged 34 dives per year, whilst newly qualified divers averaged nine dives per year over the same period. Fourteen reported having dived to 50 metres or more, with two respondents having dived to 62 metres. Number of years' diving ranged from 31 years to novice divers with one year's experience. Twenty reported 10 years or more of experience.

Diving grade was improved in 43 of the respondents (Table 1:b) with 14 of the respondents having attained the highest grades, e.g., instructor or advanced diver, prior to the start of the study.

Table 1
Diving history

a. Number of dives (n = 100)

Start of study	End of study	During study
14,814	27,511	12,697

b. Changes in diving grade (n = 100)

No change	Change	No data
55	43	2

c. Diving practices (n = 80)

Free ascent	Air share	Free ascent + air share
28	37	15

Diving practices that might be considered to expose a diver to an increased risk of arterial gas embolism (AGE) were evaluated. A free ascent was reported by 28, and 37 had shared air at some time during their diving career. Although it was not clear if these activities were part of routine diving practice or emergency procedures, it is most likely that they were elements of diver training. Fifteen reported that they had performed both exercises (Table 1:c).

ATTRITION

At the end of the study 60 respondents reported that they were still diving. Of those individuals who had stopped diving and reported a reason for doing so, nine reported unrelated medical problems, 15 reported social reasons including three who had had children, three specifically reported losing interest, and the remainder gave financial or social reasons. 'Drop out' rates of divers with asthma in this study after the first year were compared with the drop-out rates of the British Sub-Aqua Club (BSAC) data for the UK recreational diving population as a whole (personal communication, Mary Tetley, BSAC, 2001), and found to be similar; and were also comparable to those obtained in a study by Edge et al.[4]

ASTHMA PROFILES, PROPHYLAXIS, PREVENTION, PRE-DIVE MANAGEMENT

Seventy-six respondents had developed asthma in childhood and adolescence. The mean age of onset of asthma was 12.5 years, range 1–44 years. Most respondents reported more than one trigger factor causing them to wheeze and these are shown in Table 2 in descending order of frequency. At the end of the study, trigger factors in those still diving showed similar trends (Table 2). Fifty-five respondents described themselves as wheezing 'rarely', but 29 reported that they wheezed weekly or daily.

Asthma prophylaxis/prevention using inhaled steroids alone was practised by five respondents, but 37 relied on relief alone, another 50 used both a reliever and prophylaxis, and eight did not provide data. Of those individuals reporting pre-dive asthma management, none on prophylaxis/prevention alone used an inhaler before diving, whilst 16 of those using relief only used a pre-dive reliever, and 18 on dual therapy used a pre-dive reliever (Table 2).

PROBLEMS AND ADDITIONAL INFORMATION REPORTED BY SOLICITED FREE TEXT

One diver had reported dysbaric illness, experiencing two episodes of neurological decompression illness (DCI), both occurring during the course of the study. Interrogation of medical records revealed that in the opinion of the treating physicians paradoxical gas emboli secondary to right-to-left shunting through a large patent foramen ovale (PFO) was likely. A large PFO was later confirmed by contrast echocardiography. It should be noted that this diver rarely

Table 2
Trigger factors, pre-dive management and underwater wheezers (n = 100)

Trigger factors	Start of study	End of study
Exercise	60	35
Pollen	48	31
Cold air	47	29
Cold infections	45	24
Cold air and exercise	33	20
Emotion	29	15
Animals	26	17
Dust mites	26	19

Pre-dive management	
Reliever with preventer only	0
Reliever with reliever only	16
Reliever with preventer and reliever	18

Trigger factors	'Underwater wheezers'	Divers with 'problems'
Exercise	6	5
Pollen	6	1
Cold air	4	3
Cold air and exercise	4	3
Emotion	1	3
Dust mites	0	3
Animals	0	3

wheezed and that he reported his triggers as cold air and exercise; there were no signs and symptoms of asthma during the episodes of DCI.

Divers wheezing underwater numbered 12, with seven of this group reporting no problems when this happened. Of the remaining five, one diver reported wheezing to be a problem when commencing an ascent from 22 metres after a 17-minute dive, and on a latter dive in warm water to 12 metres. Two had aborted their dives when wheezing commenced. Two rested after they became wheezy then continued their dives. One related this to hard finning, which was also found to be a problem on the surface. One reported feeling anxious when this happened. The most common reported trigger in this group was exercise, followed by pollen, colds, cold air, emotion, and dust mites. Some respondents in this group reported multiple triggers.

Eight divers provided comments concerning difficulties when diving that they perceived to be related to their asthma. They did not report having wheezed underwater. Of this group, two divers reported difficulties snorkelling long distances in heavy seas, experiencing sensations of breathlessness if not wheezing. One did not dive in winter owing to cold air, and one expressed a preference for diving in warm water. One reported that asthma "affected his diving", though did not define this statement. One reported using air more quickly, and another had aborted dives after experiencing wheezing prior to diving, and had subsequently become wheezy after the aborted dive. Only one reported a problem if consuming alcohol the night before (pollen allergy was reported as the only trigger). This group, excluding the last respondent, reported a similar distribution of trigger factors to the group reporting having wheezed underwater (Table 2).

Five respondents, although reporting no specific problems with their asthma, had given up diving citing asthma in combination with other factors as the underlying reason.

Six respondents had each accumulated over a thousand dives, when taking into account dives logged at the start of the study and reported during the time of the project. Of these, three reported cold air as a trigger, three reported exercise as a trigger, and one respondent reported both as triggers. Four of this group used prophylactic and bronchodilator inhalers, and two used only bronchodilators. One respondent used a pre-dive bronchodilator. One respondent in this group had stopped diving due to an entirely unassociated illness. None of this group reported that they had wheezed underwater.

Seven respondents also provided comments to the effect that diving had had a beneficial effect on their asthma by reducing their need to use bronchodilators.

Discussion

This simple field study highlights the problems inherent in studying a group of recreational divers over a period of time. It was not possible to statistically analyse these data; divers on the study did not dive every year therefore did not always return consecutive year data. Social history (marital status, house moves and employment) further contributed to the difficulties in maintaining contact with respondents and accounted for attrition during the period of the study. In future studies, alternative methods of follow up, e.g., e-mail and text messaging through mobile phones, should be considered as well as increasing the number of participants to allow statistical analysis.

Diving practices vary and this has relevance to the period of time over which a diver gains experience. Diver training comes from a number of providers and this has made recreational diving more accessible to a wider population who have diverse health problems. Some individuals may dive rarely after their training, but any health risks relevant to diving will remain constant. The average number of dives per year for each diver was 25, although some performed far fewer dives and some many more.

Asthma appears to be on the increase in the general population. In the 1994–8 NHS UK study on asthma prevalence, rates of 5–6% in the 16–44 age group were reported.[5] In 2001 an audit by the National Asthma Campaign (in the UK) reported 1 in 13 adults (7.7%) were being treated for asthma.[6] This amounts to 5.1 million individuals as opposed to the 3.4 million reported in a previous audit. It is reported from New Zealand that 15% of adults aged 15–44 have a history of wheeze,[7] underlining the fact that this is an increasing issue of concern for diving medical practitioners worldwide.

The UKSDMC guidelines specifically exclude from diving those individuals with asthma that is precipitated by cold air, exercise, and emotion. Individuals with allergic asthma and normal pulmonary function who are well controlled by inhaled steroids are permitted to dive provided they do not need to regularly use a bronchodilator. The British Thoracic Society (BTS) guidelines published in 2003[8] are almost identical to the UKSDMC guidelines. The strict application of these criteria would have excluded at least 60 of the divers in our study, which may be considered by some to be excessively restrictive. However, there are insufficient data at present to identify clearly those most at risk. Most, if not all, respondents would have had medical examinations prior to diving, although not necessarily performed by diving medical physicians, and it is therefore unlikely that their self-reported diagnoses of asthma are inaccurate.

It is impossible to determine the accuracy of a diver's self-assessment of his or her precipitating factors. Anecdotal data suggest many asthmatics may believe themselves to be free of significant disease and will not declare their condition. Prospective divers may suspect that declaration of their asthma will result in automatic failure to pass a medical examination or cause them to require one. One respondent (a health professional) was concerned that data supplied should remain confidential in the event of the study pointing to a more proscriptive approach in the UK to divers with asthma.

Decompression illness (DCI) in this group was no more common than might be expected in the general diving population.[9–11] It could be argued there may have been too much emphasis on pulmonary barotrauma as a cause of morbidity in divers with asthma. A diver with asthma is likely to be as much at risk on the surface as underwater due to the potentially strenuous nature of the sport. It may be that varying forms of diving practice around the globe contribute to the variation in morbidity that appears to be represented in accident statistics. In support of this argument it is worth noting that although 12 divers reported wheezing underwater some of these specifically reported finning or snorkelling in heavy seas as a precipitant factor. A search of the literature suggests other diving physicians share this view.[12–14]

If medical referees submitted data from examination of prospective divers to a central database the establishment of a national database of divers with asthma would be feasible, and could allow follow up of both health and diving history. Divers would need to give consent at their first medical examination for data to be retained on such a database. A template for reporting divers with a history of asthma, who have been assessed by a diving medical physician, is now available.[8] Amendments to the British Hyperbaric Association database with regard to recording pre-existing morbidity would then allow cross reference, should any individuals present for treatment at a hyperbaric unit. In the proceedings of the SPUMS Annual Scientific Meeting 2001, Francis refers to the desirability of such a database.[15] Unfortunately, at the present time, not all hyperbaric units in the UK submit details of diver treatments to the BHA database. It is acknowledged that divers with asthma presenting at a chamber may not give detail of their medical history.

The authors hypothesise that variations in the reported morbidity of those diving with asthma in various parts of the world may also be related to the conditions under which training is undertaken. In Britain open water dives may be conducted at times of the year when ambient air and water temperatures are low, and it could be that some trainees either exclude themselves from diving under these conditions, or exercise considerable caution until they gain sufficient experience. Data obtained from the Swedish study may support this view, as asthma was not perceived to be a morbidity factor in this cohort.[16]

Medical referees in the UK are, for the most part, general practitioners who have undertaken diving medical courses; they are also required to be divers. Assessment of divers (trainee or qualified) with a possible history of asthma induced by exercise is practical in most GPs' surgeries, but bronchial challenges are less feasibly undertaken.[17,18] It is worth noting that some individuals in our study population reported that they found diving beneficial for their respiratory disease certainly with regard to breath control, and they submitted anecdotal evidence to support their observations.

This prospective study suggests that, despite diving often contrary to current medical advice, divers with asthma in this study did not report more episodes of physician-diagnosed DCI than would be expected.[9–11] However, data in our study should be treated with caution, as it was too small for definitive conclusions to be drawn. The findings also suggest that there is a risk of wheezing for divers with a history of asthma precipitated by cold air, exercise or emotion, and that this risk is present on the surface as well as underwater. With the incidence of asthma increasing, diving physicians are likely to receive an increasing number of inquiries from individuals who have a history of asthma and wish to learn to dive.

Conclusions

After consideration of the data available from this study it would seem reasonable to conclude that the risk to divers with well-controlled asthma and without the triggers of cold air, exercise or emotion is low. UKSDMC and BTS guidelines would have excluded all of the divers in the study who reported either wheezing underwater or problems on the surface.

The way forward to ensure that applicants with asthma who wish to dive are properly assessed currently exists in the UK. Self-assessment forms similar to the Recreational Scuba Diving Council self-declaration used by PADI now channel prospective divers for referral to diving physicians. There will, however, always be individuals who complete self-assessment forms omitting or misrepresenting relevant medical information, either deliberately or out of genuine ignorance as to the nature of their illness.

The authors acknowledge that a response bias may exist in the findings of this study. More physiologically based research may be required to provide definitive answers. However, the project provides useful information relating to asthma and diving, and gives a valuable insight into the impact of mild asthma, trigger factors, and the use of asthma medication in a reasonable population of fit asthmatics.

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Peter Glanvill, MB, BS, is a General Practitioner at the Springmead Surgery, Chard, Somerset, United Kingdom. Marguerite St Leger Dowse is a Research Coordinator and Philip Bryson, MRCGP, is Medical Director of the Diving Diseases Research Centre, Hyperbaric Medical Centre, Tamar Science Park, Plymouth, United Kingdom

Address for correspondence:
Peter Glanvill
Springmead Surgery,
Chard, TA20 2EW,
Somerset,
United Kingdom
Phone: *+44-(0)1460-63380*
Fax: *+44-(0)1460-66483*
E-mail: *<Pglanv@aol.com>*

Case report

Extreme survival: a serious technical diving accident

Barbara Trytko and Simon Mitchell

Key words
Decompression illness, technical diving, rebreathers/closed cicuit, hypercapnia, case reports

Abstract

(Trytko B, Mitchell S. Extreme survival: a serious technical diving accident. *SPUMS J*. 2005; 35: 23-7.)
A 34-year-old technical diver involved in a dive to 105 metres' sea water incorrectly assembled his rebreather and suffered carbon dioxide toxicity at depth. He developed anxiety, confusion and dyspnoea resulting in a rapid ascent with loss of consciousness. In the process, he omitted 51 minutes of decompression time. His subsequent presentation with life-threatening decompression illness and salt-water aspiration, and the management of these problems are discussed.

A note on terminology: *In this paper we follow Francis and Mitchell[1] in utilising the term 'decompression sickness' (DCS) to refer specifically to the consequences of bubble formation from dissolved inert gas, and the term 'decompression illness' (DCI) to refer to the broad spectrum of bubble-induced symptoms that may arise from DCS and arterial gas embolism.*

Introduction

Perhaps the most significant recent trend in recreational diving is the emergence of so-called 'technical diving' methods, adopted to extend underwater duration and/or to facilitate dives deeper than the conventional 'recreational limit' of 40 metres' sea water (msw). There is debate over which diving activities and methods qualify for the 'technical' sobriquet, but one proposal is that it includes diving that involves special techniques, decompression procedures and utilisation of gases other than air, or equipment other than single-cylinder, open-circuit scuba.[2] This definition embraces equipment applications such as multiple-cylinder configurations or rebreathers, and techniques such as decompression diving, nitrox and mixed-gas diving. Such diving requires additional training as well as significant investment in equipment and logistics. Technical divers often operate in hazardous, open ocean environments, and to depths previously encountered only in the context of commercial or military practice.

Clearly there are hazards associated with such activity. The decompression protocols utilised by deep technical divers can only be considered experimental and there is an undefined risk of DCS that may be significant even in dives that are conducted according to plan. Moreover, accurate calculations and obsessive attention to detail in the preparation of dive plans and equipment are essential. Mistakes will inevitably occur and may result in disaster in an environment that leaves little room for error. It seems inevitable that as technical diving becomes more prevalent we will see an increase in the number of divers with severe manifestations of DCS.

This paper describes a technical diving incident. We report this case because it is illustrative of some unique hazards of deep technical diving, and of the particularly severe DCI that diving physicians are likely to encounter more frequently in this group.

Case report

Diver X is a 34-year-old, experienced technical diver who had completed more than 2000 dives previously, including many to depths greater than 60 msw using mixed gases. Indeed, he is one of Australia's most experienced recreational mixed-gas divers. He was fit and had never suffered DCI.

Diver X was diving 10 kilometres offshore with three other divers and three support crew. The dive was to an irregularly contoured reef, with the depth varying between 95 and 110 msw according to the depth sounder. The plan was to spend 12 minutes at a maximum depth of 110 msw (including descent time) followed by staged decompression over 75 minutes.

Diver X was using a Biomarine Mark 15 closed-circuit rebreather (CCR). The diluent cylinder was filled with trimix 10/57 (10% oxygen, 57% helium, balance nitrogen) and the PO_2 setpoint was 130 kPa (1.3 ATA). In addition, he carried two 2.64 m^3 aluminium cylinders of 'bailout' gas in a sling arrangement. One contained air and the other nitrox 50 (50% oxygen, balance nitrogen). The system was set up for air to be introduced to the CCR loop as an alternative diluent so that nitrox could be used during decompression.

The divers were to enter the water staggered in two groups of two, with a five-minute interval between them. Diver X was the second diver of the first pair into the water and descended without difficulty to 105 msw via the anchor line. During the next three minutes at depth, Diver X was noted to adjust his rebreather. At approximately eight minutes he indicated to his buddy that there was a problem with his CCR but was otherwise well and began an ascent after communicating he was all right to do so without assistance. He later recalled feeling dyspnoeic and anxious. At this time the next pair was descending via the anchor line.

On initiation of his ascent, Diver X was observed by his buddy to appear calm and in control. The first diver of the next pair formed the same opinion after an exchange of signals at 80 msw. However, on passing the second diver of the second group, who was some 15 msw further up the anchor line, it was obvious that Diver X was having problems. He did not respond appropriately to signals and would not accept a bailout regulator when it was offered. The second diver aborted his descent and attempted to control his and Diver X's ascent toward the surface. Unfortunately, at 24 msw, the buoyancy of Diver X's drysuit and equipment made this difficult. In addition, the second diver was passing his decompression ceiling and the difficult decision was made to release Diver X for an uncontrolled buoyant ascent.

Diver X surfaced face down and unresponsive 20 metres from the boat and was seen immediately. He was retrieved onto the boat deck and was noted to be apnoeic, apparently pulseless and to have red froth at his mouth. CPR was commenced with 100% oxygen from an Oxy-Viva™. After 1½ minutes he regained consciousness and complained of dyspnoea and lower-limb paralysis. In a very fortunate sequence of events, the nearest aeromedevac service was both close to the site and in a high state of readiness. Approximately 20 minutes after surfacing Diver X was retrieved by helicopter to the emergency department of the nearest major teaching hospital where he arrived approximately 40 minutes after leaving the water.

On arrival he was receiving assistance with respiration from a paramedic on a Laerdal self-inflating resuscitation bag with 100% oxygen. He was otherwise alert and complaining of dyspnoea, severe back pain, numbness with paralysis below the level of his ribcage and progressive weakness of his arms and neck. A presumptive diagnosis of severe DCS with the 'chokes', probable pulmonary barotrauma, arterial gas embolism, and salt-water aspiration was made. On-call hyperbaric unit staff were contacted as the accident occurred outside of usual operational hours.

On examination he was noted to have marked cutis marmorata, tachypnoea, chest signs consistent with aspiration, sinus tachycardia of 152 on ECG, unpalpable peripheral pulses and lower-limb arreflexia with marked lower-limb weakness. A supine chest X-ray demonstrated increased interstitial markings consistent with aspiration, but no pneumothorax or mediastinal gas. Arterial blood gases showed a metabolic acidosis, severe haemoconcentration, and a coagulopathy (Table 1).

Table 1
Haematological and biochemical parameters on Day 1

Time	**1045**	**1245**	**1520**	**2140**
FiO_2	1.0	1.0	1.0	0.4
Intubated		@283 kPa	@283 kPa	
pH	7.24	7.20	7.26	7.29
PaO_2 mmHg	113	317	490	86.5
SBE mmol.l^{-1} (N -2.0–2.0)	-12.5	-7.5	-8.2	-6.9
Lactate mmol.l^{-1} (N 0.5–1.6)	5.0	3.1	1.7	3.3
Hb g.l^{-1} (N 115–165)	254	229	179	148
INR (N 0.8–1.1)	2.0			1.6
APTT secs (N 27–36)	105			51

FiO_2 – fractional inspired oxygen
SBE – standard base excess (37°C) at CO_2 = 40 mmHg
INR – international normalised ratio
APTT – activated partial thromboplastin time
N – normal range

Diver X's condition progressively deteriorated, the patient exhibiting increasing tachypnoea, dyspnoea and bulbar weakness at which point the decision was made to intubate. Ongoing resuscitation consisted of large volumes of crystalloid and colloid. One and a half litres of colloid and three litres of crystalloid were given in the first half hour. A lignocaine bolus of 1 mg/kg was administered soon after intravenous access was obtained and continued as an infusion of 4 mg/min for one hour and 2 mg/min for the next 47 hours. Arterial and central venous lines were inserted for haemodynamic monitoring and intermittent use of vasopressors. He was transferred for compression immediately the chamber was made operational.

Initial compression was to 283 kPa (2.8 ATA) – the maximum pressure capability at the facility – whilst ventilating with 100% oxygen. In view of the significant aspiration it was necessary to maintain sedation and paralysis for optimal ventilation. This prevented any assessment of clinical response to treatment, and a decision was therefore made to treat with an extended and modified US Navy treatment table 6 (Navy Department 1993). Two extensions were made at 283 kPa and the rate of ascent from 283 kPa to 192 kPa was halved with a stop at 242 kPa for five minutes. Total treatment time was six hours and 22 minutes. A further two and a half litres of colloid and three litres of saline were administered during the treatment. Endpoints for fluid resuscitation were haematocrit and urine output.

Following compression Diver X was transferred to the intensive care unit where further invasive haemodynamic monitoring, consisting of a peripherally inserted cardiac output monitoring device (PiCCO™), was instituted in view of continued instability. Haemodynamic parameters suggested fluid overload and significant capillary leak prompting the administration of diuretics with subsequent improvement and weaning of inotropic support.

As he stabilised sedation was withdrawn to assess neurological response. By late evening he was rousable to verbal stimuli and appeared to have regained all motor movement. He was extubated the next day and although requiring modest levels of inspired oxygen, he was otherwise normal on examination with no obvious neurological deficits. He remained in intensive care for a further 36 hours for monitoring while lignocaine was continued, and was treated with two further compressions to 242 kPa, for 90 minutes with 10-minute ascent time, on consecutive days in view of minor leg pain that was intermittent and cramping in nature. There was no evidence of other pathology.

Ongoing issues requiring a prolonged hospital stay were hypoxia secondary to aspiration and urinary retention. The hypoxia slowly resolved over the next five days and required no further treatment. Urinary retention was noted after discharge from intensive care when the first attempt at catheter removal was made. In view of a past history of urethral stricture he was reviewed by the urologists who performed various investigations and concluded a probable decompression-related aetiology.

Resolution of inability to void occurred over the next few weeks and required no further intervention although he has had urology follow up throughout. However, he has had ongoing problems with hesitancy, constipation and pain in the sacral distribution. These are improving with time. This is despite full clinical neurological assessment suggesting complete recovery otherwise. No further neurological investigations were performed at the time in view of clinical recovery and the perception that further management would not be altered by an abnormal result.

He was formally assessed and reviewed in the Department of Diving and Hyperbaric Medicine four weeks after being discharged, at which time he was advised against diving in future and to return if there were further issues.

Diver X has subsequently, over 12 months, made a full return to his professional life and, rather controversially, to technical diving also. He has completed greater than 50 mixed-gas dives (deepest 100 msw) since the accident with no problems so far as reported to the authors (personal communication, Diver X, December 2004).

Discussion

THE DIVE AND THE CAUSE OF THE ACCIDENT

This accident was subsequently concluded to have been caused by CO_2 toxicity. CO_2 toxicity is a recognized hazard of both open-circuit and rebreather diving, though in rebreather diving there are potential causes other than hypoventilation, which is the main contributor in open-circuit dives. Problems such as exhausted scrubber material, incorrectly packed scrubber canisters with ‘channelling’ of gas around the material, and over-breathing the scrubber with consequent ‘breakthrough’ of unscrubbed CO_2 are all potential causes. CO_2 toxicity produces dyspnoea and headache early; and delirium, reduced consciousness, and finally unconsciousness as levels rise.[3]

In Diver X’s case, the cause was idiosyncratic to his particular CCR. Assembly of the Mk15 rebreather prior to each use includes folding a rubber flange into place on the CO_2 scrubber–counterlung assembly known as the ‘centre section’. This flange establishes the gas flow path through the CO_2 scrubber. If it is not correctly placed the flow may bypass the scrubber allowing CO_2 to build to toxic levels. Diver X had not folded the flange correctly during his preparations for this dive.

It is interesting that Diver X did not notice any problems until he reached the bottom at 105 msw. There are several potential reasons for this. First, it is usually recommended, but not universally practised, that a rebreather is breathed for five minutes prior to entering the water in order to unmask any problems such as the one described above. He did not conduct a significant pre-breathe at the surface prior to the dive. Second, the long descent on a deep dive involves significant physical exertion and any dyspnoea would almost certainly be attributed to that. Third, during a descent to 100 msw (1,114.3 kPa, 11 ATA) the CCR would have added 11 times the surface counterlung volume of uncontaminated diluent gas to the loop. This would have helped dilute the CO_2; an advantage that would have abruptly ceased on arrival at the bottom.

It is also notable that Diver X did not switch to open-circuit bailout when it became obvious to him that there must be a problem with the breathing gas in his CCR loop. In this regard, he even refused the assisting diver’s offer of an open-circuit regulator. In reflecting on this later, Diver X observed that he felt so short of breath that he perceived he would drown if the CCR mouthpiece was removed, and he could not bring himself to do it. This is an important observation. Many CCR divers carry open-circuit bailout whose use will require a mouthpiece swap, and Diver X’s experience suggests that assumptions about the ease of such swaps under circumstances of CO_2 toxicity may be flawed. This forms a strong argument for the use of combined rebreather/open-circuit mouthpieces where activation of a lever or similar can effect the swap without the mouthpiece being removed. For completeness, it must be noted that Diver X acknowledges air to be an inappropriate choice of bailout gas for this very deep dive, though he maintains that this was not a factor in his failure to use it.

SEVERITY OF DCI AND ITS TREATMENT

Cases of severe multisystem DCI like this are rare. Although haematologic changes such as haemoconcentration and coagulopathy are reported from animal models of severe DCS, it is unusual to see these phenomena in humans.[4] Nevertheless, the severity of Diver X's case is not surprising given the circumstances of the dive. For an eight-minute bottom time at 105 msw, and utilising the gases specified earlier, the Proplanner™ decompression planner prescribes the decompression algorithm in Table 2. Even if we assume Diver X's ascent was conducted at the correct rate (9 m/min), it is obvious that he has omitted a very significant decompression obligation. Such situations do not arise in mainstream recreational diving, and it does seem likely that the increasing number of deep technical divers (and dives) will result in increasing numbers of similar cases.

Diver X enjoyed a remarkable recovery from very severe, progressive, multisystem DCI whose natural history untreated was probably towards death or permanent disability. It can therefore be surmised that his treatment was appropriate. Whilst it is impossible to draw conclusions about the efficacy of individual components of that treatment regimen, it is reasonable to at least speculate on the potential benefits of some of the circumstances and therapeutic strategies.

Table 2
Decompression for dive to 105 msw for 8 minutes prescribed by the Proplanner™ decompression calculator (nominal safety factor setting, PO_2 setpoint = 1.3). Ascent to the first stop and between stops is at 9 msw.min^{-1}. Travel time is in addition to the stop times shown

Stop depth (m)	Stop time (min)	Gas management
69	2	Diluent = trimix 10/57
51	2	Diluent = trimix 10/57
42	2	Diluent = trimix 10/57
33	1	Diluent = trimix 10/57
30	1	Change diluent to air
27	1	Diluent = air
24	1	Diluent = air
21	1	Diluent = air
18	1	Diluent = air
15	1	Diluent = air
12	3	Diluent = air
9	7	Diluent = air
6	4	Flush loop with 100% oxygen
4.5	24	100% oxygen
Total	**51**	

The contribution of Diver X's rapid evacuation to a definitive treatment facility cannot be underestimated. A longer evacuation or management at a lower-level facility without intensive care expertise may well have had disastrous consequences in this case in view of the requirement for endotracheal intubation and mechanical ventilation, invasive haemodynamic monitoring, serial haematological investigations, vasopressor support, and aggressive fluid resuscitation in order to stabilise him for recompression treatment. Such intervention is not available at many hyperbaric facilities. This, of course, is not to say that seriously ill DCI patients should not be managed at lower-level hyperbaric units in the absence of more comprehensive facilities. However, recompression of itself is not likely to stabilise the physiological derangements apparent 40 minutes after surfacing in Diver X's case, and outcome in such cases is likely to be poor if comprehensive care is not available.

The optimum recompression treatment for life-threatening multisystem DCI following massive omitted decompression is not known. Perhaps the only claim that can be made with some confidence is that it should occur as soon as possible, but even that is not (and probably never will be) definitively proven. Arguments can be made for and against the use of deep recompression treatments and heliox mixtures.[5] At the present time neither of these options are well supported by data, and the US Navy table 6 (involving administration of oxygen at 280 kPa) is the mainstay of treatment for more severe DCI.[5] In the present case, where treatment pressure was limited to 280 kPa and the only available treatment gas was oxygen, a table 6 was the logical choice. The table 6 was extended in a conventional fashion,[6] in keeping with the severity of the presentation and the inability to monitor clinical progress in a sedated, intubated and ventilated patient. The reduction of the treatment table ascent rate was imposed in view of anecdotal reports of deterioration during ascent in other cases that followed massive omitted decompression.[7]

The rationale for the use of lignocaine in the treatment algorithm is well described elsewhere.[8] Although use in DCS (arising from bubble formation in tissues or venous blood as distinct from arterial gas embolism) is speculative at best, this does receive qualified support from the UHMS Adjuvant Treatments Committee.[9]

Conclusions

As with many illnesses, prevention of DCS is better than cure. It is important that divers who are pushing technical diving boundaries are well trained, highly disciplined and vigilant to minimise the incidence of these episodes. Although the evolution of technical diving equipment may reduce failures and errors over time, there is risk of error in any system in which humans are involved. To reduce this possibility, technical diving training agencies should place great emphasis on maintenance of high course standards, and the impeccable credentials of their instructors.

As technical diving gains popularity and acceptance it behooves us as clinicians to be prepared to treat life-threatening DCI with a broad armamentarium of clinical interventions. This includes aggressive resuscitation in the initial presentation. There are some locations with on-site chambers and those who would argue that the best treatment for this condition is immediate recompression, but this option is not usually available. However, during a progressively deteriorating and life-threatening presentation, as in this case, compression alone is unlikely to be adequate and needs to be supplemented by scrupulous management of the 'ABCs'. It is imperative that this initial management be expeditiously instituted, before the initial compression if necessary.

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Barbara Trytko, FANZCA, FFICANZCA, DipDHM, is a Consultant in the Intensive Care and Diving and Hyperbaric Medicine Units at the Prince of Wales Hospital, Randwick,Australia.
Simon Mitchell, MB ChB, DipDHM, DipOccMed, PhD, is a Consultant in Diving and Hyperbaric Medicine at the Royal New Zealand Navy Hospital, Auckland, New Zealand.

Address for correspondence:
Department of Diving and Hyperbaric Medicine,
The Prince of Wales Hospital, Barker Street,
Randwick NSW 2031,
Australia.
Phone: *+61-(0)2-9382-3883*
Fax: *+61-(0)2-9382-3882*
E-mail: *<trytkob@sesahs.nsw.gov.au>*

Review article

Development and testing of deterministic and probabilistic decompression models

David J Doolette

Key words
Decompression, models, diving theory, review article

Abstract

(Doolette D. Development and testing of deterministic and probabilistic decompression models. *SPUMS J*. 2005; 35: 28-31.)
Decompression models link the probability of decompression sickness (pDCS) to an index of decompression stress calculated from the depth/time/breathing-gas history of a dive. Decompression models developed and tested on the basis of experimental dives can then be used to predict the outcome of future, similar dives and, therefore, be used to produce decompression schedules. Deterministic decompression models categorise decompression schedules as either having a low pDCS ('safe') or not ('unsafe'). Probabilistic models define a unique pDCS for any dive. The methods for calculating decompression stress can be similar in the two types of models. These two model types are the result of different development and testing philosophies.

Introduction

Decompression sickness (DCS) is a disease caused by bubble formation from excess dissolved gas upon reduction in ambient pressure (decompression). Most readers will be familiar with the well-known beer-bottle analogy of DCS. The pressure inside an unopened bottle of beer is higher than the normal ambient pressure outside, and the beer (body tissues) contains a high concentration of dissolved carbon dioxide in equilibrium with a high partial pressure of carbon dioxide (nitrogen or other inert gas) in the gas space (lungs). The pressure inside the bottle is released by removing the cap (decompression) and the beer becomes supersaturated – the condition where the dissolved gas pressure (concentration/solubility) exceeds ambient pressure. Gas is released from the beer as bubbles. This beer-bottle analogy of DCS is a model; a simplified description of a complex system that helps conceptualisation.

The purpose of this paper is to define decompression models, to explain some terminology found in the scientific literature relating to decompression models, and to examine these in the broader context of models in general. Subsequently, this paper will examine how decompression models are developed and tested.

What is a model?

A model is a description of observed behaviour, simplified by ignoring certain details. Models allow complex systems to be understood and their behaviour predicted within the scope of the model but may give incorrect descriptions and predictions for situations outside the realm of their intended use.[1] The beer-bottle analogy is an analogue model whereby a complex system is modelled using a simple physical system. Models are commonly mathematical where the complex system is modelled using a set of equations. Often these models can be visualised as curves or surfaces that relate, for instance, independent variables (input) to dependent variables (output).

What is a decompression model?

An example of this is a simple decompression model, which links the probability of DCS (pDCS) to an index of decompression stress (Figure 1). Goats were compressed on air to different ambient pressures (x-axis), held for usually four hours, then decompressed more or less directly to one atmosphere absolute.[2] The pDCS, estimated from the relative frequency of signs of DCS, in groups of goats exposed to each pressure is plotted as circles. These data can be well described by a sigmoid curve (model) shown in Figure 1 produced by the risk function:

$$pDCS = 1\text{-}\exp(-0.00034atm\text{^}5.65)$$

This component of a decompression model is empirical, the linking function (curve) is chosen by inspection and expectation of the shape of the data. The shape of curve represents some unknown and unmeasured underlying physiological processes. Whereas this risk function is appropriate for decompression data, other types of data have different shapes. Readers might be more familiar with straight-line relationships or the slightly different-shaped sigmoid curve characteristic of dose-response relationships in pharmacology.

Figure 1
The probability of decompression sickness, pDCS (filled circles, estimated from the relative frequency of DCS), in goats for near-saturation dives followed by rapid decompression. 'Probabilistic' model with risk function fit to the data

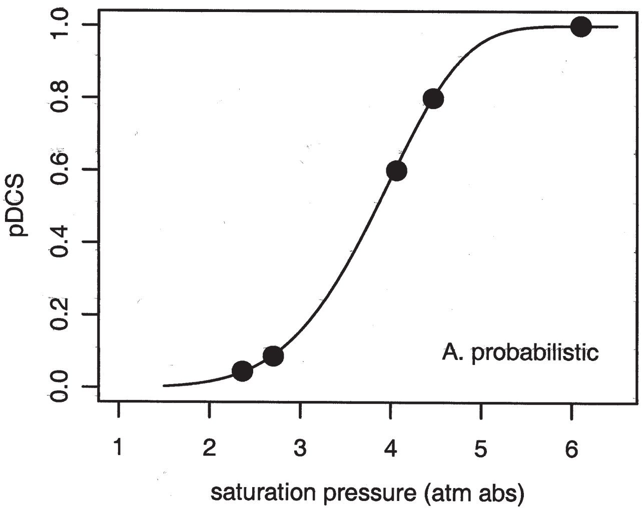
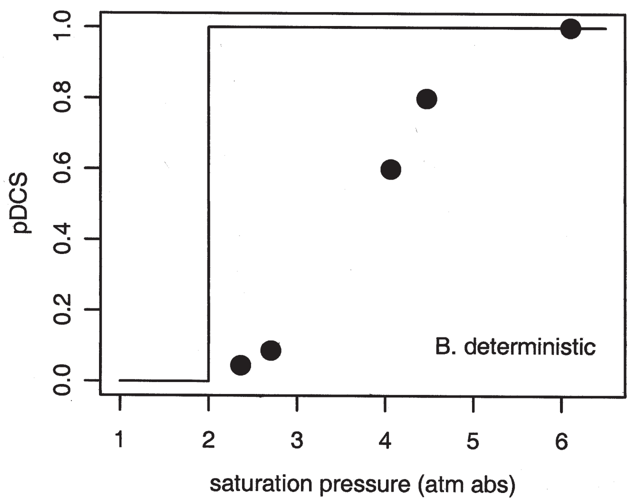


Figure 2
'Deterministic' model with threshold set arbitrarily at a low decompression stress



The parameters that provide the linking function of best fit in Figure 1 (0.0034 and 5.65) were found by a mathematical procedure, called 'least-squares' regression, which minimises the sum of the squared distances between each data point and the curve (unexplained random variation). This procedure is simple but has strict requirements of the data. A more general procedure is to maximise the product of the likelihood of each data point being the resulting distance from the model ('maximum likelihood' regression). For the frequency data in Figure 1 the result would be the same; however, the maximum likelihood method, but not least squares, is appropriate for modelling data with a binary outcome such as DCS or no DCS.

The value of a model is that it can be used to make educated guesses about similar systems. The model in Figure 1 is a statistical model because the probability of an event, in this case DCS for other similar dives, is inferred by taking a limited number of samples. Useful decompression models also have a mechanistic (not statistical) component, which is the method of calculating decompression stress. Decompression stress is typically some notional value of tissue supersaturation or bubble volume calculated from the depth/time/breathing-gas history of the dive using a model of known or assumed behaviour of gas in tissues.

This mechanistic component can take many forms and will not be dealt with in detail in this paper. In Figure 1, depth of the exposure is an approximate index of decompression stress (x-axis). The mechanistic model underlying this is that all tissue dissolved-gas pressures would have reached near equilibrium with inspired air during the long exposure and changed very little during the rapid decompression to one atmosphere absolute, so that the resulting tissue supersaturation is therefore proportional to the exposure depth. More widely applicable decompression models have a mechanistic component that can calculate decompression stress from the depth/time/breathing-gas history for dives of any complexity.

Probabilistic and deterministic decompression models

In decompression modelling jargon, the model depicted in Figure 1 is a 'probabilistic' decompression model because it links decompression stress to pDCS via a smooth risk function. Figure 2 shows a 'deterministic' decompression model. In a deterministic model there is a threshold decompression stress that separates dives with and without DCS. Decompression modelling jargon aside, a statistical model of the form in Figure 2 could link decompression stress to DCS via a Heaviside step function (a discontinuous function that takes values of zero or one) that sets pDCS = 0 below and pDCS = 1 above a threshold decompression stress that could be found by best fit to the data (and would be further to the right in Figure 2). In practice, and in Figure 2, the threshold decompression stress for a deterministic model is placed arbitrarily at a value resulting in low pDCS. Decompression schedules can be produced directly from deterministic decompression models. A probabilistic model must be converted to a deterministic model by selection of an acceptable pDCS before it can be used to produce decompression schedules.

Although the preceding description highlights the similarity between probabilistic and deterministic decompression models, practical models often have subtle differences in the methods of calculating decompression stress. In both Figures 1 and 2, decompression stress was proportional to the maximum supersaturation and this, or, similarly, maximum bubble volume, is characteristic of deterministic models. In probabilistic models the decompression stress is often the integral of supersaturation or bubble volume over some defined interval of time from the beginning of decompression. For instance, a similar decompression stress could result from a brief period of high supersaturation (such as following a brief, deep dive) or a sustained period of low supersaturation (such as following a long, shallow dive). Another difference between probabilistic and deterministic decompression models is that they usually result from different development and testing philosophies.

Model development and testing

Deterministic decompression models are primarily a means of producing decompression schedules and organising experience with decompression schedule outcomes. Deterministic decompression models have generally been developed *a priori* based on knowledge and assumptions, and then selected decompression schedules produced by the model are tested. If the results of schedule testing are not acceptable the model is modified and new schedules produced and tested. For instance, the model on which the 1957 US Navy standard air tables were produced is based on the original 1908 model of Haldane and colleagues but with incremental modifications made during approximately 2,000 test dives. The 1957 tables were promulgated after a series of 600 test dives where selected schedules were accepted if they had no DCS in four test dives.[3,4] In this sort of model development, the modifications to the mechanistic component of the model are made informally, based on the developers' instincts and knowledge of schedule-testing outcomes.

The ultimate utility of probabilistic models is to produce decompression schedules, but development focuses on the model rather than the schedules. Model development is mathematically formalised for probabilistic models. The structure of the mechanistic component is developed *a priori*, but the parameters of this part of the model are determined *a posteriori* by best fit of the decompression model to already available decompression data. In some cases, rather than testing schedules generated by the model of best fit, the model itself is validated via successful prediction of the outcomes of another set of decompression data.

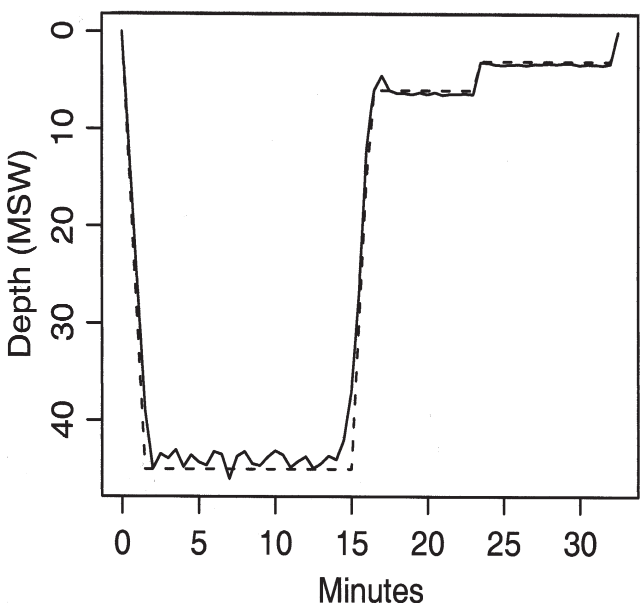
The requirements for decompression data for probabilistic modelling are a large number of dives with well-defined pressure/time/breathing-gas history and outcome such as DCS or no DCS. The dives in the database used to train the decompression model should be similar to the intended use of the calibrated model. For instance, a database comprising heliox and surface decompression dives would be unsuitable to calibrate a model for air diving with in-water decompression. If the new model is for a type of diving that is not well represented in the decompression database, traditional test trials of schedules are required. These dives can be added to the database for future use and recalibration of the model. One of the primary sources of data for air and nitrox diving is the US Navy database.[5] This database contains over 8,000 well-documented dives with an approximate 5% rate of DCS collected from previous decompression trials from several laboratories. Unlike traditional schedule testing, for probabilistic modelling there is no requirement for dives to follow a specified format or be repeated, so data can be collected from the field. Some recent well-documented US Navy operational dives will be added to the US Navy database (Gerth, personal communication, 2004). Divers Alert Network is collecting field data from recreational divers that are suitable for probabilistic modelling, and to date approximately 102,000 dives have been collected, although the incidence of DCS is low.[6]

The probabilistic-model approach to testing and validation has several advantages compared with the deterministic approach. First, as noted above, there is not always a need for a specific testing programme for probabilistic modelling, as existing or operational data can be used.

Second, in the deterministic approach, testing individual schedules results in broad binomial confidence intervals for pDCS. For instance, the 95% confidence interval for pDCS for any particular schedule from the USN 1957 standard air tables accepted following four DCS-free dives is 0–0.6. It is now more common to use a larger number of dives per schedule to narrow this confidence interval, for instance zero DCS in 20 dives has pDCS 95% confidence interval of 0–0.17. Considerable economy can be achieved by using well-designed sequential trials but large testing programmes are necessary.[7] In the probabilistic approach different schedules do not have to be analysed separately.

Third, the deterministic approach results in a more subtle loss of information compared with the probabilistic approach. Figure 3 shows a decompression schedule (dashed) and an

Figure 3. Dive profile (solid line) and decompression schedule (dashed line). See text for explanation



actual dive profile (solid). In the first instance assume, reasonably, that this dive did not result in DCS. In a probabilistic approach the very minor depth violations of the schedule during the bottom phase and at the first decompression stop would result in a small increase of the pDCS. In the deterministic approach, this dive would have to be considered 'unsafe' despite having a low pDCS and would, therefore, contaminate the data. Finally, in the probabilistic approach the time of symptom onset can be used as information to input to the model since the time course of decompression stress is followed. Consider the pDCS with symptom onset 10 minutes or alternatively 10 hours following the dive in Figure 3. To use time of symptom onset, the decompression stress and pDCS are calculated for successive intervals of time from the beginning of decompression. In the example dive, the decompression stress would be highest during and soon after decompression so pDCS would be higher for an interval including 10 minutes than for an interval including 10 hours following diving. This information is typically lost in the deterministic approach.

Summary

Decompression models can be broken down into a biophysical component that calculates decompression stress from the depth/time/breathing-gas history of a dive and a function that links decompression stress to an outcome such as DCS. Probabilistic and deterministic models can have similar biophysical components but differ in how they link decompression stress to outcome. Probabilistic models are powerful tools for model development and validation but must be converted into a deterministic format for production of decompression schedules.

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David Doolette, PhD, was a guest speaker at the SPUMS Annual Scientific Meeting in Noumea in 2004. This paper is based on presentations he gave at that meeting.
Visiting Research Fellow,
The University of Adelaide,
Adelaide, SA 5000, Australia
Phone: *+61-(0)8-8303-6382*
Fax: *+61-(0)8-8303-3909*
E-mail: *<David.Doolette@adelaide.edu.au>*

David Smart, Robyn Walker, Mike Davis, Cathy Meehan and Andrew Patterson at the Committee Meeting, Sydney, October 2004

SPUMS Annual Scientific Meeting 2003

Abstract

Neurobehavioural changes from no-decompression diving among Royal Malaysian Navy divers

Halim Mohammed

(Mohammed H. Neurobehavioural changes from no-decompression diving among Royal Malaysian Navy divers. *SPUMS J* 2005; 35: 32. **Abstract only**)

Introduction: The possibility that occupational diving may cause long-term neurological injury is a topic of continued debate. Although diving can lead to damage of the central nervous system (CNS) when accompanied by serious decompression illness (DCI), there is yet no strong evidence of long-term neurological damage among those who dive within the ‘safe’ no-decompression limits without episodes of DCI. However, there have been studies implying that even these uneventful and conservative dives may result in subtle neurological deficits.

Objective: To study the neurobehavioural changes occurring after an eight-week period of repeated no-decompression diving, in a cohort of 35 trainee divers of the Royal Malaysian Navy.

Subjects and methods: Thirty-five trainee divers of the Royal Malaysian Navy (RMN), aged between 20 and 28 years old volunteered to participate in this study. The World Health Organisation Neurobehavioural Core Test Battery (WHO-NCTB) was employed to assess the neurobehavioural status of the trainee divers before and after an eight-week period of repeated no-decompression dives. The WHO-NCTB tests administered were the Digit Symbol, Benton Visual Retention, Pursuit Aiming, Santa Ana Manual Dexterity and Simple Reaction time. The test scores obtained before and after dive exposures were compared.

Results: We found the WHO-NCTB to be well suited as a simple and objective assessment of the neurobehavioural status of divers. Twenty-six divers completed the study with an average of 22.4 hours of incident-free no-decompression diving per subject. Although a majority of the trainee divers had minor subjective symptoms after completing the training, they performed significantly better in the Digit Span ($P < 0.01$) and Santa Ana Manual Dexterity tests ($P < 0.01$) while showing no statistically significant changes in Simple Reaction Time, Digit Symbol, Benton Visual Retention, Pursuit Aiming, and Grooved Peg Board tests ($P > 0.05$). They performed worse post dive in the Finger Tapping test, though this was only significant for the non-dominant hand ($P < 0.05$). No correlation was found between dive exposure and the change in neurobehavioural test scores ($r = 0.47$).

Conclusion: We conclude that the eight-week duration of repeated no-decompression diving during dive training did not seem to affect the tested neurobehavioural function of the trainee divers.

Dr Halim Mohammed is the Director of the
Institute of Underwater and Hyperbaric Medicine
Armed Forces Hospital, RMN Base
32100 Lumut, Perak, Malaysia
Phone: *+60-5-930-4071*
Fax: *+60-5-683-7169*
E-mail: *<drhalimm@tm.net.my>*

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Psychology, performance, diving, abstracts, meetings

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Surf Life Saving Australia

Peter J Fenner

Key words
Drowning, rescue, resuscitation, first aid, history, review article, general interest

Abstract

(Fenner PJ. Surf Life Saving Australia. *SPUMS J*. 2005; 35: 33-43.)
Surf Life Saving Australia (SLSA) is one of the greatest voluntary organisations in the world. Over almost a century, nearly half a million rescues have been performed. Currently some 22,000 volunteers patrol the Australian surf beaches each weekend. In recent years a professional arm was also introduced to SLSA, where lifeguards patrol the beach every day. SLSA members are expert at rescue and resuscitation of drowning victims, with results that are better than any other published figures. This standard is achieved by comprehensive training, annual examination updates, and by the use of some of the best rescue equipment available. To keep surf lifesavers fit for their task, they are encouraged to enter and train for competitive events that are held at all levels of the organisation right to the national Surf Life Saving Championships, the largest annual sporting event in Australia; an event needing major first-aid and medical coverage to reduce injury morbidity.

Introduction

Volunteer members of Surf Life Saving Australia (SLSA) have been patrolling surf beaches in Australia for almost a hundred years. HRH Prince Philip, Patron of Surf Life Saving Australia, has described the organisation as "*one of the greatest humanitarian organisations in the world*".

There are currently some 22,000 active volunteer surf lifesavers throughout Australia patrolling many popular beaches Australia-wide. These patrol areas are set up in sections of the beach where the surf is as safe as possible, and are delineated by red and yellow patrol flags placed at each end. The public are then encouraged to swim in these protected, patrolled areas, carefully watched by lifesavers to ensure their safety. These volunteers have been singularly successful, with no-one drowning between the flags since SLSA was founded in 1906.

Surf lifesavers must be a minimum of 15 years old, be competent swimmers and have skills in rescue, resuscitation and first aid. This is achieved by a minimum time of 20 hours' intensive training. They then undertake a written and practical examination, to ensure their skills are of sufficiently high standard. If they pass they are awarded their Bronze Medallion, which qualifies them to voluntarily patrol a beach. SLSA is probably the only organisation in the world where 15-year-olds on patrol regularly place their own life at risk, to be able to save others.

The syllabus for the Bronze Medallion includes knowledge of the surf; local council laws for beaches; and first aid to a basic first-aid-certificate standard with particular emphasis on marine envenomation, as stings (mainly *Physalia sp*. – the 'Bluebottle') are the most common requirement for first-aid treatment in surf life saving. The resuscitation training includes both one- and two-person resuscitation, for children and adults, as lifesavers usually operate in a team situation. This standard must then be updated and examined every year. At the age of 16 years, members are encouraged to proceed to advanced resuscitation, when oxygen provision via bag/valve/mask is introduced. Oxygen use and storage is very safe, with no problems or incidents in SLSA use.

Surf lifesavers' skills and success rates in resuscitating people are legendary, with the best published statistics in the world for successful rescues and resuscitation.[1,2] This high success rate is achieved and maintained by regular skill updates each year, all to the same standard as the original Bronze Medallion exam. This yearly proficiency test must be completed satisfactorily before a surf lifesaver can start the new season on patrol.

The organisation is continually assessing new equipment for its efficiency, and to ensure it is 'user friendly'. If it passes this stringent testing, it is introduced, making SLSA one of the best-equipped surf-rescue associations in the world.

Surf lifesavers' strength, skill and knowledge of the surf are sharpened by regular competition and training in all grades; from inter-club competition, through state and national championships, and even to international competition, where Australian surf lifesavers have been exceptionally successful over many years.

Origins of surf life saving

In 1902 it was still against the law to enter the ocean during daylight hours in Australia! Then William Gocher, the editor of a local Sydney paper, announced he was going to swim at Manly Beach to challenge this law. There were crowds to see him enter the water and when police failed to charge him, similar action by many local residents forced a change in the law, and people were allowed free access to enter the ocean. Unfortunately, with the usual surf conditions, together with the inexperience of most bathers in this environment, many were caught in rips (see below) or knocked over by waves and drowned. To counter this, groups of volunteers 'patrolled' the beach to watch for those in trouble. From this group of volunteers the Bondi Beach Surf Bathing Association was formed in 1906 and this was the basis for the development of Australian surf life saving clubs and the Surf Life Saving Association of Australia, now known as Surf Life Saving Australia (SLSA).

Surf lifesavers/lifeguards

There is often confusion about the definition or description of lifesavers and lifeguards. In Australia, surf lifesavers are volunteers, who patrol the beaches whenever possible, although usually just the weekends. Surf lifeguards are the professional arm of Surf Life Saving Australia whose occupation is patrolling the beach. They may provide a beach presence all day, up to seven days a week, although volunteer lifesavers often cover or assist in the weekend duties. The presence of some lifeguards may be seasonal, varying with the weather, beach visitations (much higher in school holidays) and the various coastal local councils.

Surf patrols

Most patrols consist of a minimum of three lifesavers, but often there are six, based in the area between the patrol flags. The flags, contrary to popular belief, are placed as far apart as possible, providing an area that the patrolling lifesavers can cover safely, but between any dangers, such as rips or sandbanks.

In surf conditions, particularly with breaking waves, large amounts of water are driven to shore, which must then return out to sea. This 'extra' volume of water usually travels sideways along a beach (a 'side sweep') and at certain points where sweeps meet from both directions, large volumes of water are swiftly carried out to sea. This body of dangerous seagoing water is referred to as a 'rip' (Figure 1). Frequently on either side of the rip is a sandbank just under the surface of the water. Swimmers often find themselves being carried sideways in a sweep, and then rapidly propelled out to sea. A 'rip' is referred to as an 'undertow' in some countries.

A good patrol captain will space his team for maximum efficiency: one lifesaver is usually stationed in an elevated tower, one in the central enclosure set up on the beach, where equipment such as portable oxygen and first-aid supplies are stationed, and at least one lifesaver is down at the water's edge, equipped with a rescue tube ready for instant rescue. Rescue boards are usually available at specific locations, ready for immediate use. Often this location is at the middle and each end of the patrol area, alongside the flags, so that they are quickly available for use, both inside and outside the flags.

Patrols frequently have a mobile unit roving along the beach to try to keep watch on swimmers outside the flags. This unit may be an inshore rescue boat (IRB or 'rubber duck', Figure 2), a personalised watercraft (PWC, Figure 3), or a four-wheeled bike. All carry life-saving equipment for easy transport to areas outside the patrolled area.

An innovation in the last few years, to extend the efficient scanning of long stretches of beach, or beaches away from the patrolled area, has been the installation of video cameras. These have been placed on top of some of the taller buildings on the Gold Coast, giving them excellent coverage of a large area; they are proving to be very effective, checking for potential or current problems. A trained console operator watches a screen and can direct the cameras in most directions, and even zoom in to areas where more detail may be required. The closest surf lifesavers can then be directed by radio to any area of concern.

Surf rescues

At the end of the 2003–2004 season (May), some 484,000 people had been rescued since Surf Life Saving Australia first started in 1906: an amazing figure. In 2006, now dedicated as the Year of the Lifesaver and the centenary of the SLSA organisation, this figure may be up around the 500,000 mark.

During the 2002–2003 season (September–May), a typical season, there were 9,448 rescues. These rescues are achieved in a number of ways and using various types of equipment and are described in descending count of rescues.

Figure 1
A 'rip' on a surf beach; large volumes of water are swiftly carried out to sea in the central, calmer area

RESCUE TUBE (Figure 4) – 1,957 rescues

The tube is towed behind the rescuer, who wears swim fins to swim faster and to assist with a stronger kick for the rescue. On reaching the victim, the tube is then wrapped around the victim underneath their arms to support them. They can either be towed back to shore, or supported until further help is available. Despite requiring considerable skill, a victim can even be given expired air resuscitation (EAR) in deep water, using the mouth-to-nose method, thus preventing water entering the airway.

IRB (Figure 2) – 1,947 rescues

The craft is quick and highly manoeuvrable, and is currently regarded as the most useful tool for rescues in the surf. Although an IRB is a very efficient and popular craft, many crew injuries also occur from their high speed and manoeuvrability in rough seas. These features are essential for taking advantage of that brief period between wave sets to quickly rescue the victim, pull them into the IRB and then accelerate quickly out of the danger zone before the whole boat, crew and rescued victim are up-ended in the rough surf. This technique needs a lot of practice and can easily lead to crew injury.

Figure 2
An inshore rescue boat (IRB; 'rubber duck')

RESCUE BOARD (Figure 5) – 1,844 rescues

These are large surf boards that are paddled out to rescue the victim, who is then manoeuvred onto the middle of the board. They are long enough for the rescuer to lie on the back of the board to paddle it back to shore.

NO GEAR – 1,626 rescues

Usually the lifesaver wades or swims to the person with no rescue aid. This type of rescue can be dangerous and is not encouraged, unless the rescue pick-up is in shallow water with no swimming necessary.

PWC (Figure 3) – 777 rescues

This craft is often referred to as a 'jet ski', although this is, in fact, a registered trademark of just one manufacturer. It is becoming very popular, as it is small, light and highly manoeuvrable, and can be controlled by one person only (ideal for the single professional lifeguard). For rescues it has a small, floating 'mat', or tray that is towed behind. The driver approaches the victim and slows, but maintains some momentum, using this to assist as the victim is grasped (usually by the arm) and skilfully scooped, or 'flipped' on to the floating mat. They can be brought quickly back to shore and resuscitated, if necessary. Some PWCs carry two people, making the rescue much easier, with the assistant able to perform the rescue and then support the victim on the floating mat. PWCs are becoming very successful and useful in Australia, and are in common use by Hawaiian lifeguards with amazing records of success and safety. They cause far fewer injuries than the IRB and will probably become the main rescue tool in the future.

Figure 3
A personalised watercraft (PWC)

Figure 4
Rescue tube

JET RESCUE BOAT (JRB)/OFFSHORE RESCUE BOAT (ORB) – 293 rescues

These are larger boats that operate mainly in the 'blue zone', away from the breaking surf. Because of their jet propulsion system they can be beached and launched from the beach if necessary.

SURFBOATS – 52 rescues

The surfboat is rowed by four surf lifesavers, with a sweep standing in the rear to manoeuvre it. The surfboat is well known in competition, but it does have a rescue capacity. Many years ago, before the advent of the faster IRB, it was fitted with a reel, line and belt, situated at the bow should a rescue be necessary.

SURF SKI – 21 rescues

Fibreglass skis, like open, flat kayaks, are specially designed for rescue work, although not in common use.

HELICOPTER – 7 rescues

Surf rescue helicopters do not rescue many people and are mainly used for transport of victims to hospital. They usually fly patrols, searching for or spotting swimmers in difficulty, or in dangerous situations. They can then direct other rescuers into the right area. However, when a rescue is necessary in areas of difficult access, or further out to sea, a specially trained crewman can jump out and secure the victim, who is then winched up into the helicopter and transported to hospital. Helicopters are very expensive to run and depend heavily on sponsorship.

OTHER RESCUES – 924

The surf reel, once the famous symbol of SLSA, has now been phased out as a rescue tool, as it could be so dangerous. Surf lifesavers have actually drowned attempting a rescue when the line was snagged and they were unable to release the mechanism securing them to the belt. However, there have been some remarkable rescues in the past, with beltmen swimming some 800 metres out through huge surf, needing two surf lines tied together (400 m standard line length) where no boat or surf board could get past the break. The beltman has then supported the patient until a larger boat was able to leave a safer path out to sea from a river, or harbour.

History of resuscitation in SLSA (Table 1)

Prior to the 1960s, surf lifesavers used the Eves rocker – a barrel on which the victim is rolled backwards and forwards to try to empty the lungs. Later the Sylvester-Brock and Holger-Nielsen techniques were used until these were all

Figure 5
Rescue board

Table 1
The medical contribution to SLSA

1960 The 1960 International Convention on Life Saving Techniques in Sydney led to the first recommendations on teaching expired air resuscitation (EAR) and cardiopulmonary resuscitation (CPR) in life saving. These were introduced into Australia with the publication of the 1961 *Surf Life Saving Australia (SLSA) training handbook*.

1964 National Medical Advisers, Drs Coppleson, Bennett and Clifton gave further specific advice on EAR and CPR, and discussed the use of apparatus for the supply of oxygen. These recommendations were incorporated into the next training manual.

1970 A National Medical Panel was formed and endorsed, with the Chairman being the National Medical Officer (NMO) for SLSA. Dr Warren Gunner was the inaugural Chairman; he remained in this position until 1993. This first meeting of the National Medical Panel also introduced CPR teaching for all Bronze Medallion holders, 15 years of age and over.

1973–1975 Professor Don Harrison, then Chairman of the World Lifesaving Medical Panel, became the NMO, and was responsible for the introduction of oxygen via the Oxy-Viva™, together with the Advanced Resuscitation Certificate, a brilliant move that still has not reached all other first-aid providers to date. Certified advanced resuscitation techniques were taught and introduced at the same time, with the oxygen supplied either as a supplement for a breathing victim, or through the Royal Melbourne (RM) Head in the Oxy-Viva™ for the non-breathing victim. Masks were introduced for all surf lifesavers, who were taught to use them for all resuscitation cases.

1975–1982 Professor Tess Brophy (later Crammond) was appointed as the NMO.

1982–1996 Dr Ian Mackie was appointed as the NMO.

1985 The new Australian Standard required manufacturers to stop production of the RM Head. After some research Ian Mackie initiated the adoption of the bag-valve-mask set up, combined with the Air-Viva™ resuscitator. The potentially dangerous (in inexperienced hands) RM Head was abandoned.

1988 The National Medical Panel meeting was held on the Gold Coast in conjunction with the World Lifesaving Congress and Championships with a major recommendation for surf lifesavers to be offered immunisation against Hepatitis B.

1991 Ian Mackie introduced the rigid, adjustable cervical brace for the management of suspected neck injuries. Release of the Marine Stinger Guide (SLSA Innovation Award for the author, Peter Fenner).

1992 Peter Fenner (then Surf Life Saving Queensland First Aid Officer) obtains special permission from the Queensland Department of Health for bronchodilators to be introduced and kept in the first-aid room for acute asthma treatment; other States quickly followed.

1995 Semi-automated defibrillators (SAEDs) first trialled in surf life saving: a world first and another SLSA Innovation Award for the author, Peter Fenner.

1996–2004 Dr Peter Fenner appointed as the NMO.

1997 The first defibrillation by a volunteer surf lifesaver was successfully performed on the beach on the third shock, with the patient still alive and well today.[1]

1998 Introduction of defibrillators to SLSA (with third SLSA Innovation Award for the author).

2002 Oropharyngeal airways were introduced to Advanced Resuscitation Certificate holders, together with a new handbook on training.

2003 Introduction of the spinal board (with concomitant use of the spinal collar). Fenner, with the assistance of a talented team of experts, including Dr John Lennard, Surf Life Saving New South Wales Medical Officer, developed and adapted techniques to secure standing victims, who walk out of the surf complaining of neck pain, and, of course, for the prone victim who may or may not be conscious and/or breathing. Their introduction was based on the experience of the USA lifeguards, who had used spinal boards for a number of years.

phased out in 1961 and cardiopulmonary resuscitation with mouth-to-mouth and external cardiac compression was introduced.

SLSA members are competent resuscitators, as each year they are fully re-examined in their resuscitation, or advanced resuscitation, technique and timing. Accurate resuscitation statistics are available back to at least 1973. The results were first published in 1998, and updated in subsequent publications.[1,2,4–6]

Table 2
Success rates of resuscitation with increasing distance from patrolled areas (n = 154)

Distance from clubhouse (m)	< 200	200 to 399	400 to 799	800 to 999	> 1000
Success rates	31/39	38/51	13/22	5/13	14/29
Percentage	79.5	74.5	59.1	38.5	48.3

Drowning and resuscitation

The extent of the drowning problem on Australian surf beaches is illustrated by the age-related data for 1992 to 1997, during which time there were 162 deaths (Figure 6).The distribution of drownings over the season follows the temperature trend, with the highest incidence of drownings corresponding with the summer Christmas school holidays, even though the majority of victims are not children. Many families take their annual vacation at this time, to take advantage of clement weather, as well as the traditional school holiday period.

An almost constant 80% of the total rescues performed by surf lifesavers are on males, with the highest-risk age group being those aged 18–30 (the 'daring' ones), paralleling the fatality data (Figure 6). An assessment of a beach and the patrol area shows that families stay mainly inside the flags, whereas those furthest from the patrol area are usually young males (personal observation and research).

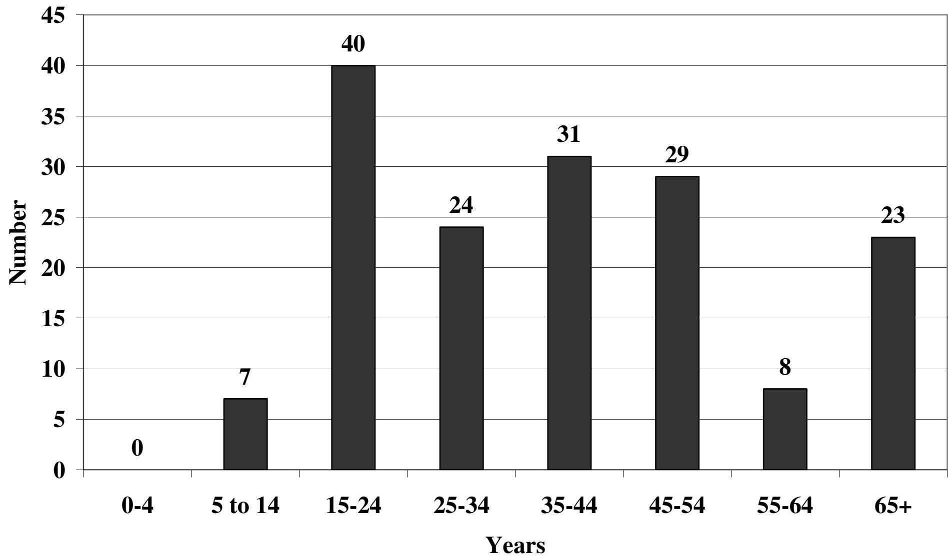
Because of the large volume and speed of the water moving out to sea, the area of a rip is often noticeably calmer than the breaking surf waves on either side of it. Often, inexperienced people wanting to swim may spot an area in rough surf where it is much smoother and where waves do not break as hard, making it look more appealing for swimming. As well as being swept sideways by sweep currents, others enter directly into the rip area as it looks so calm and safe compared with the surrounding surf and are carried rapidly several hundred metres out to sea.

Rips are the greatest single cause of rescues, resuscitations and drownings, up to 43% of drowning deaths occurring in these rapid outward-flowing sea currents. The majority of victims (62.5%) drown within a kilometre of a life-saving service, indicating that these people chose to bathe adjacent to rather than within the patrolled area.

Statistical analysis of victims for whom the place of residence was available, showed that in 2002–2003, 19.5% were international tourists, 63.4% were Australian residents who lived more than 50 kilometres inland, while 17% lived within 10 kilometres of where they drowned. Those who live inland and international tourists have usually never encountered surf conditions, and up to 15% of international tourists who drown in the surf do so within 24 hours of reaching Australia. After a long struggle to introduce them, teaching videos are now shown on some incoming international commercial flights, advising tourists to swim in patrolled areas, and of the danger of rips.

In the patrolled area up to 92.5% of victims are successfully

Figure 6
Australian surf-beach drownings 1992 to 1997 by age group (total: 162)



resuscitated. The success rate falls off exponentially with distance from the patrolled area: within 200 metres there is an 80% success rate, at 400 metres 75%, and from 400 to 800 metres a 59% success rate (Table 2). Logistic regression analysis of distance against resuscitation outcome shows that the odds of a successful resuscitation were 79% lower for resuscitations taking place 800 m or more from the club house than for resuscitations that took place within 200 m of the club house ($P = 0.002$).

Almost 55% of victims vomit, largely because they swallow seawater, and resuscitation success is reduced when vomiting is present.[2] In 40% of cases achieving a good airway causes difficulty, although 76% of the cases have no material present in the airway. It was this difficulty that encouraged the author to introduce oropharyngeal airways into SLSA training in 2002. Despite the difficulties of reaching and retrieving victims, 60% of them are reached within three minutes. In 25% the time to the first breath is between just one and three minutes, whilst 50% received their first breath of EAR within five to 10 minutes.

In the statistics up to 1999, facemasks were rarely used, as they had not been promoted for safety in resuscitation. However, in current teaching of resuscitation in SLSA, the emphasis has been taken off 'mouth-to-mouth' resuscitation and placed on 'mouth-to-mask' resuscitation. A mask and gloves are now kept in 'bum bags' that surf lifesavers wear on their waist for quick and easy access, whilst on patrol.

Semi-automated defibrillators (SAEDs) were introduced into surf life saving in 1995 by the author. SAEDs had been used successfully thirteen times up until the end of the 2003 season. In nine cases surf lifesavers were able to defibrillate the victim, whilst in four cases the SLSA SAED was used by ambulance officers when they arrived at the scene. There were nine survivals to hospital, of whom seven were discharged alive. No follow-up details are available, but it is understood these survivors are fit and well. Current information on defibrillation proves it should be completed within eight minutes, as a successful outcome is less likely after that. However, two cases have taken significantly longer: in Noosa 27 minutes, and a remote area of Victoria 40 minutes, before actual defibrillation; both showing the standard of resuscitation that surf lifesavers can achieve in maintaining efficient CPR.

Rescues

Not everyone who has been rescued will need resuscitating, and so rescues and resuscitations have been compared separately. By 1997, there was a much higher ratio of rescued victims who did not need resuscitating. This is partly due to the faster IRBs, and also to the greater emphasis on new skills such as scanning; the skills needed in watching the beach and surf for people who may be in trouble, or who may be placing themselves in a risky situation if not prevented.[7] This trend in a reduced proportion of those needing resuscitation compared with rescue continues.

The proportion of all rescues compared with all resuscitations varies between age groups (Figure 7). The 0–15 age group represented 22% of the total rescues but just 2% of the resuscitations. The 60+ age group made up 5.3% of the rescues and 11.9% of the resuscitations.

The older groups contain a higher percentage of those needing resuscitation – increasing statistically in a linear fashion ($P < 0.00001$) – so over 91% of the over 60s need resuscitation (Figure 8).

Figure 7
The age distribution of all rescues and of all resuscitations expressed as percentages of the totals

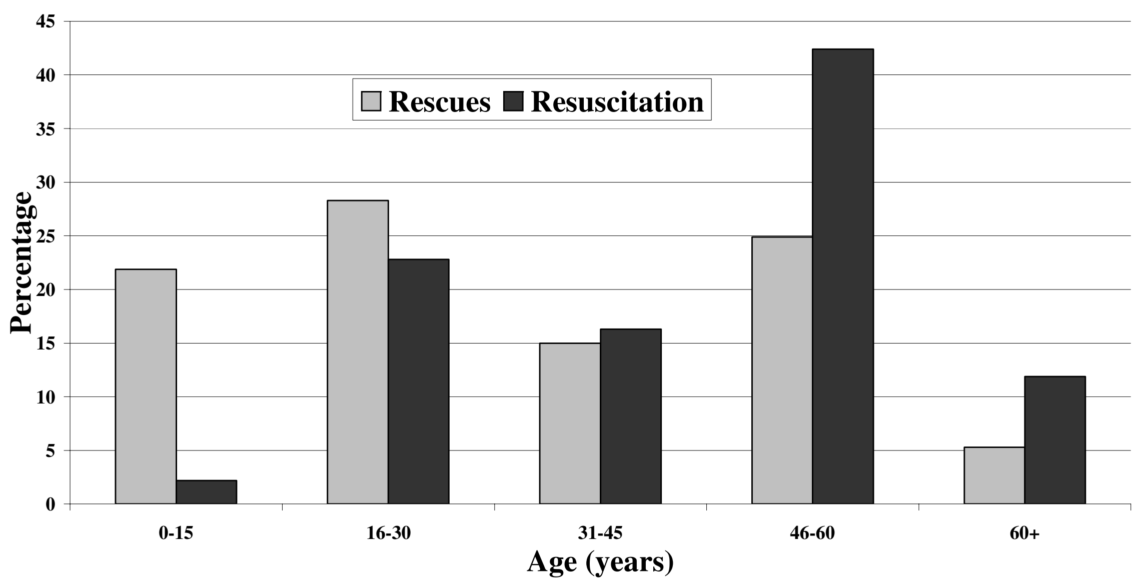


Table 3
Level of supervision observed during a single day on a popular Gold Coast beach by an experienced surf lifesaver; 54.6% of 119 children had poor or inadequate supervision

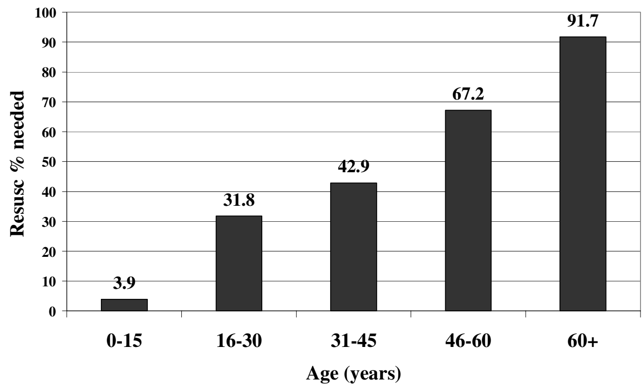
Supervision level	Number	Percentage
1a. Adult with child with active involvement	20	16.8
1b. Adult with child no/minimal active involvement	10	8.4
2a. Adult close to child (in water) with active involvement	16	13.5
2b. Adult close to child (in water) no/minimal active involvement	2	1.7
3a. Adult at water's edge, close supervision and/or involvement	18	15.1
3b. Adult at water's edge, no/minimal supervision and/or involvement	11	9.2
4a. Adult distant, observation/supervision maintained	22	18.5
4b. Adult distant, no/minimal observation maintained	13	10.9
5a. Adult presence not able to be identified	7	5.9
5b. Adult definitely not present	0	
Total	**119**	
Supervised (1a, 2a, 3a)		45.4
Low-level supervision (1b, 2b, 4a)		28.6
Very-low-level (inadequate) supervision (3b, 4b)		20.1
No supervision (5a, 5b)		5.9

Alcohol was present in 10.4% of rescues and 19.7% of the resuscitation cases; drugs were noted to be present in 2.2% of the rescues, and 5.0% of resuscitation cases, this difference being statistically significant ($P < 0.001$).[1]

Children on surf beaches

Unlike general statistics for drowning, infants do not figure in surf drowning statistics. However, a small but sad proportion of deaths on surf beaches occur in children less than 10 years old; mainly due to poor parental supervision. Some of these deaths occur when a youngster is in the charge of minors at the time of the incident, some even when the young victim is less than a kilometre from a patrolled area.

Figure 8
Rescues needing resuscitation according to age group (%); the need for resuscitation increases considerably with increasing age



Parents need to educate their children to swim only between the red and yellow patrol flags. Also they need to be present and watchful of their children, even when they are swimming in a patrolled area. Children drown silently and with little apparent motion other than a side flailing of their arms, almost as if they are playing in the water. The only obvious visual effect is that the head is extended and they recurrently bob under the water, briefly inhaling and exhaling in the surface interval, with no time to call for help, until within 20 to 60 seconds they finally remain submerged.[8]

A visual survey on children assessed as 10 years old or younger, arranged by the author, was conducted by Peter Dawes over several hours on a busy Gold Coast beach. Numbers were small, and although further trials were planned they were never completed but really need to be. This small survey gives an idea of the inadequate supervision of children in a dangerous beach situation (Table 3). The groups in the table are self-explanatory and show that only 45.4% of children are suitably supervised at the beach, 28.6% are poorly supervised and 26.1% had negligible or no supervision. This gives a staggering figure that 54.6% of the children on this surf beach were in danger of wandering into the surf and quickly drowning unless the surf lifesavers were able to spot them almost immediately; a very difficult task on a beach with thousands of people and a patrolled area where many hundreds of people may be gathered.

Web-based reporting of SLSA statistics

Before the author resigned as the National Medical Officer in late 2004, sponsorship was arranged with a private trust to set up a website database for surf-orientated statistics. It enables data to be entered directly by any surf-club member in Australia (but requires specific approval from at least one appointed person in each club). Reported drowning statistics can be inaccurate, as surf lifesavers patrol the beaches only at set times and days, and so further data are now retrieved from the national coroner information system through the Monash University National Centre for Coronial Information. This ensures that SLSA surf-drowning fatality statistics are accurate, and that no deaths by surf drowning occurring outside normal patrol hours are missed. As well as the data on drownings, rescue and resuscitation cases, marine stings and even injuries are to be included.

These data are being integrated with physical current data in a risk-based analysis of all the beaches in Australia for physical and geographical risks.[8] Working with SLSA, Professor Andy Short of the University of New South Wales has now personally visited 6,895 of some 9,000 beaches around Australia with approximately 30,000 kilometres of coast. By 2004 data had been published on three States (Queensland, New South Wales and Victoria) with the other States' data following shortly. The database will be further extended, combining physical and geographical risks with surf drownings, rescues and resuscitation cases. Data on wave height from the wave buoys anchored off the coast of Australia will then be added and, hopefully, wind speed and direction from weather balloons and other data sources. Injuries and marine stings may be added as funding and means permit.

The purpose of this new database is not only to provide good risk analysis of a beach to cover all these entities, but also, in the future, to be able to predict the safety of various beaches in various wind and weather conditions. This will enable surf life saving clubs to best deploy their patrol members, either moving them to other beaches *in toto*, or, if possible, splitting them to provide sufficient patrol members for a number of safer, nearby beaches. This would be an excellent resource tool.

Research on scanning techniques for observing an area, and the largest area safe to monitor, was implemented in 1998, after single lifeguards observing a large number of patrons spread over a wide area expressed concerns. Despite input from most of the aquatic safety organisations around the world, it was discovered that no organisation's technique had any scientific, evidence-based content. Research into the existing literature and ideas was conducted, resulting in the publication of the first scientific article on the techniques of scanning.[7] There had been a previous excellent study of the speed and manner in which people drown, all captured on video by Pia.[9] This provided some excellent information on which to base calculations for the scanning techniques that were to be taught to SLSA members.

Shark kits

Professor Tess Crammond (née Brophy) introduced 'shark kits' to surf life saving clubs in the early 1980s, after a number of shark attacks on the Queensland coast. They contained instruments and dressings that could be used for injuries from a shark attack, or other severe lacerations, e.g., from propellers. Doctors also used them for road traffic accidents if they occurred close to surf life saving clubs. Crammond arranged for Queensland hospitals to replace sterile dressings, intravenous fluids and autoclave the instruments annually. However, this cost grew so great the service had to be ceased, and the kits were removed from the great majority of surf clubs in about 1998.

Figure 9
Surfboat competitors at the Australian Surf Life Saving Championships

Australian Surf Life Saving Championships

To keep surf lifesavers fit for their patrols and possible rescues, they are encouraged to train, with their interest retained by regular competition. Surf carnivals are held throughout the season, usually starting in late September. Local competitions lead to state championships and, at the end of the season, the Australian Surf Life Saving Championships are held.

Figure 10
Belt race competitors at the Australian Surf Life Saving Championships

There are:
- six days of competitive events, from heats to finals
- more than 7,000 competitors, of whom some 750 are ‘Masters’ (30–80+ years)
- 450 officials to run and judge all the events
- 60,000 or so spectators, especially on the Saturday and Sunday when the major finals events take place
- over 100 VIPs in the grandstand on the Saturday and about 300 on the Sunday
- 90–100 TV crew for filming all the events for national TV
- 28 IRBs to assist in placing buoys and maintaining their correct position and distance; to serve as rescue craft for any competitor needing assistance; and, often, for a judge to sit in to assist in placing and identifying competitors
- three jet rescue boats for water safety (and cameras)
- six PWCs for lifesavers and water safety and three or four on which a cameraman sits as passenger for close-up water shots.

On average about 200 or more surf clubs out of the possible 356 clubs all round Australia send competitors. The Australian Surf Life Saving Championships are the largest annual event in Australia. The largest overall is the Olympics, followed by the Commonwealth Games and the Australian Surf Life Saving Championships is the third largest in the world.

When the whole carnival is under way, it occupies some 1.6 kilometres of beach; the venue for the past 10 years has been Broadbeach on the Gold Coast. The events are spectacular with very competent and skilled competitors, making for impressive viewing. However, with rough surf often present there are injuries, and consequently a good contingent of medical and first-aid personnel are needed.

FIRST-AID FACILITIES

The first-aid facilities consist of three large, demountable buildings or cabins, with a central covered-in area. The medical officer, the safety coordinator and the nursing sister are in the central cabin. This is a busy area where many treatments take place. Equipment includes two emergency beds, defibrillators, electrocardiograph, pulse oximeter, sphygmomanometers, full resuscitation gear with oxygen, drugs and suture packs, and most of the materials needed in a busy general-practice centre or even an emergency department! The huge quantities of first-aid supplies are usually totally depleted by the end of the event.

In the second cabin are another three beds and four chairs for treating injuries, and the third cabin houses the physiotherapist, who is kept very busy at all times through the carnival. The physiotherapy area is equipped to usual practice standards. A covered area in front of these cabins is used for those awaiting treatment, and those undergoing simple treatments, such as the application of ice for sprains and strains.

A four-wheel-drive transport vehicle is essential and its cabin is long enough to carry a stretcher and resuscitation gear. In addition, at least one four-wheel-drive motorbike can very quickly deliver a first responder and a small amount of essential equipment to any area where it may be needed.

The safety coordinator also has a driver and crew in another well-equipped four-wheel-drive truck and his own four-wheel-drive bike. There are at least two first aiders at the first-aid base, and two first aiders manning each of seven first-aid treatment tents on the beach. For immediate advice, the first-aid teams are equipped with radios with their own frequency.

Figure 11
Shoulder injury sustained during the ‘flags’ event

A high percentage of injuries occur in the surfboat events, especially in the younger crews and female boat crews (Figure 9). Many crews now wear helmets: several years back a 17-year-old died after a surfboat collision, when he was thrown out of the boat, suffered a head injury and unfortunately drowned. Injuries in the surfboat arena are much higher with heavy surf conditions, with some spectacular 'wipe-outs' seen.

The main injuries in all areas are sprains and strains, mainly amongst the competitors, but also amongst the many officials, often occurring when they need to rush over loose sand to check finish positions, when their muscles are not warmed up. Minor fractures are common, particularly in the rough surf, but they are rarely serious, with the worst having been a compound fractured femur a few years ago.

Dislocations are also common, with a high percentage being dislocated shoulders in the 'flags' arena (Figure 11). In this event, competitors jump up from the prone position, facing away from the finish line, run up the beach jostling for position before they all dive to retrieve 'flags' – 30 cm lengths of rubber hose – pushed vertically into the sand, in order to remain in the competition. Competitors landing awkwardly, especially with another competitor falling on them, are common victims of fractures and dislocations.

In 2002, 42 competitors and 11 spectators required sutures and even officials are not immune from cuts from broken glass, or lacerations from tripping over tent pegs. Head injuries occur but fortunately they are not usually serious, with simple concussion or cuts needing suturing. Needless to say in such a large gathering where there are many older officials and spectators, even Masters competitors, there will be heart problems and a fair smattering of most medical conditions over the six days. Injuries occur in approximately 5.5% of officials, and although many spectators are treated, because there are so many of them, the percentage is actually quite small. Even with 7,000 competitors the percentage treated is small.

Conclusion

The work of Australian surf lifesavers has been eloquently expressed:

> *When I think of all the good things about this country, when I think of what it is about being Australian that makes me feel proud, one of the things that come to mind is our surf lifesaver....*
> *Young Australians who patrol for absolutely nothing other than a sense of pride and the knowledge that they are out there saving lives, keeping our beaches safe for you and me and most importantly for our kids.*

Mike Gibson, *Sydney Daily Telegraph*, April 1996.

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This paper is based on a presentation given at the SPUMS ASM in Noumea 2004.

Surf Life Saving Australia and Harvie Allison gave kind permission to reproduce their photgraphs.

Peter J Fenner AM, MD(London), MB, BS, DRCOG, FRCGP, FACTM, is an Associate Professor, James Cook University School of Medicine, Townsville, and a General Practitioner, North Mackay, Queensland.
He is an advisor in marine envenomation to the World Health Organisation and International Life Saving, and was a guest speaker at the SPUMS ASM 2004.

Address for correspondence:
PO Box 3080, North Mackay,
Queensland 4740,
Australia.
Phone: *+61-(0)7-4957-7800*
Fax: *+61-(0)7-4937-7824*
E-mail: *<pjf@occupationalhealthmackay.com.au>*

Articles reprinted from other journals

Efficacy of a jellyfish sting inhibitor in preventing jellyfish stings in normal volunteers

Kimball AB, Arambula KZ, Stauffer AR, Levy V, Davis VW, Liu M, Rehmus WE, Lotan A, Auerbach PS

Objective: To evaluate the protective effects of a jellyfish sting inhibitor formulated in sunscreen lotion vs conventional sunscreen against *Chrysaora fuscescens* and *Chiropsalmus quadrumanus* jellyfish.
Methods: Twenty-four healthy subjects at 2 research sites were randomly assigned to receive the jellyfish sting inhibitor (Nidaria Technology Ltd, Jordan Valley, Israel) to one forearm and conventional sunscreen to the other arm in a blinded fashion. Subjects were stung with jellyfish tentacles on each forearm for up to 60 seconds. Erythema and pain were assessed at 15-minute intervals over a 2-hour period.
Results: In the *C. fuscescens* group, all 12 arms pretreated with conventional sunscreen demonstrated erythema, and all subjects noted subjective discomfort. In contrast, no arm pretreated with the jellyfish sting inhibitor had objective skin changes ($P < .01$). Two subjects noted minimal discomfort in the arm treated with the sting inhibitor ($P < .01$). In the *C. quadrumanus* group, discomfort was reported in 3 of the 12 inhibitor-treated arms compared with 10 of the 12 placebo-treated arms ($P < .05$). Erythema was noted on 1 arm treated with the inhibitor and 9 arms treated with the placebo ($P < .01$).
Conclusions: The jellyfish sting inhibitor prevented sting symptoms of *C. fuscescens* jellyfish in 10 of 12 subjects and diminished the pain of the jellyfish sting in the remaining 2 subjects. The jellyfish sting inhibitor also inhibited the more severe sting of the *C. quadrumanus* jellyfish in the majority of subjects. The jellyfish sting inhibitor does not eliminate the sting from *C. fuscescens* or *C. quadrumanus* jellyfish but significantly reduces the frequency and severity of stings.

Department of Dermatology, Stanford University School of Medicine, Stanford, CA 94305, USA. <akimball@stanford.edu>

Reprinted with kind permission of the Wilderness Medical Society, Colorado Springs, Colorado from Kimball AB, Arambula KZ, Stauffer AR, Levy V, Davis VW, Liu M, Rehmus WE, Lotan A, Auerbach PS. *Wilderness Environ Med*. 2004; 15: 102-8.

Key words
Reprinted from, marine animals, envenomation, treatment, abstracts

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Cerebral effects of hyperbaric oxygen breathing: a CBF SPECT study on professional divers

Di Piero V, Cappagli M, Pastena L, Faralli F, Mainardi G, et al

We investigated the effects on cerebral blood flow (CBF) of pure oxygen breathing exposure during dives in a group of professional divers, in both the normobaric (NBO) and the hyperbaric oxygen (HBO) breathing conditions. Using single photon emission computerized tomography (SPECT) and Tc-99m hexamethylpropylenamine oxime (HM-PAO), we studied 10 young divers and six normal volunteers. Divers were studied by SPECT in the NBO and HBO conditions, in two different sessions. The HBO state was obtained in a hyperbaric chamber at 2.8 ATA for 15 min. By ANOVA, we did not observe any significant difference in CBF distribution between controls and divers in both NBO and HBO conditions. By individual analysis, divers showed a decreased CBF in a total of 33 regions of interest (ROIs) during NBO and 46 ROIs during HBO with respect to control values. In particular, two divers showed a remarkable increase in the number of hypoperfused ROIs during HBO (+7 and +5 ROIs, respectively). Pure oxygen breathing exposure in young divers is associated with a patchy distribution of brain areas of hypoperfusion. This phenomenon is more pronounced in the HBO state than in the NBO state. Further studies on CBF are needed to help identify divers potentially prone to harmful oxygen effects.

Department of Neurological Sciences, University of Rome, Rome, Italy. <vittorio.dipiero@uniroma1.it>

Reprinted with kind permission from Di Piero V, Cappagli M, Pastena L, Faralli F, Mainardi G, et al. Cerebral effects of hyperbaric oxygen breathing: a CBF SPECT study on professional divers. *Eur J Neurol*. 2002; 9 : 419-21.

Commentary by Paul Langton, Perth WA:

This paper examines the effects of pure oxygen on cerebral blood flow. In this small study there was no overall difference in cerebral blood flow under normobaric or hyperbaric conditions, in either young divers or control subjects. The study was not powered to detect small differences between these conditions and groups. Sub-analysis based on individual regions of interest demonstrated a relative reduction in (asymptomatic) cerebral perfusion during pure oxygen breathing. The significance of this observation is unclear. Arguably, the principal role of cerebral blood flow is oxygen delivery. It is plausible that the reduction in perfusion in the setting of high, normobaric blood oxygen saturations is simply an example of auto-regulation.

In contrast, the P_aO_2 achieved with hyperbaric oxygen is likely to be several orders of magnitude greater than that seen physiologically. In this setting the potential for hyperoxic vasospasm is increased. Ideally, this laboratory observation needs to be correlated against a measure of cerebral function related to the identified 'regions of interest'. The hyperbaric oxygen exposures may be of relevance to patients receiving HBO therapy and their chamber attendants. In isolation, the findings are of little relevance to recreational diving. Larger studies with clinical or functional correlates will be of interest.

Key words
Reprinted from, hyperbaric oxygen, cerebral blood flow, abstracts

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Is diving safer than skiing?

Ben Davison, the Editor of *Undercurrent*, writes:

Though DEMA's [Diving Equipment and Marketing Association] published goals include "speaking on behalf of the sport," I could take issue with some of its efforts to do so. Take, for instance, its latest effort to discredit the premise behind the movie *Open Water*, where divers are left at sea when their dive boat departs without them. DEMA's public statement on the film was that these were circumstances not likely to occur in the real world of diving – when, of course, the events of *Open Water* were inspired by a real-life incident…[Editor's note – there have been several instances of divers being left behind at dive sites, including the couple on the Great Barrier Reef and a large group of divers lost off an island in Palau].

If we want to 'get the facts' about diving's risk, the National Sporting Goods Association has done a comparison of fatalities in several popular outdoor sports [Table 1]. Unfortunately, based on the statistics, diving doesn't rank well when compared with swimming, skiing or bicycling, and these statistics may even be deflated given the varied lengths of a typical sports day. For example, the typical scuba boat diver puts in about 1.5 hours during a day of participation (balancing one-tank days with multi-tank days), with shore divers putting in somewhat more time getting to and from dive sites. But skiers and cyclers probably put in more hours per day most of the time, which would lower their risk for time spent even further in comparison with divers. All well and good, but to borrow Churchill's line about "lies, damn lies and statistics," do statistics really tell the story here? Dive risk, like that in most outdoor sports, is on a sliding scale. Downhill skiers, for example, can take the 'f&f&f&' course through the trees, or they can stick to the 'bunny slope'. Divers can putter around beautiful coral gardens in 30 feet of water in a protected bay, or they can fly in a 10-knot current through a deep-water pass on a night dive. We dive in some places with sharks, even with lots of sharks, and, while we are very seldom attacked, it can happen. Let's call it what it is. Hey, if we make diving sound dangerous enough, we might attract some players from the 'extreme sports' junkies.

Reprinted with kind permission from *Undercurrent*, the private guide for serious divers, <*www.undercurrent.org*>

Table 1
National Sporting Goods Association's comparison of fatalities in several outdoor sports

	Skiing and snowboarding	Recreational scuba diving	Swimming	Bicycling
Fatalities (2000 or 2001)	45	91	1,200	800
Participants (x 10^6)	10.7	1.6	54.8	39.5
Fatalities per 10^6 participants	4.21	56.9	21.9	20.5
Fatalities per day of participation x 10^6	0.83	5.1	0.61	0.34

Critical appraisal

Hyperbaric oxygenation did not improve recovery rate from osteoradionecrosis

Clinical bottom line

1 No indication of benefit from hyperbaric oxygen, a trend to better outcome with sham.
2 Success rate high in both arms (probably 74% with HBO versus 86% with sham).

Citation

Annane D, Depondt J, Aubert P, Villart M, Gehanno P, et al. Hyperbaric oxygen therapy for radionecrosis of the jaw: a randomised, placebo-controlled, double-blind trial from the ORN96 study group. *J Clin Oncol*. 2004; 22: 1-8.
Lead author's name and e-mail address: Djillal Annane; <djillal.annane@rpc.ap-hop-paris.fr>

Clinical question

For patients with established osteoradionecrosis of the mandible, does the addition of hyperbaric oxygenation (HBO) to standard therapies result in any improvement in satifactory outcomes.

Search terms

Hyperbaric oxygenation, osteoradionecrosis, radiation tissue injury

The study

Double-blind, concealed and randomised controlled trial with intention to treat.

The study patients

Adults with established osteoradionecrosis but excluded if pathological fracture, bone loss to inferior border of mandible, or active cancer.

Stratified randomisation

Group A – exposed bone < 20 mm diameter, no fistula and no clear need for surgery. Group B – exposed bone > 20 mm diameter, fistula or clear need for surgery.

Control group

(N = 37; 37 analysed) Conservative treatment involving analgesia, antibiotics, debridement/curettage/irrigation plus daily sessions for 90 minutes breathing 9% oxygen at 2.4 ATA to a total of 30. Ten further postoperative sessions if surgery required.

Experimental group

(N = 31; 31 analysed) As above, but sessions involved breathing 100% oxygen at 2.4 ATA.

The evidence

See Table 1.

Comments

1 A trend to poor outcomes with HBO led to termination of the trial (blinded and predetermined).
2 Unusual definition of 'recovered' did not allow good outcome if an individual moved from Group A to Group B, but was later cured.
3 Numbers do not add up. There appear to be two individuals operated on in control group who cannot be accounted for at randomisation (further information sought).

Table 1
Hyperbaric oxygen therapy for osteoradionecrosis of the mandible: Main outcomes at one year

Outcome	Time to outcome	Control ER	HBOT ER	Relative risk reduction	Absolute risk reduction	NNT	NNH
Recovered	1 year	0.194	0.324	-67%	-0.13	-8	
95% CI:				-173% to 39%	-0.34 to 0.08	13 to INF	3 to INF
Recovered as above or cured following surgery	1 year	0.742	0.865	-17%	-0.12	-8	
95% CI:				-42% to 9%	-0.31 to 0.07	15 to INF	3 to INF
Persistent ulceration	1 year	0.419	0.405	3%	0.01	71	
95% CI:				-53% to 59%	-0.22 to 0.25	4 to INF	5 to INF

ER – event rate; INF – infinity; NNT – number needed to treat; NNH – number needed to harm

Conclusions

This trial contradicts earlier work and suggests common clinical practice is not conferring any advantage on patients with osteoradionecrosis. Of prime importance, and despite the discouraging appearance of the primary outcome measure, is that most individuals are 'cured' at one year whether they receive HBO or not. Watch the correspondence pages closely as what is likely to be a lively debate unfolds.

Appraised by
Dr Michael H Bennett,
Medical Director,
Department of Diving and Hyperbaric Medicine,
Prince of Wales Hospital,
Randwick, NSW 2031
AUSTRALIA
E-mail: *<m.bennett@unsw.edu.au>*

Appraised Tuesday, 21 December 2004

Key words
Reprinted from, hyperbaric oxygen, osteoradionecrosis

Diving-related fatalities document resource

All the coronial documents relating to diving fatalities in Australian waters up to and including 1998 have now been deposited by Dr Douglas Walker for safe keeping in the National Library of Australia, Canberra.

These documents have been the basis for the series of reports previously printed in this Journal as Project Stickybeak.

These documents will be available free of charge to bona fide researchers attending the library in person, subject to the stipulation that the researcher signs an agreement that no identifying details are to be made public.

Accession number for the collection is: MS ACC 03/38.

It is hoped that other researchers will similarly securely deposit documents relating to diving incidents when they have no further immediate need of them. Such documents can contain data of great value for subsequent research.

SPUMS notices and news

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 medically qualified financial member of the Society.
2 The candidate must supply evidence of satisfactory completion of an examined two-week full-time course in Diving and Hyperbaric Medicine at an approved Hyperbaric Medicine Unit.
3 The candidate must have completed the equivalent (as determined by the Education Officer) of at least six months' full-time clinical training in an approved Hyperbaric Medicine Unit.
4 The candidate must submit a written proposal for research in a relevant area of underwater or hyperbaric medicine, and in a standard format, for approval by the Academic Board before commencing their research project.
5 The candidate must produce, to the satisfaction of the Academic Board, a written report on the approved research project, in the form of a scientific paper suitable for publication.

Additional information

The candidate must contact the Education Officer to advise of their intended candidacy, seek approval of their courses in Diving and Hyperbaric Medicine and training time in the intended Hyperbaric Medicine Unit, discuss the proposed subject matter of their research, and obtain instructions before submitting any written material or commencing a research project.

All research reports must clearly test a hypothesis. Original basic or clinical research is acceptable. Case series reports may be acceptable if thoroughly documented, subject to quantitative analysis, and the subject is extensively researched and discussed in detail. Reports of a single case are insufficient. Review articles may be acceptable if the world literature is thoroughly analysed and discussed, and the subject has not recently been similarly reviewed. Previously published material will not be considered.

It is expected that all research will be conducted in accordance with the joint NHMRC/AVCC statement and guidelines on research practice (available at http://www.health.gov.au/nhmrc/research/general/nhmrcavc.htm) or the equivalent requirement of the country in which the research is conducted. All research involving humans or animals must be accompanied by documented evidence of approval by an appropriate research ethics committee. It is expected that the research project and the written report will be primarily the work of the candidate.

The Academic Board reserves the right to modify any of these requirements from time to time. The Academic Board consists of:
Dr Chris Acott, Education Officer, Professor Des Gorman and Associate Professor Mike Davis.
All enquiries should be addressed to the Education Officer:
Dr Chris Acott,
30 Park Avenue
Rosslyn Park
South Australia 5072
Australia
E-mail: <cacott@optusnet.com.au>

Key words
Qualifications, underwater medicine, hyperbaric oxygen, research

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SPUMS Annual General Meeting 2005

Notice of Annual General Meeting of SPUMS to be held at Coco Palm Resort, Baa Atoll, Maldives at 1800 hr on Wednesday 27 April 2005

Agenda

Apologies:
Minutes of the previous meeting:
Unratified minutes of the previous meeting will be posted on the meeting notice board and appeared in the *SPUMS J.* 2004; 34: 159-64.
Matters arising from the minutes:
Annual reports:
President's Report.
Secretary's Report
Education Officer's Report
Presidents' Committee Report
Annual Financial Statement and Treasurer's Report:
Proposal regarding subscription fees for 2006:
Election of office bearers:
Nominations have been called for the positions of President, Secretary and three (3) Committee Members.
Appointment of the Auditor:
Business of which notice has been given:

Conference report

Report on the World Congress on Drowning, 7 June 2002, Amsterdam

Part 1. Expert meeting: Introducing children to diving

Jürg Wendling

Three years ago the Dutch association for water rescue and life saving, Maatschappij tot Redding van Drenkelingen, celebrated its 235-year jubilee with a 3-day congress on drowning with invited experts from all over the world. The meeting attracted hundreds of participants, including several SPUMS members, and was very successful in bringing academics and field experts together.

The Congress Coordinator, Professor Bierens, invited nine task-force teams to cover diverse topics and prepare draft consensus statements for discussion during parallel sessions. In a final plenary session the revised consensus statements from all nine task forces were presented.

The task-force topics were:

- Epidemiology
- Prevention
- Rescue
- Resuscitation
- Hospital treatment
- Immersion hypothermia
- Cerebral protection
- Diving and drowning
- Water-related disaster

This report describes one expert meeting from the task force 'Diving and drowning'. Other statements from this task force as well as a selection of the other task forces will be reported in a subsequent issue.

Expert meeting: Introducing children to diving

Participants included David Elliott, Rob van Hulst, Alfred Bove, Glen Egström, Des Gorman, Chris Acott, Peter Bennett, Mark Carney, Christophe Dey, Philippe Izard, Jim Caruso, Ulrich van Laak, Hanjo Roggenbach, Rik Rösken and Andrea Zaferes. The meeting was jointly chaired by Maida Taylor and Jürg Wendling.

Introduction

The participants were asked to discuss the topics on an evidence basis rather than based on educational dogma and opinion on national regulations. This is particularly difficult in a topic combining children and diving as both involve a high level of enthusiasm and risk.

Starting with the facts, we can state that children's diving programmes have existed since the late 1980s (in local clubs, PADI junior programmes and others). Most of the fitness-to-dive guidelines recommend against diving before the age of 15, 16 or 17. There is recently, however, a tendency towards a more liberal view. The Swiss Society for Underwater and Hyperbaric Medicine (SUHMS) stated, for instance, in their guidelines of 1994, "*discourage introduction of children to dive, recommended above 16 years. No age limit but not below 5 years and if ever then in special conditions considering the risks*". Seven years later, in the 2001 guidelines, SUHMS, together with the German and Austrian societies GTÜM and ÖGTH, stated "*not under 5 years, no restriction above 16 years. Age to 14 years: SCUBA diving is recommendable, but only with restrictions*". There have been few fatal accident reports involving children, and these are mostly in circumstances where a father is diving with his child.

Presentation of experts

The following papers were presented and cover physiology, complications and practical experience with children's dive training:

- Developmental physiology relevant to children's diving (Izard)
- Development of physical fitness in children and experience of diving with children (Egström)
- Assessment of mental fitness (Taylor/Pressmann)
- Particularities in children's behaviour (van Laak)
- Pedagogical aspects of introducing children to diving (Zaferes)
- Case reports of drowning for medical/physiological reasons (Caruso, Acott and others)
- Safety management for children's diving (contributions from Hanjo Roggenbach, Germany; Guy Vanderhoven, Belgium; Mark Carney, PADI UK; Philippe Izard, France; and Christophe Dey, comparison with professional diving, France).

Whilst these papers will be available on a DVD-ROM, a summary of the physiological aspects is shown in Table 1. The diving experience of PADI Europe is presented in Table 2, while the CMAS experience, originally from France, has been published in this journal previously,[1] and more recently by Vanderhoven from Belgium.[2]

Interesting enough to be mentioned separately are the two statements:

> "*Testing limits is the nature of childhood*" (van Laak)
> "*Concrete thinking is an obstacle for making intelligent decisions*" (Zaferes)

Both are attitudes typical in children's behaviour, with a potential to produce diving accidents.

Table 1
Physiological aspects of children's readiness to dive (Izard)

- Bronchial growth ends at 8 years
- Lung compliance developed up to 18 years (risk of barotrauma)
- Tendency of hyperventilation and breath-holding with risk of hypoxia in children of less than 8 years
- Frequency of otitis media
- Immature function of Eustachian-tube opening mechanism
- Unfavourable relationship of surface to weight (risk of hypothermia)
- Limited capacity to understand mathematical and physical properties and laws up to 8 years
- Emotional lability (tendency towards sudden changes of behaviour and mood)
- Exploring and playing behaviour (possibility to test effect of forbidden actions in inappropriate situations – barotrauma)
- Limited capacity to perceive responsibility for themselves and for others

Table 2
PADI Europe experience with junior programme: comparison of junior divers with adult divers*

Certification	2001	2002	% juniors
Junior scuba divers	253	286	12.0
Adult scuba divers	2,362	2,364	
Junior open water divers	1,174	1,338	6.3
Adult open water divers	22,016	20,928	
Junior adventure divers	0	0	0
Adult adventure divers	94	202	
Junior advanced OW divers	145	188	1.9
Adult advanced OW divers	9,510	9,593	

*During this period there were two accidents, 1 leg injury in rough sea and 1 DCI after a father-and-son-dive. There were no fatalities

Round table I. Physiology

The expert group tried to sort out whether there is a consensus on these questions:

1 What is the minimum age for scuba diving?
2 Do children need medical assessment of fitness to dive?
3 What are the recommended limitations for training children to scuba dive (medical and pedagogical)?

The age question was discussed at length, with opinions ranging from a minimum age of 17 years (USA) to as low as six or seven years old. Even if one agrees that there are some physiological limits around eight years, one rational answer to this question is that age limit depends on the risk assessment of the particular situation (Gorman), which means that under particularly protective circumstances almost everything is possible, but for sure not autonomous diving for young children. Medical assessment of fitness to dive was strongly recommended, possibly on an annual basis, and it should extend to physical and mental fitness, which needs communication and cooperation with the diving instructor. Training programmes need to be adapted to the mental development of children.

Round table II. Safety aspects

This round table addressed the question of how children might dive with an acceptable residual risk. The questions were:

- Should safety measures be based on risk assessment and a contingency plan?
- Should the buddy of a child have minimal competence as a divemaster (competence to rescue a child and to self-rescue with a child in distress)?
- Can parents replace an instructor as a buddy for a child (inherent risk of emotional distortion of decisions; absence of competence for rescue procedures)?
- Is an instructor to student ratio of 1:4 or more compatible with acceptable risk (1:2 would be much safer)?

The general consensus was that children need particular protection from environmental hazards but also one-to-one coaching by an instructor or competent person. This person must be able to self-rescue. Due to differing opinions and lack of time for further discussion, the final questions remained unanswered.

Final recommendations (consensus statements from children's group)

- It is recommended that the policy of training children to dive may ignore the mental immaturity of many young persons.

- The safety plan, when diving with children in open water, must include sufficient and competent instructional personnel to assure the safety of the child(ren) in their care.

- It is recommended that children are medically assessed before beginning a training course and annually for medical, physical and mental fitness to dive. There is no consensus as to the minimum age as there is no agreed risk assessment.

- Children's diving programmes should be adapted to the age and maturity of the child and should avoid undue stress.

The meeting was a very intense discussion with all participants contributing. However, it is remarkable that even scientific experts find it difficult to discuss issues relating to children in unemotional terms. The increasing evidence of an acceptable safety (residual risk) with the modern practice of introducing children to diving imposes a need for continued debate at future meetings and for further research.

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Dr. med. Jürg Wendling is a general and hand surgeon at Spitalzentrum Biel, Switzerland. He is a diving and hyperbaric medicine specialist, committee member of the European Committee for Hyperbaric Medicine and chairman of the Medical Subcommittee of the European Diving Technology Committee and Director of DAN Europe Suisse.
Faubourg du Lac 67,
CH-2502 Bienne, Switzerland
Phone: *+41-(0)32-322-3876*
Fax: *+41-(0)32-322-3839*
E-mail: *<mail@wendling.ch>*

Key words
Meetings, children, scuba diving

The Poetry Doctor

John Parker

A shocking dive

It was a sunny day,
The dive was early morning.
When we set off on our way
There could have been no warning.

The site was well offshore,
A deep pinnacle of rock.
All was heavenly, calm and clear
When we felt a sudden shock.

We suddenly surged to shallows,
Then as sudden back to depth.
Our ears were very painful
But we hadn't held our breath.

The visibility plummeted,
Water temp fell low,
As cold and dirty water
Surged up from down below.

We surfaced and set off for shore,
Happy with our dives,
Confused at what had happened
Or how they'd saved our lives.

We just could not believe our eyes,
What disaster had befell.
We'd left an inner paradise
To a Tsunami outer hell.

There have been numerous news stories about divers going diving early on Boxing Day in Thailand instead of lying on the beaches and how their dives saved their lives. Their experiences of the Tsunami passing over them whilst underwater vary in degree but their reports of sudden depth variations, and drop in visibility and water temperature seem consistent. What emotions must be felt after such an experience?

<www.thepoetrydoctor.com>

Letters to the Editor

The inner ear and diving

Dear Editor,

I refer to the letter to the Editor 'An additional mechanism for aural injury' by D Taylor and J Lippmann.[1] The authors propose an additional mechanism for aural injury while diving, ie., the cumulative effects of minor symptomless aural injury over a long diving career. They suggest that possible repeated barotrauma could lead to fibrosis and scarring, or that subclinical decompression sickness could lead to aural injury in analogy to the pathological brain lesions that have been found by Knauth et al.[2] To highlight the effects of diving on the hearing system in divers Taylor and Lippmann suggest a study where scuba divers are examined by pure tone audiometry using air- and bone-conduction testing.

We would like to add our own experience to this discussion. Before talking about aural injury one should distinguish between conductive hearing loss that has its origin in the outer or middle ear and sensorineural hearing loss that is represented by inner-ear or retrocochlear damage. Reduction of the hearing function in divers has been reported for more than 50 years. There are several publications that find reduced hearing levels in either professional divers who have to deal with very noisy working conditions or Abalone divers[6] with a history of multiple ear barotrauma and decompression illness.[3,4] These studies do not allow for the conclusion that there are possible long-term effects of diving to the hearing function independent of noise injury or residual hearing loss after acute inner-ear injury.

Skogstad et al compared hearing function in a cross-sectional study on 26 Norwegian construction divers and 26 workshop workers where both groups had been exposed to noise.[5] Auditory function was compared and, surprisingly, divers had less hearing impairment at low frequencies (0.25 and 0.5 kHz). Another study from Skogstad et al examined 54 occupational divers at the beginning of their diving career and three years later.[6] They subdivided the divers into a group of low exposure (less than 100 dives in three years) and one of high exposure (more than 100 dives in three years). For both ears combined, they did not find a statistically significant difference between the groups. Compared with an external control group the divers even had better hearing levels than the general population.[7]

To rule out the effects of noise and multiple acute inner-ear injuries we examined 64 sport divers and compared the results of the pure tone hearing threshold with the results of 63 non-divers.[8] We excluded three divers with a history of acute inner-ear injury and one diver with a tumour in the internal ear canal. We decided to examine sport divers because sport divers have no noise impact underwater and, therefore, the noise levels are comparable to a non-diving population (there were no statistical differences between the groups in terms of noise history).

We divided the participants into three age groups: 10–30 years, 31–40 years and 41–60 years. The sport divers had an average diving experience of 10 years and an average of 650 dives in their history (range 195–2000). We have not found any air conduction hearing loss in any diver or non-diver. Nor have we found any statistically significant differences in bone-conduction hearing function between sport divers and non-divers.

We conclude that in our study diving had no impact on the hearing ability of the tested sport divers who had a respectable diving experience. Notably in the age group 41–60 years we had a low statistical power in the high frequencies and therefore further research is certainly necessary. Until it is proven that diving itself harms hearing function we think it is too early to discuss whether there are subclinical effects of decompression illness or recurrent minor inner-ear barotrauma.

There is certainly a need for well-conducted studies that examine the amount of hearing function impairment and we would like to offer our help in planning such a study. Testing the high frequencies, especially in older divers (above 40 years), leads to high standard deviations with the need for large study groups. In the age group 41–60 in our study we would have needed a study group of 90 persons to achieve a statistical power of ninety per cent to find differences larger than 10 dB. For this reason we are planning a study design that keeps that fact in mind.

Dr. med. Christoph Klingmann
Consultant, Department of Otolaryngology, Head & Neck Surgery
Im Neuenheimer Feld 400, D-69120 Heidelberg, Germany
E-mail: *<christoph.klingmann@med.uni-heidelberg.de>*

Prof. Dr. med. Peter K. Plinkert
Head of the Department of Otolaryngology, Head & Neck Surgery
Im Neuenheimer Feld 400, D-69120 Heidelberg, Germany
E-mail: *<Peter.plinkert@med.uni-heidelberg.de>*

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Key words
Letters to the Editor, diving, ear barotrauma, inner ear barotrauma, inner ear decompression illness, hearing

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Diving medicals

Dear Editor,

I am concerned to hear from divemasters and instructors returning from Queensland, principally having worked in the Cairns region, who report seeing dive medicals signed off for student divers as having been done to the AS4005.1 by registered medical practitioners on our Diving Doctor list. These medicals are all done in less than 15 minutes. Students get only a peak expiratory air-flow test instead of formal spirometry, and tuning-fork hearing tests instead of a formal baseline audiogram as per the Australian Standard. In other words, the proper standard investigations are not being done. Sharpened Romberg score tests are reportedly not being done either.

If these practices are occurring, they make a mockery of all the good work done by SPUMS and having a unified Australian Standard for the past 12 years. These types of medicals are now starting to occur in Victoria, with a doctor doing the “medicals” at the back of the dive shop.

Dr Ross G Wines
PO Box 3027, Doncaster Est,
Victoria 3109, Australia

Key words
Letters to the Editor, medicals – diving, standards

Book review

The art of living under water

Mårten Triewald

96 pages, hardback
ISBN 0-9543834-1-9
London: Historical Diving Society; 2004
Available from the Historical Diving Society, 25 Gatton Road, Reigate, Surrey, RH2 0HB, United Kingdom
Ph: +44-(1737)-249961; Fax: +44-(1384)-896079
Copies can be ordered by e-mail: <books@thehds.com>
Website: <www.thehds.com>
Price £24.00 plus postage and packing (UK £3.50, Europe £4.50, rest of world £5.50)

This enthralling publication is the fourth in a series of monographs published by the Historical Diving Society. Introduced by Michael Fardell and Nigel Phillips this monograph comprises Triewald’s *The art of living under water* together with *Use of the art of living under water*. It is the first edition of either work since 1741 and the first edition to appear in any language other than Swedish.

Fardell and Phillips’ introduction and commentary include a section on the life of Triewald based on an essay by the late Captain Bo Cassel of the Royal Swedish Navy. It is a well-written and informative section of the book with extensive footnotes and suggestions for further reading. It tells us that Mårten Triewald was born in Stockholm on 18 November 1691.

Born into an obviously intelligent family (his father was a master blacksmith and head of the Guild of Blacksmiths, while elder brother Samuel was a diplomat and politician who spoke and wrote nine languages), Mårten expressed considerable disdain for universities throughout his entire life. Instead he was a keen observer of natural phenomena with a seemingly insatiable curiosity and an almost innate ability to understand how things worked and make improvements based on the natural laws.

Before we get onto the subject of this monograph, it is worth looking at the variety of topics that aroused Triewald’s interest. Like so many people of the period he had an interest in almost everything. He published a book about bees, researched and wrote on the ventilation of mines, the germination of old melon seeds, the heating of soil by steam, and the diseases of horses and reindeer. He also investigated treatments for lunatics, the elimination of newts from carp ponds, oyster fishing, and the cultivation of foreign fruit trees.

He devised a system for removing the foul air from large warships and supplying fresh air to the lower decks that was widely praised in Sweden and abroad. He also made important observations of natural phenomena including the aurora borealis. He was elected a Fellow of the Royal Society of London in 1731 and was one of the six prominent Swedes who founded the Royal Swedish Academy of Sciences.

So to the subject matter. In *The art of living under water* Triewald explains the improvements he devised for the common diving bell and also explains the physics involved in diving and using diving bells. Early diving bells were simply upturned bell-shaped containers with an iron ring suspended by chains below the rim for the divers to stand on. Obviously, the further these bells were submerged, the further the water level rose inside them.

Halley's improvements, observed by Triewald at a demonstration in 1709, were the installation of a tap at the top of the bell to let out foul air and the provision of barrels of air that could be hauled down to the bell to replenish its air supply. By lowering the barrels deeper than the bell and providing a hose at the top of the barrel, divers inside the bell could keep the water level down to the rim of the bell. Halley also provided a bench for the divers to sit on, and a view port at the top of the bell to let in light.

Triewald's original bell was similar to Halley's; however, Triewald soon found that this design was too large, too heavy, difficult to transport and expensive to manufacture. So he set about designing a smaller, lighter bell. Of course the disadvantage of a smaller bell is that the small volume means less air for breathing.

Triewald realised that only the top one third of air in the bell was available for breathing by the diver; the other two thirds lay at the bottom part of the bell. In his new bell, he installed a tube that started at the bottom of the bell and spiralled up inside the bell ending near the top. Affixed to the top end was a piece of flexible tube that the diver could put in his mouth in order to breathe fresh air from the bottom of the bell. According to Triewald this also circulated the air in the bell keeping the top part cool.

As this new bell was made of copper, he had the inside tinned to reflect the light that entered from the three view ports on the top and this helped reflect light onto the sea bed. Triewald found that a diver could stay down in this bell for the same length of time as in one three times its size without the need for extra air barrels.

Triewald also introduced into Sweden a number of ingenious tools designed for the salvage of cargo from sunken ships. These tools and their use are described in *Use of the art of living under water*, complete with instructions for raising a sunken vessel. Anyone with an interest in ship salvage will be intrigued to read this section, particularly the way Triewald managed to convince the King of Sweden to grant him sole salvor's rights over most of the Swedish coast.

All in all an excellent read, *The art of living under water* is a hardback publication of 95 pages. Most of the illustrations are from the original publication and the publication has been translated into the English of the period. As usual the Historical Diving Society is to be applauded for having this very rare publication translated and published.

In case you hadn't noticed, I thoroughly enjoyed reading this delightful book. Anyone with an interest in diving history, salvage diving, mechanical history or tinkering with old equipment should read this. A limited edition of just 500 copies, it is available direct from the Historical Diving Society.

Steve Goble
Senior Technical Officer in the Hyperbaric Medicine Unit, Royal Adelaide Hospital

Key words
Book reviews, bell diving, history

SPUMS Journal CD

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Credit card facilities are not available for this.

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(Revised March 2004)

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Documents should be submitted electronically on disk or as attachments to e-mail. The preferred format is Word 97 for Windows. If submitted as a paper version, two printed copies of all text, tables and illustrations should also be mailed. All articles should include a title page, giving the title of the paper and the full names and qualifications of the authors, and the positions they held when doing the work being reported. Identify one author as correspondent, with their full postal address, telephone and fax numbers, and e-mail address supplied. The text should be subdivided into the following sections: an Abstract of no more than 250 words, Introduction, Methods, Results, Discussion, Acknowledgements and References. Acknowledgments should be brief. References should be in the format shown below. Legends for tables and figures should appear at the end of the text file after the references.

Paper versions and electronic files should be double-spaced, using both upper and lower case, on one side only of A4 paper. Headings should conform to the current format in the *SPUMS Journal*. All pages should be numbered. Underlining should not be used. Measurements are to be in SI units (mm Hg are acceptable for blood pressure measurements) and normal ranges should be included.

The preferred length for original articles is 3,000 words or less. Inclusion of more than five authors requires justification as does more than 30 references per major article. Case reports should not exceed 1,500 words, with a maximum of 10 references. Abstracts are also required for all case reports and reviews. Letters to the Editor should not exceed 500 words (including references, which should be limited to five per letter). Legends for figures and tables should be less than 40 words in length.

Illustrations, figures and tables should not be embedded in the wordprocessor document, only their position indicated. All tables are to be in Word for Windows, tab-separated text rather than using the columns/tables option or other software and each saved as a separate file. They should be double-spaced on separate sheets of paper. No vertical or horizontal borders are to be used. Illustrations and figures should be separate documents in JPEG or GIFF format. Please note that our firewall has a maximum size of 5Mbytes for incoming files or messages with attachments.

Photographs should be glossy, black-and-white or colour. Slides should be converted to photographs before being sent. Colour reproduction is available only when it is essential for clinical purposes and may be at the authors' expense. Indicate magnification for photomicrographs.

Abbreviations should only be used in brackets after the complete expression, e.g., decompression illness (DCI) can thereafter be referred to as DCI.

References

The Journal reference style is the 'Vancouver' style *(Uniform requirements for manuscripts submitted to biomedical journals*, updated July 2003. Web site for details: <http://www.icmje.org/index.html>).

In this system references appear in the text as superscript numbers.[1,2] The references are numbered in order of quoting. Index Medicus abbreviations for journal names are to be used (<http://www.nlm.nih.gov/tsd/serials/lji.html>). Examples of the format for quoting journals and books are given below.

1 Freeman P, Edmonds C. Inner ear barotrauma. *Arch Otolaryngol.* 1972; 95: 556-63.
2 Hunter SE, Farmer JC. Ear and sinus problems in diving. In: Bove AA, editor. *Bove and Davis' Diving Medicine, 4th ed*. Philadelphia: Saunders; 2003. p. 431-59.

There should be a space after the semi-colon and after the colon, and a full stop after the journal and the page numbers. Titles of quoted books and journals should be in italics. Accuracy of the references is the responsibility of authors.

Consent

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PROJECT STICKYBEAK

This project is an ongoing investigation seeking to document all types and severities of diving-related accidents. Information, all of which is treated as being **CONFIDENTIAL** in regards to identifying details, is utilised in reports and case reports on non-fatal cases. Such reports can be freely used by any interested person or organisation to increase diving safety through better awareness of critical factors.

Information may be sent (in confidence) to:
Dr D Walker
PO Box 120, Narrabeen, NSW 2101, Australia.

DIVING INCIDENT MONITORING STUDY (DIMS)

DIMS is an ongoing study of diving incidents. An incident is any error or occurrence which could, or did, reduce the safety margin for a diver on a particular dive. Please report anonymously any incident occurring in your dive party. Most incidents cause no harm but reporting them will give valuable information about which incidents are common and which tend to lead to diver injury. Using this information to alter diver behaviour will make diving safer.

Diving Incident Report forms (Recreational or Cave and Technical)
can be downloaded from the DAN-SEAP web site: <www.danseap.org>
They should be returned to:
DIMS, 30 Park Ave, Rosslyn Park, South Australia 5072, Australia.

PROJECT PROTEUS

The aim of this investigation is to establish a database of divers who dive or have dived with any medical contraindications to diving. At present it is known that some asthmatics dive and that some insulin-dependent diabetics dive. What is not known is how many. How many with these conditions die is known. But how many dive safely with these conditions is not. Nor is the incidence of diving accidents in these groups known.
This project is under the direction of Dr Douglas Walker and Dr Mike Bennett. The investigation has been approved by the Ethics Committee of the Prince of Wales Hospital, Randwick, approval number 01/047.

If you are in such a group please make contact. All information will be treated as CONFIDENTIAL.
No identifying details will appear in any report derived from the database.

Write to: Project Proteus
PO Box 120, Narrabeen, NSW 2101, Australia.
E-mail: <diverhealth@hotmail.com>

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