Diving and Hyperbaric Medicine

The Journal of the South Pacific Underwater Medicine Society (Incorporated in Victoria) A0020660B
and the European Underwater and Baromedical Society

Volume 38 No. 2 June 2008

Deep air diving and decompression sickness

35 years of Australian scuba diving fatalities

Lung function in Singapore Navy divers

Oxygen toxicity for the 'teckie' diver

Extreme breath-hold diving

ISSN 1833 - 3516
ABN 29 299 823 713

Print Post Approved
PP 331758/0015

PURPOSES OF THE SOCIETIES

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

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY

OFFICE HOLDERS

President	
Dr Mike Bennett	<M.Bennett@unsw.edu.au>
Past-President	
Dr Chris Acott	<cacott@optusnet.com.au>
Secretary	
Dr Sarah Lockley	<spumssecretary@gmail.com>
Treasurer	
Dr Guy Williams	<spums@fastmail.net>
Education Officer	
Dr David Smart	<david.smart@dhhs.tas.gov.au>
Public Officer	
Dr Vanessa Haller	<vanessa.haller@cdmc.com.au>
Chairman ANZHMG	
Dr David Smart	<david.smart@dhhs.tas.gov.au>
Committee Members	
Dr Glen Hawkins	<hawkeye@swiftdsl.com.au>
Dr Sarah Sharkey	<sarah.sharkey@defence.gov.au>
Dr Scott Squires	<scott.squires@defence.gov.au>

ADMINISTRATION

Membership	
Steve Goble	<spumsadm@bigpond.net.au>

MEMBERSHIP

For details of the different types of SPUMS membership:
Full, Associate, Student, Corporate and Retired
and further information on the Society, or to complete a membership application, go to the Society's **website:**
<www.SPUMS.org.au>
or **E-mail:** <spumsadm@bigpond.net.au>

The official address for SPUMS is:
C/o Australian and New Zealand College of Anaesthetists,
630 St Kilda Road, Melbourne,
Victoria 3004, Australia

EUROPEAN UNDERWATER AND BAROMEDICAL SOCIETY

OFFICE HOLDERS

President	
Prof. Alf Brubakk	<alf.o.brubakk@ntnu.no>
Vice President	
Dr Peter Germonpré	<peter.germonpre@mil.be>
Immediate Past President	
Dr Noemi Bitterman	<noemib@tx.technion.ac.il>
Past President	
Dr Ramiro Cali-Corleo	<irocali@daneurope.org>
Honorary Secretary	
Dr Joerg Schmutz	<joerg.schmutz@hin.ch>
Member at Large 2007	
Dr Phil Bryson	<phil.bryson@ddrc.org>
Member at Large 2006	
Prof. Maide Cimsit	<mcimsit@istanbul.edu.tr>
Member at Large 2005	
Dr Armin Kemmer	<armin@kemmers.de>

ADMINISTRATION

Honorary Treasurer & Membership Secretary
Patricia Wooding
16 Burselm Avenue, Hainault, Ilford
Essex, IG6 3EH, United Kingdom
Phone & Fax: +44-20-85001778
E-mail: <patriciawooding@btinternet.com>

For further information on EUBS and to complete a membership application go to the Society's **website**:
<www.eubs.org>
or **E-mail:** <patriciawooding@btinternet.com>

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

Editor:
Assoc. Prof. Mike Davis, New Zealand
Assistant Editor: Sarah Webb
Christchurch Hospital, Private Bag 4710
Christchurch, New Zealand
Phone: +64-(0)3-364-0045
Fax: +64-(0)3-364-0187
E-mail: <spumsj@cdhb.govt.nz>

European Editor:
Dr Peter Mueller, Germany
E-mail: <pete@ejuhm.de>

The Editor's offering

Diving fatalities in Australia have been documented for over three decades by *Project Stickybeak*,[1,2] and similar efforts are in place in other countries, though none probably as detailed as Dr Walker's. In a previous editorial, I identified five major problems with accident collection systems at that time (2002) and called for greater cooperation between the various individuals and organisations involved in collecting such data to pool their efforts to create a unified reporting system for diving accidents.[3] It is pleasing to see a step in that direction with the DAN Asia-Pacific (DAN A-P) report in this issue.[4] The only previous analysis of the *Stickybeak* data was contained in several papers by Edmonds and Walker from a decade or more ago.[5–7] DAN A-P is progressively taking over the reins from Dr Walker and working towards establishing a comprehensive international database.

I recently assisted DAN A-P in approaching the Chief Coroner and Water Safety in New Zealand for permission to use their data in this process. This does present some ethical dilemmas that have not really been addressed by other groups. In New Zealand, we are in the position that a diving magazine, *Dive New Zealand*, can publish coroner's reports of diving fatalities in full on their website for all to read, as they are in the public domain. However, DAN A-P or I, if we wish to use these data for *bona fide* research, must seek formal ethical permission first, and anonymity of the victims must be assured in any publication; a somewhat illogical anomaly. The release of the full court proceedings into the public domain is intended to contribute to diving safety by allowing divers to see the mistakes others have made and so apply the lessons to their own diving. Unfortunately the right messages are not always clear in coroners' proceedings; some form of independent expert commentary is also needed. As has been remarked before, one wonders whether recreational divers actually learn from others' mistakes!

The lack of accurate denominators, that is, the number of divers and/or dives in the at-risk population, has always been a major problem in the study of the epidemiology of diving accidents, but an increasing number of studies, including two papers in this issue[4,8] and other studies referred to in them, are beginning to provide a much fuller picture of the risks associated with different types of diving. The diving at Bikini is at the extreme limit of open-circuit air/nitrox diving, whilst the brief report in the Letters column on diving at the Poor Knights Islands is an example of mainstream tourist diving, carefully documented. It is becoming clear that risk is not uniform, but rather, as one might predict, multifactorial, and that risk is lower the more tightly diving operations are controlled and the fitter the divers involved.

Editorial news

Diving and Hyperbaric Medicine is now ISI-indexed on Science Citation Index Extended (SCIE) as well as on EMBASE. This is an important step and is an incentive for researchers to submit their work. At the end of this issue is a full set of 'Instructions to authors'. This has been completely revised and will be placed on the Society websites, so submitting authors have no excuse for formatting their submissions incorrectly. The single-page summary version will continue to appear in each subsequent issue.

The composition of the new Editorial Board will be three members from each Society, plus the Editor. The EUBS members are Professor Alf Brubakk, Norway; Dr Peter Mueller, Germany; and Dr Peter Germonpré, Belgium. SPUMS members are Associate Professors Mike Bennett and David Smart, Australia; and Dr Neal Pollock, USA. The intention is to create a small, focused, international group to steer our publication into the future.

The SPUMS ASM, held in late May in Kimbe, Papua New Guinea, and convened by Dr Chris Acott, was very successful. Also, the diving was outstanding; it was good to see healthy coral, and stunning drop-offs. The EUBS meeting in Graz is fast approaching. I wish the organizing committee and all registrants the very best for an excellent meeting, from which I hope many good manuscripts will be submitted to *DHM* in the coming year!

Some members did not receive the March issue until into June. All were posted on April 20th, so this delay was entirely due to international postal services.

References

1 Walker D. *Report on Australian diving deaths 1972–1993*. Melbourne: JL Publications; 1998.
2 Walker D. *Report on Australian diving deaths 1994–1998*. Melbourne: Divers Alert Network Asia-Pacific; 2002.
3 Davis FM. Diving accident surveys. *SPUMS J*. 2002; 32: 178.
4 Lippmann J. Review of scuba diving fatalities and decompression illness in Australia. *Diving and Hyperbaric Medicine*. 2008; 38: 71-8.
5 Edmonds CW, Walker DG. Snorkelling deaths in Australia, 1987–1996. *Med J Aust*. 1999; 171: 591-4.
6 Edmonds CW, Walker DG. Scuba diving fatalities in Australia and New Zealand 1. The human factor. *SPUMS J*. 1989; 19: 94-104.
7 Edmonds CW, Walker DG. Scuba diving fatalities in Australia and New Zealand 2. The environmental factor. *SPUMS J*. 1990; 20: 2-4.
8 Sayer MDJ, Akroyd J, Williams GD. Comparative incidences of decompression illness in repetitive, staged, mixed-gas decompression diving: is 'dive fitness' an influencing factor? *Diving and Hyperbaric Medicine*. 2008; 38: 62-7.

Mike Davis

The front-page photo of a diver's helmet was taken on the *USS Saratoga*, sunk in the Bikini lagoon, The Marshall Islands, during the "Baker" atomic bomb test. (copyright Jim Akroyd)

Original articles

Comparative incidences of decompression illness in repetitive, staged, mixed-gas decompression diving: is ‘dive fitness’ an influencing factor?

Martin DJ Sayer, Jim Akroyd and Guy D Williams

Key words
Decompression diving, mixed gas, wreck diving, DCI rate, dive fitness, acclimatization

Abstract

(Sayer MDJ, Akroyd J, Williams GD. Comparative incidences of decompression illness in repetitive, staged, mixed-gas decompression diving: is ‘dive fitness’ an influencing factor? *Diving and Hyperbaric Medicine*. 2008; 38: 62-7.)

Wreck diving at Bikini Atoll consists of a relatively standard series of decompression dives with maximum depths in the region of 45–55 metres’ sea water (msw). In a typical week of diving at Bikini, divers can perform up to 12 decompression dives to these depths over seven days; on five of those days, divers can perform two decompression dives per day. All the dives employ multi-level, staged decompression schedules using air and surface-supplied nitrox containing 80% oxygen. Bikini is serviced by a single diving operator and so a relatively precise record exists both of the actual number of dives undertaken and of the decompression illness incidents both for customer divers and the dive guides. The dive guides follow exactly the dive profiles and decompression schedules of the customers. Each dive guide will perform nearly 400 decompression dives a year, with maximum depths mostly around 50 msw, compared with an average of 10 (maximum of 12) undertaken typically by each customer diver in a week. The incidence of decompression illness for the customer population (presumed in the absence of medical records) is over ten times higher than that for the dive guides. The physiological reasons for such a marked difference are discussed in terms of customer demographics and dive-guide acclimatization to repetitive decompression stress. The rates of decompression illness for a range of diving populations are reviewed.

Introduction

In 1946, the United States initiated a series of nuclear weapon tests at the Bikini Atoll in the Marshall Islands. Over 12 years a total of 24 tests were carried out at Bikini with a cumulative explosive force of over 78.5 megatons (over 3,400 times the force of Hiroshima); the final test conducted there was in 1958. For the two initial tests, named “Able” and “Baker”, a diverse range of vessels was used with the intention of measuring any differences in the effects of nuclear weapons on different types of naval and merchant craft. The Able test was an airborne delivery that exploded approximately 250 metres in the air above the fleet; Baker was submerged at 25 metres’ sea water (msw) and was exploded subsurface. Both blasts were 23 kiloton detonations (identical to those detonated at Hiroshima and Nagasaki) but although some of the wrecks that still remain in the Bikini lagoon were either sunk during Able or scuttled because of the resulting level of damage, Able was largely ineffective and the majority of the present-day wrecks occurred as a result of the Baker blast. The book *For the Good of Mankind*, by Jack Niedenthal, gives a detailed description of the tests, the ships that were used, and the present-day wrecks as well as the fate of the Bikini islanders.[1]

The residual radiation levels on Bikini were considered to be safe for limited visits to begin in 1996. Almost immediately diving started on the wrecks there. The Bikini wrecks present some major challenges for recreational diving. All the wrecks lie at the bottom of the Bikini lagoon at relatively similar maximum depths of 50–55 msw. In addition, because of the remoteness of Bikini, the associated travel times, the single flight there per week and the consequential desire of the divers going there to dive as many of the wrecks as possible in a finite time, the weekly dive schedule that has developed is dominated by relatively deep, repetitive decompression diving. The necessary dive programme, which is described in more detail below, would certainly be outside that considered normal for recreational diving.

There are a number of issues that contribute toward making the diving situation at Bikini unique. Firstly, the diving operation there, which is run by the Bikini people themselves as the wrecks are now their property, is isolated totally from any other diving operators. There are occasional yachts that do make it to Bikini, but local bylaws insist that a Bikinian or a Bikini-trained dive guide must accompany all diving carried out in the lagoon. As such, the staff at Bikini Atoll Divers are able to record all the dives that are undertaken in the lagoon. Secondly, because of the significant decompression obligations that accumulate during a week’s diving at Bikini, the dives tend to be undertaken in an extremely standard fashion, that is, the same dives are done at the same stage of the week and adhere to the same profiles. Therefore, the diving is replicated fully within and between the respective diving groups. The third aspect that makes this dataset of interest is that there are two very distinct diving populations, the paying customers and the dive guides, both of whom are undertaking the exact same dive profiles and diving programmes and who are incurring the exact same decompression obligations and dealing with them in exactly the same way. The only difference is that, whereas the customer divers are typically diving for a week, the dive guides may be repeating the same dive schedules for as many as 36 weeks in every year.

This account describes the procedures supporting the staged, mixed-gas decompression diving undertaken at Bikini in detail. It then describes the decompression illness (DCI) incident rate as a combined total before comparing the DCI rates between the two groups. Because the authors did not have access to the medical records describing the incidents that occurred at Bikini, the term 'DCI' has been employed throughout the account as there was no way of differentiating between the forms of dysbarism that presented.

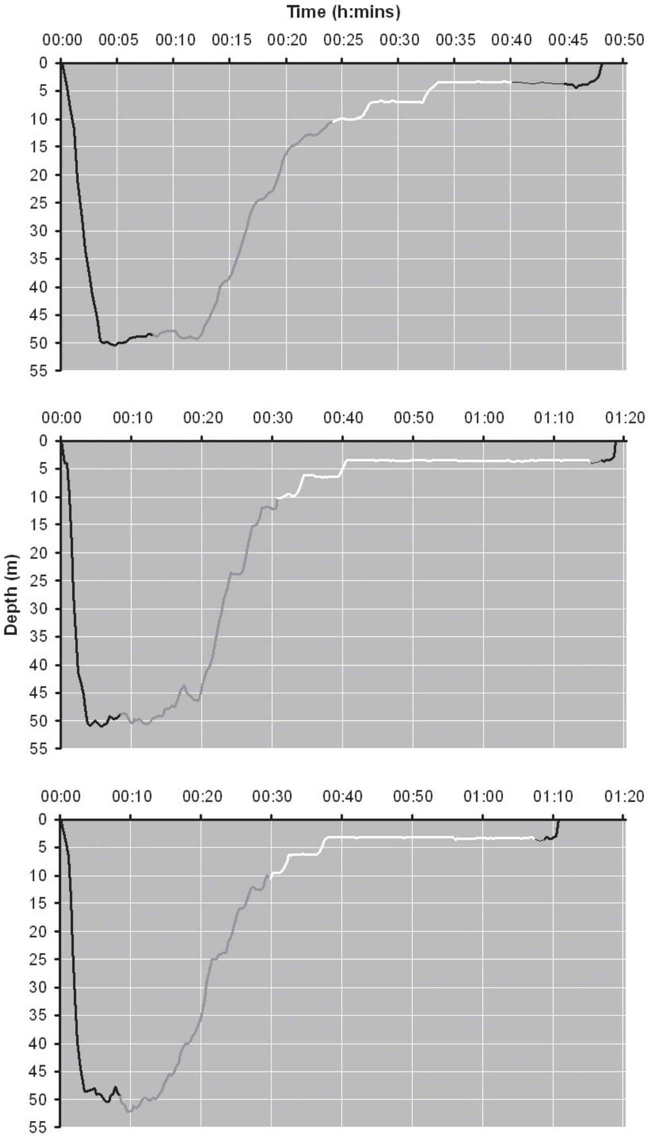
Staged, mixed-gas decompression diving at Bikini

Detailed records of diving trends at Bikini are available from 2004 to 2007. Diving at Bikini is available from the first week of March to the last week of November with a three-week break half way through the year. Therefore, in total, there are 36 diving weeks a year. In a typical week of diving at Bikini, divers perform up to 12 decompression dives: two single dives on days one and seven and five days of two decompression dives per day on days two to six. In order to maximise safety within the context of repetitive decompression diving, and to minimise the decompression obligations, a multi-level, staged air and nitrox decompression schedule is employed.

Selected dive profiles from a series of typical Bikini dives are shown in Figure 1. The area of the Bikini lagoon where most of the dive sites are has a relatively consistent maximum water depth of 50–55 msw. Many of the points of interest are at or near to the seabed and so a significant proportion of the majority of dives undertaken in a week is at depths of 50 msw or greater. When diving at those depths breathing air, one's dive computer will start to register a decompression obligation after approximately 10 minutes of dive time; ascents are initiated typically after 13–20 minutes' bottom time (Figure 1).

The bottom times employed are dictated by the maximum depth of the points of interest, the number of such points, and the size and attitude of the ship. The final ascent tends to occur at or just over 30 minutes into the run time of the dive (Figure 1). The decompression schedule starts at depth on air and is then completed shallower than nine metres by using surface-supplied nitrox with oxygen content of 80%. The minimum decompression schedule, irrespective of what divers' own dive computers may indicate, for every decompression dive at Bikini is shown in Table 1. This involves stops at 24 and 12 msw on air, before performing the nitrox phase of the decompression from 9 msw to the surface. The nitrox phase is conducted with the aid of a multi-level decompression trapeze (with horizontal bars set at 9, 6 and 3 msw) supplied with surface-supplied 80% nitrox with sufficient take offs for all customer divers and dive guides. If a diver's computer indicates additional decompression

Figure 1
Three dive profiles undertaken at Bikini (redrawn from data downloaded from a Mares NEMO™ dive computer). Top profile – dive six of a series, second dive of the day; middle profile – dive seven, first dive of the day; bottom profile – dive nine, first dive of the day. Thick black lines – breathing air and no decompression required; grey lines – breathing air, computer registering decompression required; white lines – breathing 80% nitrox, computer registering decompression required; thin black lines – breathing 80% nitrox and no decompression required.



the diver would undertake this, but if the decompression indicated is below the minimum then the diver defaults to the 'Bikini schedule'. This schedule does not differ markedly from standard air decompression tables in terms of total time when considering a single square-profile dive irrespective of the gas mixtures being employed. However, the Bikini schedule produces a slower 'deep stop' type of ascent profile compared with navy-style tables that maximise time spent at 9, 6 and 3 msw (Table 1).

In recent years at Bikini, most divers have chosen to manage their decompression obligation by using models of dive computers that are capable of being initially set to air but which can then be switched to nitrox during the staged decompression phase of the dive; this can reduce the decompression obligation markedly. Alternatively divers can choose to keep their dive computers set in air mode but employ nitrox during the decompression phase to reduce the risk of DCI. If divers switch their computers to nitrox for the decompression phase then they have to re-set them to air before surfacing.

The main concentration of wrecks within the Bikini lagoon is in close proximity to the dive centre on the main island. As a consequence, the short transfer times between dive sites and the shore mean that surface intervals greater than four hours can be easily accommodated within a normal diving day. In addition, safety is further promoted through a series of comprehensive dive briefings that ensure that divers know the exact time for departing the bottom of the dive as well as the minimum decompression schedule. The dive equipment configurations employed promote redundancy as well as surfacing with air reserves that are adequate to complete decompression obligations even if the surface-deployed trapeze is missed. Typically divers dive with twin 13-litre steel cylinder rigs compressed to 220 bar; divers are instructed to leave the bottom with no less than 140 bar remaining. Finally, divers are advised to pay special attention to their hydration levels during diving activities.

Results

Although there is the potential to undertake 12 dives per week, in reality issues with missed dives caused by transfer delays and missed diving because of illness or for increased safety mean that the average number of customer dives is closer to 10 per week. Dive parties average 10 in number and are always split into two groups, and two dive guides will always dive with each group meaning that all four dive guides will dive an average of 11 decompression dives a week, for 36 weeks.

Over the four years that data have been collated, there have been 27 incidents of presumed DCI in total. With the lack of any medical examination or confirmation by recompression, there remains a level of doubt as to whether all catalogued cases were actually DCI. Conversely the poor communications at Bikini make any follow up near impossible and so there may have been further incidents during airborne flights home. For this study, it is assumed that incorrect diagnoses balance unreported incidents and so the DCI total comprises 26 incidents in the customer-diver group and one incident in the dive-guide group.

Of the total of 27 incidents, only five required evacuations by air to recompression facilities at the earliest opportunity; the five cases that were evacuated all had a neurological component with vestibular manifestations. Air evacuation was either by specially arranged flights from the Marshall Islands airline or by the US military. Specialist treatment and recompression was received either at the Kwajalein military base or, following onward transfer, at Guam or even

Table 1
Minimum decompression schedule for decompression dives at Bikini (see text for explanation). Also shown are the air decompression schedules for three 54 msw dives on the RNPL11 tables[2] modified to fit the same format (BT – bottom time).

Bikini decompression schedule			**RNPL11 decompression table[2]**		
Depth (msw)	**Time** (min)	**Gas breathed**	54 msw BT 10 min	54 msw BT 15 min	54 msw BT 20 min
24	2	air			
24–12	2	air			
12	2	air			
12–9	1	air			
9	2	EANx80		5	5
9–6	1	EANx80		1	1
6	5	EANx80	5	4	9
6–3	1	EANx80	1	1	1
3	10	EANx80	9	14	14
3–0	1	air	1	1	1
Total deco	27		16	26	31
Deco at ≤ 9 msw	20		16	26	31

Table 2
Rates of DCI recorded at Bikini, 2004–2007, in total and for two diver groups: customers and dive guides. Sample numbers: Customers – 1440 divers; Guides – 8 divers

	Average divers per week	Dives per diver per week	Total person dives per year	Total person dives in four years	Cases of DCI in four years	DCI rate per 1,000 person dives
Customers	10	10.0	3,600	14,400	26	1.81
Guides	4	11.0	1,584	6,336	1	0.16
Total	14	10.3	5,184	20,736	27	1.30

Honolulu. No emergency evacuations took place sooner than 16 hours after the onset of symptoms and most took place over 24 hours after; the divers were tended during that time under the supervision of the dive guides with medical guidance obtained by radio-link. The other 22 divers treated had relatively minor symptoms that were predominantly cutaneous DCI. They were treated on-island with vigorous hydration and normobaric 100% oxygen and departed the island as scheduled. Medical records or follow-up accounts were not available to this present study; no diving fatalities were recorded. None of the cases of DCI resulted from physical diving accidents, equipment malfunction or missed decompression. Therefore, all could probably be described as cases of decompression sickness (DCS).

Excepting the caveats on the denominators and the accuracy of diagnosis, expressed in terms of DCI events per 1,000 person dives, the presumed total rate for diving at Bikini is 1.30 (Table 2). Split into the two groups, customer divers had a DCI rate of 1.81 per 1,000 person dives; the dive guides had a rate of 0.16 (Table 2).

Discussion

The present study gives an overall estimated DCI incident rate of 1.30 per 1,000 person-dives (customers 1.81, dive guides 0.16). However, the dive-guide rate was calculated based on a single DCI event; approximately 1,440 divers contributed to the customer DCI value whereas only eight dive guides were employed during the four years of the study. It is likely, therefore, that the total and customer incident rates will be more representative of the performance of the respective populations.

Although the exact number of dives is not available for this study, and the lack of precise medical diagnosis and/or recompression in some cases means that some of the incidence of DCI must be presumed, the study remains notable because the decompression incidence rate for customer divers is markedly higher than that for the dive guides. This is so despite the two populations performing the exact same dives, and incurring and contending with the exact same decompression obligations using the exact same decompression theory and practices. Of note, however, is that all the cases of DCI could be described as pathophysiological in that none occurred through physical diving accidents. The obvious conclusion is that the two populations of divers are physiologically different when it comes to contending with significant decompression commitments.

There are many ways to explain the differences in performance between the two groups, but these can be distilled into two main influencing factors. Firstly, it cannot be assumed that the two groups are physically similar. Physical factors that are known to influence the incidence of decompression sickness (which is most likely the primary form of DCI occurring at Bikini) include gender, age, physical ability and body mass.[3,4] Although not measured, it is possible that the financial cost of getting to and spending a week diving at Bikini, plus the age of the associated history, may attract a more aged population of divers that may be less likely to be of optimal physical fitness. Conversely, the vocation of dive guide tends to attract a younger population that are more likely to be closer to their optimum fitness. However, it is unlikely that these differences alone explain a ten-fold difference in decompression incident rates.

The second major influencing factor, and possibly the more important one, is that of physiological acclimatization. Many studies have long noted that repetitive and recent exposure to pressure reduces the likelihood of developing DCS.[3–9] Even more pertinent to the present study is the suggestion that although the risk of decompression sickness may decline over prolonged series of pressure exposures (as would occur with the dive guides in this study), there is possibly elevated risk early in multi-day diving series (corresponding to the diving customers).[9]

Although a physiological basis of acclimatization is unknown, several theories have been put forward.[9] For example, the decomplementation or depletion theory suggests that small amounts and sizes of bubble generation produced during regular repetitive diving may disrupt the complement system of the blood plasma protecting tissues from larger bubble formations that may occur in subsequent dives.[10] Alternatively, the induction theory postulates that the bubbles generated during earlier dives may cause stresses in tissues and precondition them to subsequent or repeated bubble formation.[11,12] In any event, numbers of detectable bubbles in divers have been recorded to decline over the first 6–8 days of multi-day diving supporting suggestions that DCS is more likely to occur during the first few days of diving operations and following lay-off periods of a week or more.[3,4,9] Both are trends that would include the vast majority of the customer divers who may either not be regular divers or not have dived for several days because of the duration of travel required to get to Bikini.

A review of published DCI/DCS rates (the studies vary in how they report DCS, DCI or both) shows a considerable range from 0.00 to 9.55 incidents per 1,000 dives (Table 3). The rates reported in the present study (0.16, 1.30 and 1.81) fall within the previously published range. The present study is lacking in that the exact number of dives undertaken is estimated and that the decompression incidents can only be presumed in the absence of medical records and/or trial by recompression. However, the same will also be true for many of the studies included in Table 3 and the figures quoted are considered to be largely representative of decompression incidence trends for different diving sectors. Although incident rates at or above 1.00 per 1,000 dives are toward the higher end of the overall range, there can be no doubting that the multi-day decompression wreck diving undertaken at Bikini lies at the more challenging end of the recreational scope. As such, these rates deserve to be ranked against comparable diving groups, diving techniques or diving depths.

Probably the closest study to the present one was conducted on recreational groups diving the wrecks of some of the interned World War One German High Seas Fleet scuttled in 1919 at Scapa Flow in the Orkney Islands in Scotland; estimates of DCI rates in that study ranged from 0.25 to 0.49 per 1,000 dives.[17] Although the maximum depths at Scapa Flow are shallower than Bikini (35–45 msw compared with 45–55 msw), the effects of this depth difference could be offset in part by the influence of the differences in temperature (approximately 6–14°C in Scapa compared with 26–29°C in Bikini) or even effects caused by the differences in the availability of alcohol (alcohol is restricted in Bikini whereas Scapa is in Scotland![29]). Previous studies have all noted the contributing effects of greater water depths, lower water temperatures and alcohol consumption to increased DCS risk.[3]

However, in other comparisons, the headline rates at Bikini compare better: DCI/DCS incident rates for US Navy deep air diving trials to 150 feet sea water (fsw) were much higher at 9.55 per 1,000 dives (although in that study DCI/DCS was not being categorized by medical staff);[13] rates for scuba divers working at 100–165 fsw on oil platforms in the Arabian Gulf were 1.03 per 1,000 dives.[16] In addition, those two studies involved divers who were more likely to be acclimatized to the diving.

With only a single reported occurrence of DCS in the dive guide group (a case of apparent cutaneous decompression sickness) it is not possible to make any firm comparisons of incident rates with other diving populations. Nevertheless, the consequential rate of 0.16 incidents per 1,000 dives for the Bikini dive guides is within the range for general recreational diving (Table 3) and is well below the rates discussed above for deeper and/or wreck diving. In addition, some of the studies summarised in Table 3 report fatality rates (not shown); no fatalities were recorded in the present

Table 3
Published DCI /DCS rates per 1,000 dives, including the present study. Rates in parentheses have been calculated based on a single incident of DCI/DCS. The retrospective definitions of DCI and DCS vary between authorities and may not necessarily include a recompression.

Type of diving	DCI/DCS incidence per 1,000 'dives'*	Reference
US Navy: deep air diving (150 fsw)	9.55	13
UK commercial offshore air diving (1982–86)	3.06	14
UK commercial offshore air diving (1987–88)	1.49	14
US Navy: 4th quartile of no-stop time (USN57)	1.28	15
Commercial (oil platform) scuba 100–165 fsw	1.03	16
Commercial (oil platform) all diving 165 fsw+	(0.76)	16
UK multi-dive multi-day wreck diving	0.25–0.49	17
Tropical multi-dive multi-day	0.29–0.33	18
US Navy shallow no-stop air diving	0.29	15
US Navy: 1st quartile of no-stop time (USN57)	0.22	15
Overseas US military community	0.14	19
Commercial (oil platform) all diving 30–99 fsw	0.14	16
West Canada amateur scuba	0.10	20
Caribbean amateur scuba	0.09	21
UK recreational/amateur divers	0.07	22
UK scientific diving	(0.06)	23
Japan recreational scuba	0.05	24
US scientific diving	0.05	25
International scientific diving	0.04	26
US scientific diving (1998–2005)	0.02	27
Australian scientific diving	0.00	28
Multi-day decompression diving 45–55 msw (all)	1.30	This study
Multi-day decompression diving (customers)	1.81	This study
Multi-day decompression diving (guides)	(0.16)	This study

* Dive is assumed to be a 'person dive', but not all studies make this clear

study. The DCI rate reported here plus the lack of fatalities illustrates, therefore, that the type of deep, multi-day, staged, mixed-gas decompression diving that has evolved at Bikini since it was opened for diving can be undertaken with safety rates that are comparable to other diving sectors operating less challenging diving programmes. It is most probable that factors such as physical fitness and diving acclimatization are contributing to the higher incidences of DCI being recorded for the diving group as a whole.

References

1 Niedenthal J. *For the good of mankind: a history of the people of Bikini and their islands*, 2nd ed. Majuro, Marshall Islands: Bravo Publishers; 2001.

2 BR 2806 *Diving manual.* London: Her Majesty's Stationery Office; 1972.

3 Walker R. Decompression sickness: clinical. In: Edmonds C, Lowry C, Pennefather J, Walker R, editors. *Diving and subaquatic medicine,* 4th ed. Arnold: London; 2002. p. 137-50.

4 Dunford RG, Vann RD, Gerth WA, Pieper CF, Huggins K, et al. The incidence of venous gas emboli in recreational diving. *Undersea Hyperb Med.* 2002; 29: 247-59.

5 Kindwall EP. Diving methods: compressed air work. In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving,* 5th ed. Oxford: Saunders; 2003. p. 17-28.

6 Walder DN. Adaptation to decompression sickness in caisson work. In: Tromp SW, Weihe WH, editors. *Biometeorology*. Proceedings of the Third International Biometeorological Congress; 1963; Pau, France. Oxford: Pergamon Press; 1967. p. 350-9.

7 Elliott DH. Some factors in the evaluation of oxy-helium decompression schedules. *Aerospace Med.* 1969; 40: 129-32.

8 Hills BA. Limited supersaturation versus phase equilibrium in predicting the occurrence of decompression sickness. *Clin Sci.* 1970; 38: 251-67.

9 Doolette DJ. Health outcome following multi-day occupational air diving. *Undersea Hyperb Med.* 2003; 30: 127-34.

10 Ward CA, McCullough D, Yee D, Stanga D, Fraser WD. Complement activation involvement in decompression sickness of rabbits. *Undersea Biomed Res.* 1990; 17: 51-66.

11 Huang K-L, Wu C-P, Chen Y-L, Kang B-H, Lin Y-C. Heat stress attenuates air bubble-induced acute lung injury: a novel mechanism of diving acclimatization. *J Appl Physiol.* 2003; 94: 1485-90.

12 Su C-L, Wu C-P, Chen S-Y, Kang B-H, Huang K-L, Lin Y-C. Acclimatization to neurological decompression sickness in rabbits. *Am J Physiol Regul Integr Comp Physiol.* 2004; 287: 1214-8.

13 Hunter WL, Pope GB, Arsu DA. *Decompression sickness and deep air diving*. Groton, CT: Naval Submarine Medical Research Laboratory Report No: 78-863; 1978.

14 Shields TG, Duff PM, Wilcock SE. *Decompression sickness from commercial offshore air-diving operations on the UK continental shelf during 1982 to 1988*. Aberdeen: Report to the UK Department of Energy TA/93/22/249; 1993.

15 Flynn ET, Parker EC, Ball R. *Risk of decompression sickness in shallow no-stop air diving: an analysis of Naval Safety Center data 1990-1994*. Bethesda: Naval Medical Research Institute Report No: 98-08; 1998.

16 Luby J. A study of decompression sickness after commercial air diving in the Northern Arabian Gulf: 1993-95. *Occup Med (Lond).* 1999; 49: 279-83.

17 Trevett AJ, Forbes R, Rae CK, Sheehan C, Ross JAS, et al. Diving accidents in sports divers in Orkney waters. *Scot Med J*. 2001; 46: 176-7.

18 Davis M, Walker R. Decompression illness in a tropical resort. *SPUMS J*. 2003; 33: 46-8.

19 Arness MK. SCUBA decompression illness and diving fatalities in an overseas military community. *Aviat Space Environ Med*. 1997; 68: 325-33.

20 Ladd G, Stepan V, Stevens L. The Abacus Project: establishing the risk of recreational scuba death and decompression illness. *SPUMS J.* 2002; 32: 124-8.

21 Gilliam B. Evaluation of decompression sickness incidence in multi-day repetitive diving for 77,680 sport dives. *SPUMS J.* 1992; 22: 24-30.

22 Wilmshurst P, Allen C, Parish T. Incidence of decompression illness in amateur SCUBA divers. *Health Trends*. 1994; 26: 116-8.

23 Sayer MDJ, Barrington J. Trends in scientific diving: an analysis of scientific diving operation records, 1970-2004. *Underw Technol*. 2005; 26: 51-5.

24 Nakayama H, Shibayama M, Yamami N, Togawa S, Takahashi M, Mano Y. Decompression sickness and recreational scuba divers. *Emerg Med J*. 2003; 20: 332-4.

25 Lang MA. Smithsonian underwater research. *SPUMS J.* 2005; 35: 145-53.

26 Sayer MDJ. Invited editorial: the international safety record for scientific diving. *SPUMS J*. 2005; 35: 117-9.

27 Dardeau MR, McDonald CM. Pressure related incidence rates in scientific diving. In: Pollock NW, Godfrey JM, editors. *Diving for science 2007; Proceedings of the American Academy of Underwater Sciences 26th Scientific Symposium.* AAUS: Dauphin Island; 2001. p. 111-5.

28 Carter A, Muller R, Thompson A. The rate of decompression sickness in scientific diving at the Australian Institute of Marine Science (Townsville) 1996 to 2001. *SPUMS J.* 2005; 35: 125-30.

29 Wilson CM, Sayer MDJ, Murchison AG, Ross JAS. A review of recent advances in technical drinking and the treatment of technical or extreme drinkers. *SPUMS J.* 2004; 34: 215-7.

Martin Sayer, BSc, PhD, FSUT, is Head of the UK National Facility for Scientific Diving and the Dunstaffnage Hyperbaric Unit,
Jim Akroyd is the Head Divemaster and Resort Manager for the Bikini Atoll Divers Company, and
Guy Williams, MBBS, FRACGP, is a general practitioner in the Melbourne area, a Past-President and current Treasurer of SPUMS.

Address for correspondence:
Dr Martin Sayer
UK National Facility for Scientific Diving, Scottish Association for Marine Science
Dunstaffnage Marine Laboratory, Oban
Argyll, PA37 1QA, Scotland
Phone: *+44-(0)1631-559236*
Fax: *+44-(0)1631-559001*
E-mail: *<mdjs@sams.ac.uk>*

Changes in lung function in Republic of Singapore Navy divers

Si Jack Chong, Teck Wei Tan and Jordan Yu Jin Lim

Key words

Occupational diving, pulmonary function, smoking, health surveillance, medical database

Abstract

(Chong SJ, Tan TW, Lim JYJ. Changes in lung function in Republic of Singapore Navy divers. *Diving and Hyperbaric Medicine*. 2008; 38: 68-70.)

Background: It is recognized that diving may result in long-term adverse effects on the lungs. In the Republic of Singapore Navy (RSN), divers undergo an annual examination, which includes spirometry to detect early any deterioration in lung function, to ensure that personnel are fit to continue their duties. There are few Asian studies on lung function, and none on Asian divers.

Objectives: To analyze the lung function of a group of RSN divers over a five-year period.

Methodology: This was a retrospective study based on the spirometric results of RSN divers during their annual recertification in 2001 and in 2006. There were 116 subjects who underwent the spirometry at the same centre in both 2001 and 2006.

Results: The divers showed a statistically significant increase in mean forced vital capacity (FVC) from 86.1% to 89.5% of predicted ($P < 0.01$) over the five-year period. In addition, the mean forced expiratory volume in one second (FEV_1) improved significantly from 87.2% to 90.2% of predicted ($P < 0.01$). However, there was a statistically significant decrease in FEV_1/FVC ratio from 87.0% to 85.0% of predicted ($P < 0.01$). Mean peak expiratory flow rose from 100.1% to 111.00% of predicted ($P < 0.01$). We did not find any statistically significant relationship between years of service or smoking history and changes in lung function for the divers.

Conclusion: Despite being statistically significant, these findings are probably of minimal clinical significance, but do demonstrate that there is no decline in lung function in these divers over this period of time.

Introduction

It is recognized that diving may result in long-term adverse effects to the lungs. The causes include pulmonary barotrauma and pulmonary oxygen toxicity.[1] Thus, occupational divers must meet rigorous medical criteria because of the physical demands that will be placed on them as well as the potentially hazardous environment in which they work. In the Republic of Singapore Navy (RSN), divers undergo an annual recertification, which includes simple spirometry to detect early any deterioration in lung function, to ensure that personnel are fit to continue their duties. There are few Asian studies on lung function, and none on Asian divers. The purpose of this study was to analyze the lung function of a group of RSN divers over a five-year period.

Subjects and methods

This is a retrospective study comparing the spirometric results of 116 RSN divers during their annual diving medical examinations in 2001 and in 2006. Permission to review these data anonymously was obtained from the Chief Naval Medical Officer and the Commanding Officer, Naval Diving Unit, RSN.

Spirometry was performed at the Diving Medicine Section, Navy Medical Service, using a Vitalog Compact 2™ spirometer procured in 1998, which undergoes monthly self-preventive maintenance. Naval medics from the Diving Medicine Section were trained to use a standard operating procedure for conducting the spirometry to minimise inter-tester variability. Forced vital capacity (FVC, L), forced expiratory volume in one second (FEV_1, $L.sec^{-1}$) and peak expiratory flow (PEF) rate ($L.min^{-1}$) were measured and the FEV_1/FVC ratio calculated. All values were normalised to the percentage of mean predicted values based on the European Respiratory Society's predicted values for males for standardised lung function testing. Mid-expiratory flow rates were not measured.

The results from the subjects' spirometry for the two periods were analyzed. Each spirometry included information about the subject's sex, age, weight, height, years of service and smoking history. Smoking history assessed whether the subject was a non-smoker, had smoked for fewer than 10 years, or smoked for 10 or more years.

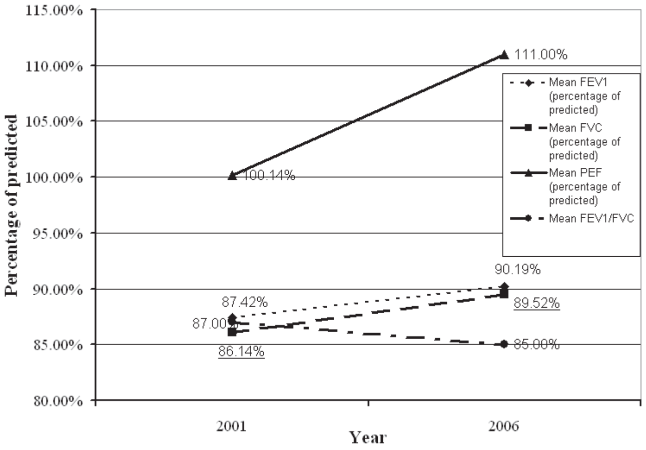
Data input, analysis and tabulation were performed using SPSS for Windows version 10.1. Lung function parameters in 2001 and 2006 were compared by paired *t*-tests. Comparisons between mean years of service and smoking history with lung function parameters were done using the Kruskal Wallis test. The level of significance was chosen to be 0.05.

Results

The subjects comprised 116 divers. They had a mean age of 31.26 (± 5.34) years and mean duration of service of 11.11 (± 5.82) years.

The divers showed a statistically significant increase in mean FVC from 86.1% to 89.5% of predicted ($P < 0.01$) over the five-year period. In addition, the mean FEV_1 improved

Figure 1
Changes in spirometry in 116 RSN divers between 2001 and 2006; FVC – forced vital capacity (L); FEV$_1$ – forced expiratory volume in one second (L.sec^{-1}); PEF – peak expiratory flow rate (L.min^{-1})



significantly from 87.2% to 90.2% of predicted ($P < 0.01$) and the mean PEF improved significantly from 100.1% to 111.0% of predicted ($P < 0.01$). However, there was also a statistically significant decrease in the calculated FEV$_1$/FVC ratio from 87.0% to 85.0% ($P < 0.01$). The results are summarized in Figure 1.

We did not find any statistically significant difference in lung function between divers less than 30 years old and divers who were 30 years or older. In addition, there was no statistically significant change in lung function with years of service for the study group.

Table 1
Relationship between smoking history and spirometric results; FVC – forced vital capacity (L); FEV$_1$ – forced expiratory volume in one second (L.sec^{-1}); PEF – peak expiratory flow rate (L.min^{-1})

Spirometric parameters	Non-smoker	Smoker < 10 years	Smoker ≥ 10 years
Mean FVC ± SD	4.09 ± 0.46	4.00 ± 0.46	4.02 ± 0.40
Mean FVC (% predicted)	90.1%	86.7%	89.6%
Mean FEV$_1$ ± SD	3.48 ± 0.43	3.40 ± 0.43	3.44 ± 0.39
Mean FEV$_1$ (% predicted)	91.2%	86.5%	90.1%
Mean FEV$_1$/FVC ratio ± SD	85.0% ± 7	84.0% ± 5	84.0% ± 6
Mean PEF ± SD	582 ± 83	561 ± 80	583 ± 78
Mean PEF (% predicted)	111.9%	105.4%	111.7%

With respect to smoking, there were 62 non-smokers (53.4%), 19 who had smoked for fewer than 10 years (16.4%) and 35 who had smoked for 10 years or more (30.2%) among the divers. There was no statistically significant relationship between the years of smoking and spirometry results ($P > 0.05$). The results are presented in Table 1.

Discussion

The work of breathing at pressure is increased due to factors such as increase in density of gas and increased turbulence of flow.[1] Continued exposure to dense gas, as encountered in divers, may cause an adaptive response. However, it is also known that diving may result in long-term adverse effects to the lungs, secondary to conditions such as pulmonary barotrauma and pulmonary oxygen toxicity.[2]

A number of longitudinal lung function studies in divers have shown equivocal results. However, there has been a paucity of studies done on Asian divers. In 404 commercial divers employed by companies operating in the North Sea FVC was 120.4% of the predicted value.[3] Although their FEV$_1$ was also increased, it was to a lesser extent. Thus the FEV$_1$/FVC ratio was reduced. It was the authors' belief that divers develop large lungs due to hyperinflation of the alveoli. As the proximal airways do not dilate in proportion, the relationship between FVC and the FEV$_1$/FVC ratio therefore changes.[4] This finding that divers have unusually large lung volumes and a low ratio of FEV$_1$/FVC suggestive of obstructive airways disease or airflow limitation was subsequently replicated in several cross-sectional studies.[5–7]

On the other hand, a longitudinal study of 39 military oxygen divers showed no accelerated decline in lung function over a six-year period.[8] This result was in line with another cross-sectional study that had reported no differences in lung function between a group of 65 military oxygen divers and 67 control subjects.[9]

Our findings are similar to those for commercial North Sea divers.[3] RSN divers demonstrated increased FVC and, to a lesser extent, increased FEV$_1$ over five years, but a reduced FEV$_1$/FVC ratio. This is likely to be due to physiological hyperinflation of the distal airways, with smaller dilation of the larger airways. The measured values for FVC and FEV$_1$ in the present study were lower than predicted values based on European norms. Reference values derived from adult Chinese have been reported to be 5 to 19 per cent lower than those for Europeans.[10] Overall, the findings of this study, despite being statistically significant, are probably of minimal clinical significance, but do demonstrate that there is no decline in lung function in these divers over this period of time.

There are certain limitations to our study. Firstly, we cannot rule out some kind of healthy worker effect, where people with significantly poorer lung function were removed from the selection pool. In addition, we used historical data for comparison rather than conducting a prospective longitudinal study. This meant that data such as diving experience, which is not documented prior to spirometry at our centre, could not be analyzed. This is less than ideal and we aim to follow up with a long-term, prospective study on this topic in the near future.

Conclusion

Overall, these findings, despite being statistically significant, are probably of minimal clinical significance, but do demonstrate that there is no decline in lung function in these divers over this period of time.

References

1 Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving,* 5th ed. Edinburgh: Saunders; 2003.

2 Reed JW, Thorsen E. Long-term pulmonary effects of diving. In: The lung at depth. Lundgren CEG, Miller JM, editors. *Lung biology in health and disease*. New York: Marcel Dekker; 1999. p. 132, 375-93.

3 Crosbie WA, Clarke MB, Cox RAF, McIver NKI, Anderson IK, et al. Physical characteristics and ventilatory function of 404 commercial divers working in the North Sea. *Br J Indust Med*. 1977; 34: 19-25.

4 Crosbie WA, Reed JW, Clarke MC. Functional characteristics of the large lungs found in commercial divers. *J Appl Physiol*. 1979; 46: 639-45.

5 Hong SK, Rahn H, Kang DH, Song SH, Kang BS. Diving pattern, lung volumes, and alveolar gas of the Korean diving woman. *J Appl Physiol.* 1963; 18: 457-65.

6 Davey IS, Cotes JE, Reed JW. Relationship of ventilatory capacity to hyperbaric exposure in divers. *J Appl Physiol*. 1984; 56: 1655-8.

7 Watt SJ. Effect of commercial diving on ventilatory function. *Br J Ind Med*. 1985; 42: 59-62.

8 Tetzlaff K, Friege L, Theysohn J, Neubauer B, Muth CM. Lung function in military oxygen divers: a longitudinal study. *Aviat Space Environ Med*. 2005; 76: 974-7.

9 Moselhi M, Abdallah SM, Azab YM. Pulmonary function in men with intermittent long-term exposure to hyperbaric oxygen. *Undersea Biomed Res*. 1980; 7: 149-57.

10 Ip MS, Ko FW, Lau AC, Yu WC, Tang KS, et al. Updated spirometric reference values for adult Chinese in Hong Kong and implications on clinical utilization. *Chest*. 2006; 129: 384-92.

Si Jack Chong, MBBS, MRCS, is Head of the Medical Doctrine and Training Branch, RSN,
Teck Wei Tan, MBBS, is Training Medical Officer, and Jordan Yu Jin Lim is a Training Medic at the Medical Doctrine and Training Branch, RSN Medical Service.
Address for correspondence:
Dr Si Jack Chong
AFPN 6060, 126 Tanah Merah Coast Road
Singapore 498822
Phone: *+65-6544-4949*
Fax: *+65-6544-4955*
E-mail: *<chong_sj@hotmail.com>*

Review of scuba diving fatalities and decompression illness in Australia

John Lippmann

Key words
Diving deaths, scuba diving, diving accidents, decompression illness, decompression sickness, data, epidemiology

Abstract

(Lippmann J. Review of scuba diving fatalities and decompression illness in Australia. *Diving and Hyperbaric Medicine*. 2008; 38: 71-8.)

Introduction: Recreational scuba diving is a popular activity in Australia, especially around the Great Barrier Reef. Despite efforts by the industry and various governments to reduce the risk, there remains substantial morbidity and mortality as a result of diving. The aim of this study was to estimate the historical and current risk of death and decompression illness associated with scuba diving in Australia.

Method: Data were collected through comprehensive internet searches of various journals and electronic databases using appropriate general and medical search engines, hand searches of relevant journals, searches of the DAN Asia-Pacific dive fatality and decompression illness databases, and consultation with various recompression facilities, and diver certification agencies and dive industry bodies.

Results and Conclusions: There were 566 diving fatalities reported between 1972 and 2006, of which 290 divers were using scuba. In addition, a total of 3,558 divers were treated for decompression illness in Australian chambers during 1995–2007 financial years. Using recent surveys of scuba diving activity, it can be estimated that there were in excess of 1.75 million scuba dives conducted in Australia in 2006. On the basis of the available data, the mortality rate in scuba divers in Australia can be estimated to be 0.57 per 100,000 dives during 2002–2006. Similarly, the incidence of decompression illness during that period in Australia was 10.74 per 100,000 dives or lower. There has been no significant increase in the annual number of scuba diving fatalities from 1972 to 2006.

Introduction

Scuba diving is an exhilarating recreational activity, undertaken around much of the Australian coastline by both Australians and international tourists. Although there are anecdotal reports of people snorkelling in Australia since at least the 1920s, the scuba diving industry began to emerge here in the 1960s. As diving is conducted in a potentially hostile environment there are some inherent risks. Many of these risks can be reduced by factors such as adequate education and training, ensuring adequate fitness and health for diving, appropriate supervision, appropriate and functional equipment, and common sense. However, there is still substantial morbidity and mortality as a result of diving, despite efforts by the industry and various governments to reduce this.

Historically, participants were mainly experienced breath-hold divers who were generally comfortable in the water and who possessed reasonably sound water survival skills. However, as the broader community has become more aware of the beauty of the underwater world and training has been targeted at a broader subset of the population, there has been an increase in the number of divers with relatively poor aquatic skills and sometimes poor fitness and health. In addition, some of the earlier, now ageing, divers who have continued diving have developed medical conditions that may render diving less safe. Unless this is carefully managed by appropriate and adequate participant screening, training, supervision and accident management systems, it can be a recipe for unnecessary morbidity and mortality.

The aim of this study was to estimate the historical and current risk of death and decompression illness associated with scuba diving in Australia by collating and reviewing the available data on scuba diving fatalities, non-fatal decompression illness (DCI) and total scuba diving activity over the period 1972–2006.

Method

As part of its ongoing research into, and reporting of, general diving fatalities in Australia and elsewhere in the Asia-Pacific region, DAN Asia-Pacific obtained ethical approval from Human Research Ethics Committee, Department of Justice, Government of Victoria, Australia to access and report on data included in the National Coronial Information System (NCIS).

DIVING ACTIVITY

Diving activity data from Australia were obtained through hand searches of the South Pacific Underwater Medical Society (SPUMS) journals, consultation with recompression facilities and diving industry bodies and internet searches as indicated in Table 1. In addition, internet searches were conducted to find relevant sporting activity surveys and reports. Finally, the major diver certification agencies in Australia were approached to provide diver certification numbers for 2007.

DIVING FATALITIES

A comprehensive search was made of the two available resources, including hand searching of the reports of 'Project Stickybeak' from 1972 to 2002.[1–6] This project has aimed to provide insights into the causes of scuba diving and snorkelling accidents to improve diving safety. The other major source interrogated was the DAN Asia-Pacific dive fatality database for scuba diving fatalities occurring between 2003 and 2006. DAN Asia-Pacific has continued and expanded the work of Project Stickybeak to create a regional database of diving fatalities. Finally, internet searches were conducted as indicated in Table 1.

Annual fatality rates were analysed using Poisson distribution models to examine any trends that may have occurred. The fatality rate was assumed to be either constant, or to follow a trend that was linearly or exponentially increasing with time.

DECOMPRESSION ILLNESS

Annual decompression illness treatment data for Australia were collected through direct liaison with various recompression centres within Australia and by hand searches of the Hyperbaric Technicians and Nurses Association Annual Reports for the relevant periods.

MORBIDITY AND MORTALITY DATA FROM OTHER COUNTRIES

Comparative diving morbidity and mortality data were sought via hand searches of relevant reports, liaison with reporting bodies, and internet searches on major search engines as indicated in Table 1.

Results

THE DIVING POPULATION

The search resulted in eight sources of information from Australia on diving activity that were deemed suitable for this study. One was a prospective estimate of cylinder fills,[7] one was a prospective survey of dive operators,[8] three were retrospective surveys from dive operators, instructors and training agencies,[9–11] one was a retrospective survey of tourists[12] and two arose from regular retrospective population surveys.[13,14]

Certifications

The first national study of the Australian scuba diving industry, published in 1989, reported that there were 50,550 new scuba divers certified in 1988.[9] By 1991, this figure had risen to 54,153.[8] However, in 2007, it had dropped to around 48,000 (personal communications from the PADI, SSI, NAUI, SDI dive training agencies, 2008.)

Dives conducted

The Victorian dive industry representative body (DIVA) conducted a survey of cylinder filling stations over a one-year period from July 1993 to June 1994. The data collection was prospective, and each station was asked to record each time a cylinder was filled. The authors estimated that there were approximately 77,706 tank fills during that 12-month period.[7] Accounting for divers who had their tanks filled privately, it was reported that around 80,000 scuba dives were performed in Victorian waters that year.

A survey conducted in Queensland in 1994 asked operators who held permits to conduct diving activities on the Great Barrier Reef (GBR) to complete a form estimating the number of scuba dives performed through their operation during that period.[11] It was estimated that approximately 1.3 million scuba dives were conducted on the GBR in 1994. This estimate was reasonably consistent with an earlier report that estimated that approximately one million recreational scuba dives were conducted in Queensland in 1991.[8]

A recent report presented the findings of a survey of the diving activities of overnight visitors to Queensland between April 2006 and March 2007. It was estimated that around 1.2 million international and domestic overnight visitors undertook scuba diving and snorkelling activities while in Queensland. Of these, 345,000 (comprising an estimated 143,000 domestic visitors and 202,000 international visitors) went scuba diving.[12] The authors of this report estimated that a minimum of approximately 1.2 million scuba dives were conducted throughout Queensland over that period. This figure is exclusive of local residents who went diving and did not stay in a hotel.

There is relatively little information about the number of people who participate in diving activities in parts of Australia other than Queensland and Victoria, where the reports discussed above were produced. However, the annual Participation in Exercise, Recreation and Sport (ERASS) reports, which survey exercise involvement in people over

Table 1
Key words and databases used for internet searches

Key words:	Scuba diving / diving / sport* activity or survey*, Australia diving / scuba diving + morbidity, mortality, death*, fatalit* Decompression sickness / decompression illness and incidence or rate, diving death* or incident* or accident* scuba diving / diving / snorkelling and death* or accident
Databases:	PubMed, Medline, Embase, CINAHL, sportDISCUS, Google, Google Scholar, Alta Vista, Yahoo, Dogpile

15 years of age, indicated a participation rate of 0.5% for scuba diving in both 2005 and 2006.[13,14] In these surveys, the estimated number of people who scuba dived in 2005 was 86,800 (95% confidence interval 64,636–108,964), and 78,300 (95% confidence interval 57,190–99,410) in 2006.

The ERASS reports also estimated that the mean number of scuba dives conducted by the diving group was 12 in 2005 and 12.1 in 2006.[13,14] This indicates an annual dive estimate of 1,041,600 in 2005, and 947,430 in 2006 for Australian residents; the average over the two years being 994,515 dives. Confidence intervals could not be determined for this estimate as the raw data could not be accessed. If we assume that:

- the ERASS two-year average for the number of dives done by Australian residents is a reasonable estimate;
- the Queensland estimate of dives by international tourists (750,000) is reasonable and was similar over recent preceding years;
- we can ignore diving tourists to other States, of whom there are relatively few compared with Queensland;

we can estimate that around 1.75 million scuba dives were conducted in Australia in 2006 (i.e., approximately one million by residents and 750,000 by international tourists). These dives were undertaken by approximately 280,000 divers.

DIVING FATALITIES

The search indicated that there were a total of 566 recorded diving fatalities between 1972 and 2006. This includes all of the main diving modalities, i.e., scuba, snorkelling, surface-supplied (hookah) and rebreather (Table 2). The data for 2002 onwards is provisional as it is likely that some additional cases will be added, especially in the later years as it can take several years before all fatality data are received for a particular year. Figure 1 shows the number of currently recorded Australian diving fatalities (all modes) per year from 1972 to 2006 (DAN A-P, unpublished data; [1–6]).

Table 3 compares the average number of diving fatalities from all modes of diving with scuba diving fatalities per decade, or part thereof. The trend models for scuba diving fatalities suggest a slowly increasing trend from an average of 7.0 fatalities per year in 1972 to an average of 9.6 fatalities per year in 2006. However, the trend terms were not statistically significant (likelihood ratio test for the slope term in Poisson loglinear regression, P = 0.12). The data are consistent with a model in which fatality rates are constant: annual fatalities are Poisson-distributed, with a mean of 8.26 fatalities per year. The model that assumes a constant mean fatality rate passed a goodness-of-fit test (chi-squared goodness-of-fit test based on residual deviance, P = 0.08) and a test of overdispersion (Dean-Lawless overdispersion index Tb = 1.2). The suggestion of increasing fatality rate in the trend models may be caused by a recent spate of fatalities (2001–2004).

Figure 2 shows the number of scuba diving fatalities per year from 1972 to 2006.

Table 2
Mode of diving for dive fatalities

Scuba	290
Snorkel	194
Hookah	62
Rebreather	6
Unknown	14
Total	566

Table 3
Average Australian diving fatalities per period (all modes and scuba)

Years	All modes	Scuba
1972–79	12.6	6.8
1980–89	12.8	7.9
1990–99	18.4	9.2
2000–06	23.0	9.1

Figure 1
Number of diving fatalities (all modes) in Australia per year 1972–2006

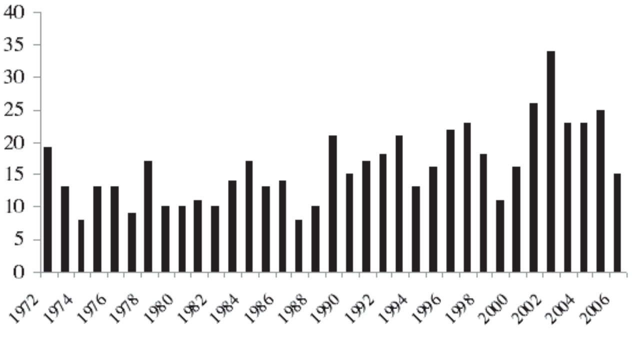


Figure 2
Number of Australian scuba diving fatalities per year 1972–2006

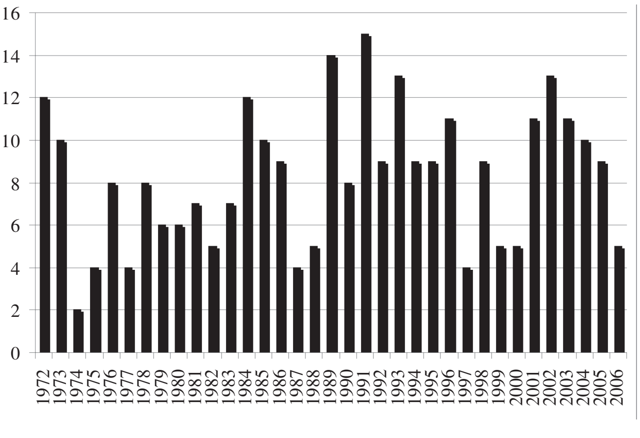


Figure 3
Scuba diving fatalities in Australian States and the Northern Territory 2002–06

Figure 3 shows the number of recorded diving fatalities in various Australian States and Territories between 2002 and 2006 inclusive.

Estimating the risk of fatality in scuba diving

Between 2002 and 2006 there was an average of 10 scuba-related fatalities per year in Australia (DAN A-P, unpublished data; [6]) Working on the basis of 1.75 million scuba dives conducted in Australia in 2006 (and assuming that this is typical for the past few years), and using the average annual number of scuba fatalities of ten, a scuba fatality rate of 0.57 per 100,000 dives (or approximately 3.57 per 100,000 divers) over that period can be estimated.

To further investigate differences within Australia, the 1993 and 1994 surveys from Victoria and Queensland respectively were used to provide the denominator to estimate the scuba fatality rate in these States at that time.[7,11] The five-year averages of scuba diving deaths in Victoria and Queensland 1992–96 were 2 and 6.4 respectively.[1,2] If one assumes that the diving activity in these States over the five-year period was similar to the years surveyed, fatality rates of 2.5 per 100,000 dives for Victoria and 0.49 per 100,000 dives for Queensland can be estimated for that period.

Global risk estimates for scuba diving fatalities

Table 4 shows some other published scuba diving fatality rates from elsewhere in the world.

DECOMPRESSION ILLNESS

The search indicated a total of 3,558 divers treated for DCI in Australian chambers from the financial years 1995 to 2007 (Figure 4; DAN A-P, unpublished data).[21] A decline in the number of divers treated for DCI is clearly evident. This is the case in all States and Territories (excluding Australia Capital Territory where divers are not treated for DCI; Figure 5). This decline is most prominent in Queensland. Between 1995 and 2007 Queensland had the highest percentage of DCI cases, followed by Victoria and New South Wales (Figure 6).

Table 4
Global risk estimates for scuba diving fatalities

Location	Method	Rate per 100,000 dives
BC, Canada[15]	Data evolved from a 14-month prospective survey of cylinder fills in British Columbia. Fatality and DCI incidence rates were calculated based on 146,291 reported air fills; 3 deaths over the period	2.05
United Kingdom[16]	Based on 16 reported fatalities in 2006 and an estimate of approximately 2 million dives from a retrospective water sports activity survey,[17] as well as estimates from the British Sub-Aqua Club (Cumming B, personal communication, 2008)	0.80
DAN America members (worldwide, mainly in USA)[18]	Retrospective review of insurance records of DAN America members who died in a dive accidents 1997–2004	11–18
Okinawa, Japan[19]	Retrospective survey of tank fills and review of mortality in divers in the US military community in Okinawa 1989–95	1.3
Stoney Cove, UK[20]	Retrospective survey of divers at Stoney Cove, a large inland diving site based in a flooded quarry, the A&E records at the local hospital and local coronial records	2.9 (N.B. rate is per 100,000 divers)

Figure 4
Divers treated for decompression illness in Australia 1995–2007

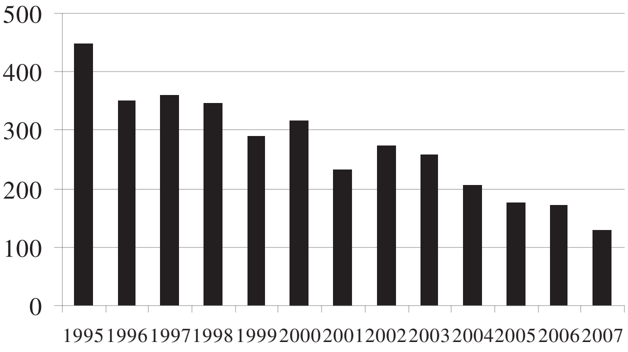


Figure 5
% DCI for various States and Territories

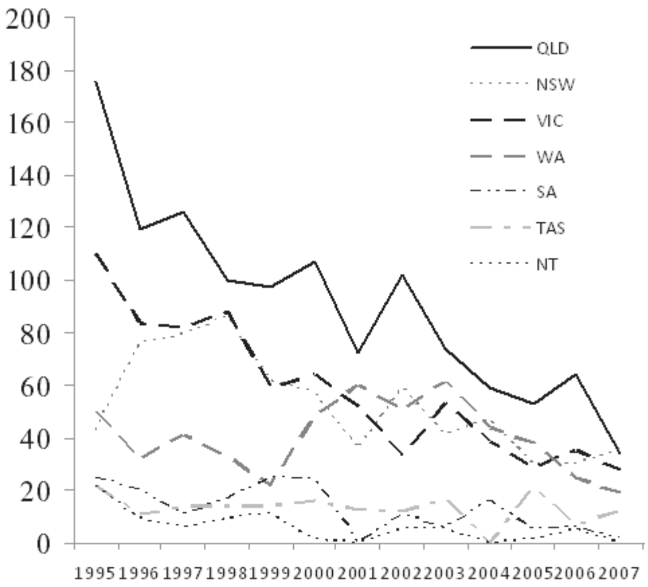
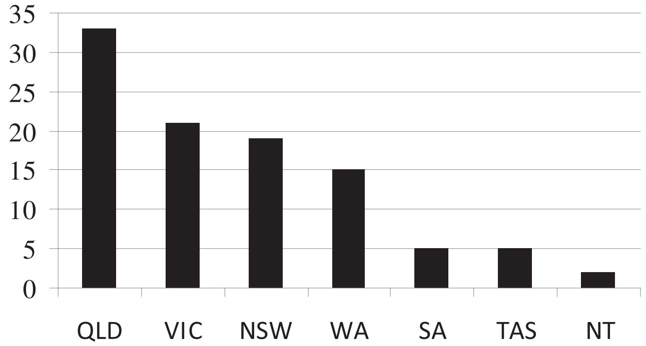


Figure 6
DCI treatment by Australian State and Territory 1995–2007



Estimating the risk of decompression illness

In Australia, between 2002 and 2006, an average of 188 divers were treated for DCI each year. Using the basis of 1.75 million scuba dives Australia-wide, an estimated rate of DCI of 10.74 per 100,000 dives (or approximately 67 per 100,000 divers) for Australia during that period can be calculated. Similarly, in Queensland, between 2002 and 2006 the five-year average of divers treated for DCI was 56.5 (DAN A-P, unpublished data). A conservative estimate of the number of dives conducted in each of these years would be in the vicinity of one million, a figure equal to or considerably lower than early surveys and substantially lower than that projected by the most recent survey (of 1.2 million).[8,10,12] On this basis, the DCI incidence rate in Queensland can be conservatively estimated to be 5.65 per 100,000 dives.

Earlier risk estimates for DCI from Australia and elsewhere

Australia: For comparison, earlier reports on decompression illness rates in Australia include reports from Victoria, Queensland and from Dunsborough in southern Western Australia. As discussed earlier there were an estimated 80,000 dives conducted in Victoria during 1993–94.[9] In that same period 80 divers were treated for DCI at the local chamber, yielding an incidence rate of 100 per 100,000 dives for that year (DAN A-P, unpublished data). Similarly, based on the reported 1.3 million dives conducted in Queensland waters in 1994,[11] and the fact that 130 divers were treated for DCS in Queensland that year (DAN A-P, unpublished data), a DCI incidence rate of 10 per 100,000 dives can be estimated.

The *HMAS Swan* was sunk in 30 metres of sea water off the southern Western Australian coast in late 1997. Over the following almost three-year period, there were a documented 27,000 dives conducted through a single dive operator on the wreck. These resulted in eight known cases of DCI, an incidence rate of 30 per 100,000 dives (DAN A-P, unpublished data).

International: Table 5 shows some other published rates of decompression illness from elsewhere in the world.

Discussion

DIVING ACTIVITY

It has always been a challenge to obtain reliable estimates of the risk of diving in various places. Because of established reporting systems in Australia, it is possible to determine with reasonable accuracy the annual number of diving fatalities or divers treated for decompression illness. However, the most elusive statistic has been a reliable estimate of the number of dives conducted, the required denominator on which to base an estimate of risk. The dive industry experienced a boom

Table 5
Global risk estimates for decompression illness

Location	Method	Rate per 100,000 dives
Mainly Caribbean but also Scapa Flow, Scotland (combined data)[18]	Prospective data collected by DAN America as part of Project Dive Exploration (PDE) study between 1998 and 2004	0–50
Mainly Caribbean[18]	Prospective data collected by DAN America as part of PDE; warm-water divers mainly from the Caribbean; 2001–2004, based on 94,012 recorded dives	19
Scapa Flow, Scotland[18]	Prospective data collected by DAN America as part of PDE at Scapa Flow in Scotland 2001–2004, based on 10,096 dives	188
Caribbean[22]	Prospective survey of 77,680 dives from a cruise ship in the Caribbean from March 1989 to March 1990. 10 reported cases of DCI	12.87
Osezaki, Japan[23]	Prospective 1996–2001 survey of Japanese divers in the Osezaki area. Based on 2,975 respondents who performed a total of 1,140,653 dives with 60 individuals reporting cases of DCI	5.26
BC, Canada[15]	14-month prospective survey of cylinder fills in British Columbia. DCI incidence rates were calculated based on 146,291 reported air fills; 14 cases of DCI over the period	9.57
United Kingdom[17]	Using estimate of 2 million dives from retrospective water sports activity survey for 2006 and treatment data indicating that 105 divers were treated for DCI that year	5.25
Okinawa, Japan[19]	Retrospective survey of tank fills and review of mortality in divers in the US military community in Okinawa 1989–95	13.4
Stoney Cove, UK[20]	Retrospective survey of divers at Stoney Cove, a large inland diving site based in a flooded quarry, the A&E records at the local hospital and local coronial records	3.9 (N.B. rate is per 100,000 divers)

in the mid-1980s to mid-1990s but is generally believed to have declined overall since that time due to economic conditions, competition from other recreational activities and some well-publicised adverse incidents. However, open-water certification numbers appear not to have fallen substantially and, according to the available surveys, scuba diving activity in Queensland appears to be similar in 2006 to what it was in 1994. Despite this, diving activity may well have reduced in certain areas (such as Victoria and South Australia) and increased in others (such as northern Western Australia).

There are several issues of concern with the recent report of tourist activity in Queensland.[12] The first is that the sample size for domestic tourists who dived was very small and, therefore, is likely to be unreliable. In addition, there appear to have been few divers under training sampled in this survey and, given that this represents a substantial proportion of the diving activity in Queensland, this may have led to an under-representation of the amount of diver training activity. In addition, even at their upper 95% confidence limits, the ERASS national estimates are substantially lower than the estimate of domestic tourists (143,000) who dived in Queensland in the following year, creating concern about the reliability of the various estimates.[12–14]

Considering the increasing dive tourism to some coastal regions in Western Australia, and the possible underestimation of the diving in Queensland due to sampling inadequacies (especially in the case of Australian tourists), the author believes that the figure of 1.75 million scuba dives estimated in this report may well be conservative and that the actual number of dives may have been closer to two million. However, this is conjecture and not supported by the evidence available at the time of writing.

FATALITIES

As can be seen from Table 2, approximately 51% of the dive-related fatalities between 1972 and 2006 involved scuba divers and 34% were snorkelling. It should be noted that many of the 11% of divers who were using surface-supplied breathing apparatus (hookah) may not have been diving recreationally. It appears from Figure 1 that there has been a trend of increasing annual numbers of combined diving fatalities from all modalities. This is supported by the data in Table 3, which indicate that the number of annual combined diving fatalities has almost doubled over the last three decades. It appears that there has been a substantial increase in snorkel-related deaths and this will be the subject of a future report. However, such a trend is not so apparent for scuba fatalities alone (as indicated in Table 3) and was not statistically significant.

The large proportion of fatalities in Queensland, as indicated in Figure 2, is likely to be reflective of the far greater diving activity in that State and not indicative of a higher risk of a diving accident in Queensland. In fact, according to this study, the risk of death in Queensland (0.49 deaths per 100,000 dives) is substantially lower than in Victoria (2.5 deaths per 100,000 dives). It is likely that this five-fold difference is largely due to different diving conditions (cold versus tropical), but may also reflect different diving patterns and possibly an effect of regulation of the diving industry in Queensland.

Table 4 indicates that the estimated scuba diving fatality rate for Australia as a whole is below most of the estimates shown for other countries. This may be due to several factors, such as variations in dive conditions and possibly better controlled diving in Australia as a whole, or in parts of Australia. The Canadian and general UK data evolved from predominantly cold-water diving, which is generally more demanding and is likely to lead to a higher accident rate.[15,16] The exception to this is Stoney Cove where the water is also relatively cold but the diving environment is well controlled.[20] The bulk of the diving in Australia is conducted in more temperate or tropical conditions, which are more conducive to safe diving.

DECOMPRESSION ILLNESS

From Figure 4 it is obvious that there has been a very substantial reduction in DCI cases treated over the later years. As indicated in Figure 5, this trend is reflected throughout Australia. This declining incidence may be partly due to reduced diving activity. However, it may also be reflective of better diver education and decompression accident prevention strategies, and improved equipment, such as dive computers that help to control ascent rate. It should be noted that, although the risk of DCI in Queensland has been conservatively calculated above to be 5.65 per 100,000 dives based on an annual activity of one million scuba dives, it is likely that 1.2 million or more dives are conducted in Queensland each year and, on this basis, the risk estimated may be closer to 5 per 100,000 dives or lower.

Interestingly, although it is a common belief that the diving industry in Victoria is smaller than in NSW (this belief being reflected in the ERASS Surveys[13,14]), Figure 6 indicates that more divers have been treated in Victoria. This could be the result of the more demanding diving conditions in Victoria, easier accessibility to a chamber, possibly lower diagnostic thresholds for treatment at the Victorian hyperbaric facility at that time (Millar I, personal communication, 2008) and possibly, in the later years, some divers from northern NSW being treated at the chamber in Brisbane, Queensland. When comparing DCI rates in Victoria and Queensland, the ten-fold difference is, again, likely to be largely due to the colder and more challenging dive conditions in Victoria.

Of interest, at the time the reported data were collected from the *HMAS Swan* in Western Australia, the typical dive profile consisted of two dives separated by a surface interval of one hour.[22] Concerned about the high rate of DCI and in an attempt to reduce this, the dive operator increased the surface interval to two hours. There have subsequently been very few DCI cases resulting from dives on the wreck since then.

Whilst the incidence of dive fatalities in Australia compares favorably with some international data, this is not necessarily the case with reported DCI incidents for Australia as a whole. However, it is likely that the rate of DCI in Queensland compares favorably with other destinations. It should be noted that in the survey from Canada, only 65% of shops surveyed responded to the survey. Therefore, the real accident rate would be lower than that stated because some dives were unaccounted for.[15] In addition, the authors of the DAN America report pointed out that this rate was derived from a limited population sample and cannot necessarily be extrapolated to the diving population as a whole.[18] DAN America members, with an average age of around forty-six years (Orr D, personal communication, 2008) may not be typical of the diving population.

Conclusions

Scuba diving is a sport participated in regularly by an estimated 80,000 Australian residents, and possibly in excess of 200,000 foreign visitors to Australia every year. There are approximately 50,000 new scuba divers trained in Australia annually.

Based on some recent sports and diving surveys it can be estimated that in excess of 1.75 million scuba dives were conducted in Australia in 2006. In addition, it is likely that more than 2 million snorkel dives are conducted annually around the Australian coastline.

The annual number of scuba diving fatalities has increased slightly over the past two decades but not to a statistically significant degree. Based on currently available surveys, the mortality rate in scuba divers in Australia can be estimated to be 0.57 per 100,000 dives or less.

The number of reported cases of decompression illness in divers in Australia has fallen considerably over the past decade and, based on the latest available diving activity surveys, the Australia-wide DCI incidence rate can be estimated to be 10.74 per 100,000 dives.

Conflict of interest

John Lippmann is the Executive Director of Divers Alert Network (DAN) Asia-Pacific. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers.

Funding

Part of this study was funded by The Department of Health and Ageing, Commonwealth Government of Australia as part of a general review of water safety in Australia.

Acknowledgements

Monash University National Centre for Coronial Information for providing access to the National Coronial Information System (NCIS) and Marde Hoy for assisting with this. Dr Douglas Walker for his substantial contributions to the collection of data on dive fatalities, Dr Michael Bennett for his editorial advice and assistance and Dr Adrian Baddeley for his statistical assistance.

References

1 Walker D. *Report on Australian diving deaths 1972-1993*. Melbourne: JL Publications; 1998.

2 Walker D. *Report on Australian diving deaths 1994-1998*. Melbourne: Divers Alert Network Asia-Pacific; 2002.

3 Walker D. Provisional report on diving-related fatalities in Australian waters 1999. *SPUMS J*. 2005; 35: 183-94.

4 Walker D. Provisional report on diving-related fatalities in Australian waters 2000. *Diving and Hyperbaric Medicine*. 2006; 36: 62-71.

5 Walker D. Provisional report on diving-related fatalities in Australian waters 2001. *Diving and Hyperbaric Medicine*. 2006; 36: 122-38.

6 Walker D. Provisional report on diving-related fatalities in Australian waters 2002. *Diving and Hyperbaric Medicine*. 2008; 38: 8-28.

7 McDonald W. Victorian air fill survey 1993-1994. *SPUMS J*. 1994; 24: 194-6.

8 Wilks J. Calculating diver numbers: Critical information for scuba safety and marketing programs. *SPUMS J. 1993*; 23: 11-4.

9 Esguerra R, Ashbolt L Callenbach P. *Report on a study of the Australian diving industry*. Lindfield: Diving Industry and Travel Association of Australia; 1989.

10 Wilks J, Knight J, Lippmann J, editors. *Scuba safety in Australia*. Melbourne: J.L. Publications; 1993. Pref i.

11 Windsor D. A study into the number of dives conducted on the Great Barrier Reef in 1994. *SPUMS J*. 1996; 26: 72-4.

12 *Queensland scuba diving and snorkelling report – visitor activities and characteristics*. Queensland Government; 2007 (internal report only).

13 Standing Committee on Recreation and Sport 2006. *Participation in exercise, recreation and sport. Annual report 2005*. Canberra: Australian Sports Commission SCORS; 2006.

14 Standing Committee on Recreation and Sport 2007. *Participation in exercise, recreation and sport. Annual report 2006*. Canberra: Australian Sports Commission SCORS; 2007.

15 Ladd G Stepan V, Stevens L. The Abacus Project: establishing the risk of recreational scuba death and decompression illness. *SPUMS J*. 2002; 32: 124-8.

16 Cumming B. NDC Diving Incidents Report 2006. British Sub-Aqua Club. Available online: <http://www.bsac.org/page/805/incident-report-2006.htm>. Accessed 17 June 2008.

17 *Watersports and leisure participation survey 2006*. Guildford Surrey: Arkenford; 2007.

18 *Annual diving report, 2006*. Durham, NC: Divers Alert Network; 2007.

19 Arness MK. Scuba decompression illness and diving fatalities in an overseas military community. *Aviat Space Environ Med*. 1997; 68: 325-33.

20 Hart AJ, White SA, Conboy PJ, Bodiwala G, Quinton D. Open water scuba diving at Leicester: five years' experience. *J Accid Emerg Med*. 1999; 16: 198-200.

21 Gilliam B. Evaluation of DCS incidence of multi-day repetitive diving for 77,680 sports dives. In: Lang MA, Vann RD, editors. Proceedings of the Repetitive Diving Workshop. Cost Mesa, CA: American Academy of Underwater Sciences; 1992. p. 15-24.

22 Australasian hyperbaric treatment data. In: *Proceedings of the Annual Scientific Meetings of the Hyperbaric Technicians and Nurses Association, 1995–2007*. Annual reports available from: the Editor, *Offgassing*, The Journal of the Hyperbaric Technicians and Nurses Association Inc, <HTNAJournal@bigpond.com>

23 Nakayama H, Shibayama M, Yamani N, Togawa S, Takahashi M, Mano Y. Decompression sickness and recreational scuba divers. *Emerg Med J*. 2003; 20: 332-4.

John Lippmann, BSc DipEd OAM, is the Executive Director of the Divers Alert Network Asia-Pacific.

Address for correspondence:
PO Box 384, Ashburton VIC 3147
AUSTRALIA
Phone: *+61-3-9886-9166*
Fax: *+61-3-9886-9155*
E-mail: *<johnl@danasiapacific.org>*

Review articles

Breath-hold diving: performance and safety

Neal W Pollock

Key words
Breath-hold diving, freediving, deep diving, physiology, ascent, hypoxia, safety, review article

Abstract

(Pollock NW. Breath-hold diving: performance and safety. *Diving and Hyperbaric Medicine.* 2008; 38: 79-86.)

Breath-hold diving was probably first conducted shortly after humans ventured into the water realm. Early efforts likely centred on exploration, hunting and gathering. The fundamentals of breath-hold diving have not changed since these earliest efforts but the performance records have undergone an almost unbelievable evolution. Single breath-hold durations (inspiring air) of 9:15 min:s and 8:00 min:s and maximal vertical transits of 214 metres' sea water (msw) and 160 msw for males and females, respectively, are daunting. Competitive performance requires genetic predisposition, motivation and training in both fundamentals and a variety of advanced techniques. The record of safety within the competitive arena is impressive but care must be taken to ensure that the appropriate practices and procedures are communicated to all levels of enthusiast. Current performance records, strategies to optimize performance, and recommendations for safe breath-hold activity are presented.

Introduction

Breath-hold or apnoea diving, increasingly known as freediving, describes in-water activity involving some diving equipment, but no self-contained or surface-supplied breathing gas. Freedivers operate in a wide range of environments and pursue an assortment of goals. Leisure recreation may range from surface snorkelling with little or no voluntary breath-hold to modest surface dives with variable breath-hold effort. Organized sports, typically conducted in swimming pools, include underwater hockey and underwater rugby. Exploration, hunting/spearfishing and other food-gathering activities can vary dramatically with the individual and targets. Formal competition in breath-hold diving has grown rapidly in recent years as an extreme sport. Numerous disciplines are now recognized by the International Association for the Development of Apnoea (AIDA; http://www.aida-international.org/) (Table 1).

Early wisdom held that the safe diving depth during breath-hold was limited by the ratio between total lung capacity and residual volume. The belief was that lungs compressed below residual volume would suffer from barotrauma. For example, a person with a total lung capacity of 6.0 L and a residual volume of 1.2 L would have an approximate maximum safe depth limit of five atmospheres absolute, or 40 metres' sea water (msw). This proposition has been clearly disproved through freediving competition. The accelerated advance of performance records within the past decade reflects the growing enthusiasm for the sport. The greatest depths are achieved in the No-Limits discipline, with a timeline of record depths shown in Figure 1. The current male depth record is 214 metres' sea water (msw), set by Herbert Nitsch of Austria in June 2007. The current female record is 160 msw, set by Tanya Streeter, originally from Britain, in August 2002. The current record for static breath-hold is 9:15 min:s, set by Tom Siestas of Germany in May 2008. The current records in all AIDA-recognized disciplines are shown in Table 1.

Chasing record breath-hold performance

The best breath-hold performance will be achieved through a combination of genetic predisposition, motivation, training and physiological manipulation. The ability to pick your parents may one day be unnecessary as the science of genetic manipulation evolves, but for now the edge still goes to the naturally endowed apnoea athlete. Motivation is an interesting

Figure 1
World record depths in freediving no-limits competition

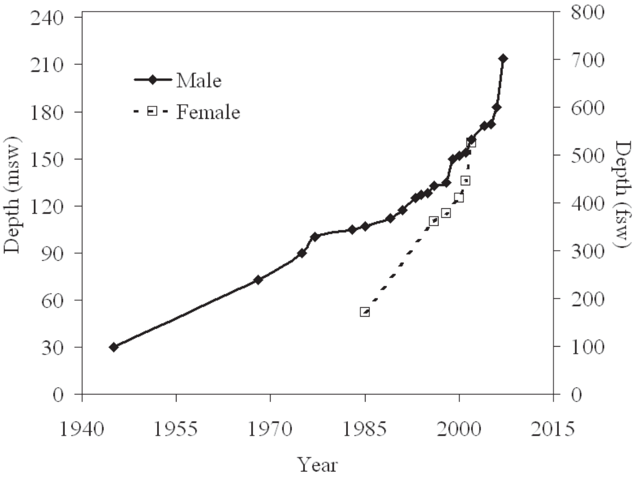


Table 1
AIDA-recognized competitive freediving disciplines and records as of 15 May 2008 (*horizontal swim)

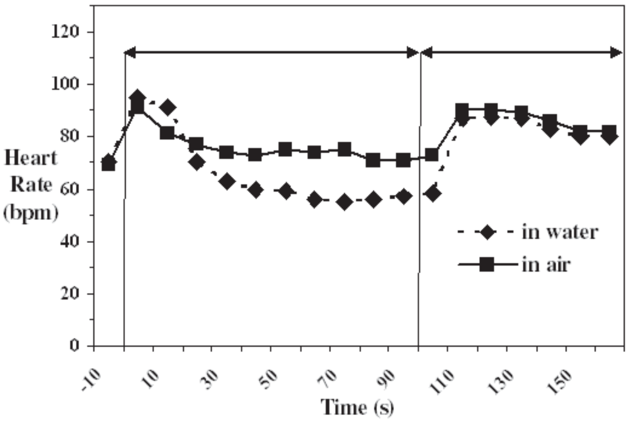
Discipline	Description	Record performance Male	 Female
		Time (min:s)	
Static Apnoea	Resting, immersed breath-hold in controlled water (usually a shallow swimming pool)	9:15	8:00
		Distance/depth (m [ft])	
Dynamic Apnoea – with fins	Horizontal swim in controlled water	244 (801)*	205 (673)*
Dynamic Apnoea – no fins	Horizontal swim in controlled water	186 (610)*	149 (489)*
No-Limits	Vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver	214 (702)	160 (525)
Variable Weight/Ballast	Vertical descent to a maximum depth on weighted sled; ascent by pulling up a line and/or kicking	140 (459)	122 (400)
Constant Weight – with fins	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	112 (367)	90 (295)
Constant Weight – no fins	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	86 (282)	57 (187)
Free Immersion – no fins	Vertical excursion propelled by pulling on the rope during descent and ascent; no fins	108 (354)	81 (266)

factor when viewed in the context of predisposition. While increasing in popularity, it is still the minority who pursue the challenge of breath-hold competition. The seemingly meteoric rise of some newcomers begs the question about the undiscovered potential outside of the breath-hold community. The factors of training and physiological manipulation are intertwined; training in physiological and, in some cases, anatomical manipulation is a major aspect of the preparation process.

Breath-hold basics

Physiological alterations begin with head-out immersion in water. Intrathoracic blood volume is increased while vital capacity is decreased. Facial immersion, particularly in cool water, initiates the classic diving reflex observed during breath-hold. Heart rate and cardiac output are decreased and peripheral vasoconstriction and blood pressure are increased.[1–3] An example of heart-rate response to facial immersion is depicted in Figure 2.

Figure 2
Heart rate response to resting apnoea in air and during facial immersion (recreated from reference 1)



More recently, the spleen has been appreciated as a source of red blood cells available to the body during breath-hold.[4–6] A modest decrease in splenic volume follows the initiation of breath-hold during facial immersion. One study of repetitive breath-hold performance was conducted with two-minute rest intervals, before splenic volume had recovered. The duration of the second maximal breath-hold was about 20% longer for both trained breath-hold divers and untrained subjects, and only five per cent longer for splenectomized subjects.[6] Greater changes in maximum duration from first to second breath-hold have been seen in other studies using similar procedures but not studying splenic response.[7,8]

A period of apnoea follows every inspiration. It is the duration of the apnoea that sets apart the unconscious breath-hold from the voluntary breath-hold. The partial pressure of carbon dioxide (PCO_2) in the arterial blood is the primary agent driving the respiratory cycle. The PCO_2 in the unconscious control cycles from a low of 40 mm Hg at end-inspiration to approximately 45 mmHg at pre-inspiration. Voluntary breath-hold can allow alveolar PCO_2 to reach into the range of 60 mmHg for the motivated individual. The drive to breathe increases concomitant with the rise in PCO_2 until the breath-hold is broken.

Maximal breath-hold has been described as a two-phase event.[9] The 'easy-going' phase ends at the physiologic breakpoint, with alveolar PCO_2 approximating that at the end of unconscious breath-hold. The 'struggle' phase follows with increasingly active involuntary respiratory muscle contraction until the 'conventional' breakpoint is reached and the breath-hold is broken. Breath-hold time can be increased by either delaying the physiological conditions reaching breakpoint status or increasing the individual tolerance to such conditions.

Extreme breath-hold efforts are not without risk. Injury and death do occur, most commonly amongst less experienced divers. Techniques for improving breath-hold performance are best practised in a controlled setting with responsible oversight.

Manipulative practices

REDUCE METABOLIC DEMAND

One of the simplest ways to extend breath-hold time is to reduce the physical effort involved and thus the metabolic demand. Comparison between the record performances of the no-fin and fin sub-categories of the breath-hold disciplines of Dynamic Apnoea and Constant Weight illustrates the energetic advantage of using fins. The Static Apnoea and No-Limits disciplines demonstrate the extremes of what can be accomplished on a single breath of air if minimal physical effort is involved.

DISTRACTION

Various techniques can be employed to prolong breath-hold time. A simple strategy involves the use of distraction. For example, encouraging relatively inexperienced breath-hold divers to meet the onset of the serious urge to breathe with an attempt to swallow can markedly improve performance. It is difficult to swallow underwater in this condition and the distraction can reduce the sense of urgency. This or other distracting techniques can be used to demonstrate the flexibility in the breathing urge.

HYPERVENTILATION

The most well-known manipulative practice used to increase breath-hold time is hyperventilation. The basis for its effectiveness is the 140–170-fold higher concentration of CO_2 in the arterial blood than that of room air. Increasing the ventilatory exchange beyond that required to meet metabolic needs can produce a rapid drop in arterial PCO_2, potentially reducing it to 20 mmHg or lower with 60 s of aggressive hyperventilation (an arterial PCO_2 of 20 mmHg corresponds to the point at which peripheral symptoms will often be noticed, commonly lightheadedness, possible visual disturbances, and a tingling in the fingertips). A breath-hold commenced after hyperventilation can be prolonged substantially since the hypercapnic drive to breathe will not develop until the normal trigger point is reached. The primary risk of pre-breath-hold hyperventilation is hypoxia. While the arterial PO_2 is slightly increased with hyperventilation, this is nowhere near the magnitude of the decline in arterial PCO_2. Serious hypoxia can develop long before the hypercapnic trigger is reached. A weak hypoxic ventilatory drive could result in unconsciousness before the diver feels any urge to breathe. Hyperventilation can be dangerous, particularly when the potential for unconsciousness without warning is ignored or disbelieved. The likelihood for disaster is increased by the very normal mindset of 'if a little is good, more is better'. A major problem in communicating the risk is the lack of physical evidence left to establish hyperventilation as an agent in breath-hold fatalities. It very likely plays a significant role in a large number of unexplained cases, a problem observed but not overcome in almost 50 years.[10–13]

Apnoeic hypoxia

Loss of consciousness occurring at or near the maximum depth of a dive could follow extreme hyperventilation. This can be described as static blackout. The situation rarely develops during vertical breath-hold dives since the compression effect of descent increases both PCO_2 and PO_2, effectively providing a safety net for the breath-hold diver at depth. The greater hazard develops during surfacing, when the reduction in ambient pressure makes both PCO_2 and PO_2 fall. The PCO_2 will move more slowly towards the breakpoint and the PO_2 will decline faster than explained by metabolic consumption alone. As PO_2 moves beyond the shoulder into the steepest portion of the oxygen dissociation curve, haemoglobin saturation and arterial oxygen content will fall precipitously. A state of problematic hypoxia can develop rapidly, particularly in the final stage of ascent where the relative rate of pressure reduction is the greatest. Even a strong hypoxic drive could be ineffective at this point. Loss of consciousness will commonly occur just before or within 10–15 s of surfacing before the oxygen in the first inspired breath can reach the brain. This condition is best referred to as hypoxia of ascent. While many will know it as 'shallow water blackout', this term is ambiguous (and therefore not recommended) since it was first used to describe unconsciousness in closed-circuit oxygen divers likely caused by high PCO_2.[14]

GLOSSOPHARYNGEAL BREATHING

The use of glossopharyngeal breathing to alter normal pulmonary volumes has gained popularity within the competitive freediving community and as a recent topic of academic study. Glossopharyngeal insufflation (also known as 'lung packing' or 'buccal pumping') is used to increase available gas above normal vital capacity. This involves gulping in a series of small volumes of air after the point of normal full inspiration has been reached, increasing both volume and intrapulmonary gas compression.[15–21] The volume of air held can be increased substantially, in one case by as much as 4.2 L (47%) over measured vital capacity.[20] Most efforts are less extreme, one study documenting a mean (± standard deviation) increase of 1.1±1.3 L (18%) over measured vital capacity.[22] Glossopharyngeal insufflation increases both the available O_2 stores and the depth at which pulmonary compression will become problematic. Aggressive efforts may result in a decreased arterial pressure, increased heart rate, reduced stroke volume, increased transpulmonary pressure and pulmonary vascular resistance, dizziness, tunnel vision, syncope,[23] and possibly pulmonary barotrauma.

Glossopharyngeal exsufflation (also known as 'reverse packing') involves use of the muscles of the glossopharynx to draw air out of the lungs and into the mouth when the lung volume is near or below residual volume.[16,20] This technique can be used to enable middle ear pressure equalisation at depths deeper than would otherwise be possible. Glossopharyngeal exsufflation can allow an additional 0.2–0.4 L to be withdrawn from lungs at residual volume.[24] Breath-hold dives initiated with the lung at residual volume ('empty lung') can also be used to simulate the effects of deeper diving under shallow and more controlled conditions. These effects are even greater if glossopharyngeal exsufflation is employed. A recent observational study followed experienced breath-hold divers conducting repetitive empty lung dives with self-selected amounts of glossopharyngeal exsufflation in a single 20-minute session with dives to depths of 3–6 m. The research team documented reversible changes in voice and compromised pulmonary diffusion capacity, irritation and slight congestion in the larynx and, in some cases, minor bleeding originating somewhere below the vocal folds.[24]

EQUALISATION TECHNIQUES

The need to equalise the sinus and middle ear spaces can be a major challenge of rapid descent through the water column. Equalisation by standard techniques, primarily Valsalva, requires concentration and some degree of muscular effort. As discussed above, glossopharyngeal exsufflation may be used to facilitate this effort with the added cost of removing oxygenated gas from the lungs. An alternative used by some competitors is to fill the spaces with liquid to reduce the effort, time and gas costs associated with equalisation. A recent case report describes the ability of a previous world record holder in the No-Limits category to passively fill his sinuses and auditory tubes with seawater during descent to obviate the need for further equalisation.[25]

MODIFICATION OF SUBSTRATE UTILIZATION

Increased competition means that small advantages can make a critical difference in final ranking. The respiratory exchange ratio (RER) is determined from expired gases to estimate whole body metabolic status, and is most meaningful under steady-state conditions. RER is computed as the volume of CO_2 expired divided by the amount of O_2 consumed. Resting RER normally approximates 0.82–0.85. Lower values indicate a shift towards fat metabolism (with a lower oxygen cost per unit energy provided) and higher values indicate a shift towards carbohydrate metabolism (with a higher oxygen cost per unit energy provided). RER rises as a function of exercise intensity, one reason to encourage minimal effort during breath-hold. Dietary intake and digestive status can also influence RER. The question recently addressed was whether dietary manipulation could affect breath-hold performance. A study of experienced breath-hold divers with depleted carbohydrate stores demonstrated changes in breakpoint CO_2 and O_2 but no change in maximal breath-hold time.[26] Conversely, a study of untrained breath-holders documented maximal breath-hold time increased by fasting and decreased by carbohydrate-rich food intake.[27] It is expected that further work, either academic or training-based, will be conducted in an effort to develop optimal dietary patterns for competitors.

Adaptation to breath-hold

The question of predisposition versus adaptation frequently accompanies extreme performance. For example, vital capacity in breath-hold divers is commonly observed to be, on average, larger than predicted.[16,20,21,28] While some of this may reflect individual predisposition or self-selection, there is also likely a response to training. Five- to six-week training programmes in glossopharyngeal insufflation have been shown to increase vital capacity within groups of normal, healthy females and elite female swimmers.[29,30]

A more open question concerns respiratory drive. One study of competitive underwater hockey players documented a marked difference in response to CO_2 rebreathing (hypercapnic ventilatory response) in comparison with dry-land athletes.[31] The underwater hockey players' responses were on the low end of the normal range, a pattern similar to that seen in a more recent study of two elite breath-hold divers.[32] Another recent study suggested that underwater hockey players might maintain higher resting end-tidal PCO_2 than control subjects,[33] but the low values for the control group suggest that hyperventilation due to an anticipatory response and/or as a response to the mouthpiece could explain the difference.

A small study of sympathetic nerve activity during tests of hypercapnic ventilatory response found similar patterns for nine elite breath-hold divers and a control group comprising individuals who were not regular divers.[34] Another small study of four elite breath-hold divers documented the individual response to air hunger while the subjects were mechanically ventilated with different levels (randomised) of hypercapnic gas. The subjective ratings were within the range of normal air hunger responses for three of the four subjects. The fourth reported no sensations corresponding to air hunger.[32]

The focus on hypercapnic responses in breath-hold research is likely influenced by the common description of the hypoxic drive being weak and therefore a risk factor following hyperventilation. Studies of hypoxic drive and breath-hold, however, indicate that the strength of the two drives may be much more comparable than previously thought.[35,36] An observational study of eight amateur, trained breath-hold divers evaluated respiratory conditions before and after static apnoea dives.[37] Hyperventilation before breath-hold reduced end-tidal PCO_2 to 18.9±2.0 (15.6–21.9) mmHg (mean ± standard deviation with range). Post-breath-hold end-tidal PCO_2 was 38.3±4.7 (29.5–43.4) mmHg and end-tidal PO_2 was 26.9±7.5 (19.6–42.2) mmHg, leading the authors to conclude that the hypoxic drive may have been the dominant factor in terminating breath-hold. The simple expedient of breathing oxygen pre-dive is well known to extend breath-hold time considerably in the laboratory, but is certainly not to be recommended in the open water.

One study of splenic contraction during breath-hold compared trained apnoea divers and untrained controls.[6] The trained divers demonstrated a significantly greater reduction in splenic volume (18% versus 14%), but the difference is small enough to be of limited practical importance.

Breath-hold safety

TRAINING AND SUPERVISION

Safety in breath-hold, as with most endeavors, is best ensured by forethought and a respect for reasonable guidelines. The impressive safety record maintained in competitive events[38] can be replicated at other levels of involvement only if an appreciation for both the techniques and risks is provided. Training programmes should be available to teach appropriate procedures and protocols to ensure safe participation. As a fundamental rule, breath-hold activities should be conducted with a responsible partner or team regardless of the conditions. There are many examples of individuals found dead with no evidence of trauma. While often impossible to confirm, it is likely that manipulative breath-hold practices were involved and that the ready presence of others could have provided timely intervention in many cases.

Effective direct supervision requires an awareness of the diver's activity during the pre-breath-hold period, close monitoring throughout the breath-hold and 30-second post-breath-hold periods, attention to any sign of compromise, and the ability to provide immediate and effective support in case of a problem. Direct supervision can be applied to many situations. A simple two-person, one-up-one-down buddy team with committed direct supervision can provide effective protection for shallow diving situations. A group of three (one-down, two-up) may be preferable as dive depths increase. Allowing a recovery period of twice the dive duration is a reasonable practice. It also ensures that one of the divers available at the surface for backup is substantially rested. Problems can arise when dive depths approach individual limits. The breath-hold performance of a potential rescuer may be badly compromised by the stress of an emergent situation.

More advanced activities require a more extensive support network, potentially employing counterbalance weighting and/or buoyancy retrieval systems and/or in-water rescue divers.[39] The rarity of serious accidents within breath-hold competitions is a testament to thoughtful planning, proper equipment and monitoring, and emergency protocols.

BUOYANCY

Buoyancy is an important consideration for breath-hold divers. Some choose to wear extra weight to minimize the effort associated with descent. The hazards during ascent, however, far outweigh the benefits of an easy descent. Buoyancy is lost under pressure, more so when a compressible suit is worn, thus a considerable degree of negative buoyancy may exist at depth. This will increase the effort required to ascend (increasing the rate of oxygen consumption and decreasing safe breath-hold time). As discussed, hypoxia of ascent is most likely to develop in the final stage of the ascent. A diver negatively buoyant near the surface will rapidly sink if consciousness is lost. This will make it more difficult, or in some cases impossible, for a timely rescue to be completed. Overweighting is frequently a contributing factor in fatal cases attributed to hypoxic loss of consciousness.[40] For safety reasons, it is recommended that divers are weighted to be neutrally buoyant at a depth of approximately 5 msw.

HYPERVENTILATION

A balance between prolonging breath-hold and mitigating the risk of loss of consciousness is possible by restricting the amount of pre-breath-hold hyperventilation. Limiting hyperventilation to two or three maximal ventilatory exchanges immediately prior to breath-hold will increase breath-hold time but is probably also safe for most leisure circumstances. An early review of non-fatal cases of loss of consciousness attributed to pre-breath-hold hyperventilation described much more extreme efforts.[11]

The competitive freediving community is generally well informed of the hazards of hyperventilation and accepts the attendant risks of more aggressive use of the technique. Most competitors employ some degree of hyperventilation.[22,38] A critical factor, though, is that the risks are mitigated by carefully structured, close monitoring and support protocols.

New terms have entered the lexicon of competitive freediving to describe the range of altered consciousness that may be experienced. "Mooglies" represent language production disturbances occurring at the end of a breath-hold.[41] "Samba" represents a loss of motor control that may include confusion, affected postural control, or muscular spasms.[41] Both loss of consciousness and significant loss of motor control disqualify competitive performance.[42] Minor losses of motor control are considered normal enough in competitive events to not warrant physical examination.[38] It is likely that the relative rarity of serious syncopal events in competition is influenced by strict rules for obligatory delivery of a series of clear and orderly signals by the surfacing diver to avoid disqualification of the attempt.

The natural migration of practices is a concern with hyperventilation. The problem may even be increased by a shift in terminology. It is not uncommon to find breath-hold divers who will deny any use of pre-breath-hold hyperventilation but will then talk about "work-up breathing", which, when described, is effectively hyperventilation. Risk is controlled through realistic appreciation and appropriate responses, not by obfuscation. Care must be taken to ensure that all participants have a realistic appreciation for the effects and risks of practices. The most critical hazard in breath-hold is that of a compromised level of consciousness developing under less than closely monitored conditions. The fear is that the excitement of breath-hold diving can spread faster than an appreciation of the risks. The finding that more than half of recently reported fatal breath-hold incidents were unwitnessed indicates a fundamental problem in practice.[13]

LIMIT BREATH-HOLD TIME

Another way to address the risk of altered consciousness is to arbitrarily limit breath-hold time. One recommendation was proposed for non-competitive breath-hold diving.[43] The point was made that hyperventilation can increase the pleasure of breath-hold dives by reducing symptoms of air hunger. Restricting dive time could reduce the risk of hypoxic compromise developing regardless of the aggressiveness of the pre-breath-hold practices employed. Based on a review of incidents, the author concluded that limiting breath-hold time to 60 s would allow for varying patterns of hyperventilation and physical activity with minimal risk of loss of consciousness. This is a reasonable safety guideline and easy to apply for recreational freedivers, particularly those with minimal experience. The only tool required to make it work is a watch with a countdown function set to beep at 45 or 50 s as appropriate for the depth to remind the diver when to begin to ascend. Freedivers who gain additional experience or progress to more advanced freediving activities will have a safe starting point from which to grow.

FLOTATION VESTS

Flotation vests designed specifically for breath-hold diving represent a potentially important safety tool currently under development. These will automatically inflate if a user-preset (adjustable) time at depth is exceeded. While such devices will not eliminate the risk of static blackout or hypoxia of ascent, or the risk of inspiring water should unconsciousness develop, they will reduce the mortal risk of such events by returning the diver to the surface. The likelihood of being unable to recover a diver in distress would be markedly reduced. This would be an extremely effective aid in many small operations or if the conditions were such that some of the support team might be forced to dive near or beyond their capabilities to perform a rescue.

REPORTING DIVING INCIDENTS

Communication of the details involved in both fatal and non-fatal breath-hold incidents is another tool to improve the safety of current and future freedivers. Learning from the mistakes of others is an important strategy in promoting safety for all. The ability to share salient details about incidents should encourage divers to reflect on and, where appropriate, improve their own practices. Divers Alert Network has included a summary section and brief case reports concerning breath-hold incidents in the annual report on diving safety since 2005.[13,44,45] Primarily focused on fatal incidents, the programme is expanding to capture non-fatal events.[46]

Conclusions

Breath-hold diving is experiencing a growth in popularity that reflects an impressive evolution of record-setting performance. Safe participation in competitive events is fostered by a wide range of carefully developed regulations and protocols. Communication of appropriate safety procedures is critical to ensure that enthusiasts at all levels of involvement are reasonably protected. Elimination of solo freediving and the incautious use of hyperventilation would have the greatest impact on the population at risk. Development of appropriate and accessible training programmes and the regular communication of incident case reports are important strategies to increase awareness of both risks and appropriate practices.

References

1 Strømme SB, Kerem D, Elsner R. Diving bradycardia during rest and exercise and its relation to physical fitness. *J Appl Physiol.* 1970; 28: 614-21.

2 Andersson JPA, Linér MH, Rünow E, Schagatay EKA. Diving response and arterial oxygen saturation during apnea and exercise in breath-hold divers. *J Appl Physiol.* 2002; 93: 882-6.

3 Lindholm P, Nordh J, Gennser M. The heart rate of breath-hold divers during static apnea: effects of competitive stress. *Undersea Hyperb Med.* 2006; 33: 119-24.

4 Hurford WE, Hong SK, Park YS, Ahn DW, Shiraki K, et al. Splenic contraction during breath-hold diving in the Korean ama. *J Appl Physiol.* 1990; 69: 932-6.

5 Espersen K, Frandsen H, Lorentzen T, Kanstrup IL, Christensen NJ. The human spleen as an erythrocyte reservoir in diving-related interventions. *J Appl Physiol.* 2002; 92: 2071-9.

6 Bakovic D, Valic Z, Eterovic D, Vukovic I, Obad A, et

al. Spleen volume and blood flow response to repeated breath-hold apneas. *J Appl Physiol*. 2003; 95: 1460-6.

7 Stewart IB, Bulmer AC, Sharman JE, Ridgway L. Arterial oxygen desaturation kinetics during apnea. *Med Sci Sports Exerc*. 2005; 37: 1871-6.

8 Valic Z, Palada I, Bakovic D, Valic M, Mardesic-Brakus S, Dujic Z. Muscle oxygen supply during cold face immersion in breath-hold divers and controls. *Aviat Space Environ Med*. 2006; 77: 1224-9.

9 Lin YC, Lally DA, Moore TO, Hong SK. Physiological and conventional breath-hold breaking points. *J Appl Physiol*. 1974; 37: 291-6.

10 Craig AB Jr. Causes of loss of consciousness during underwater swimming. *J Appl Physiol*. 1961; 16: 583-6.

11 Craig AB Jr. Underwater swimming and loss of consciousness. *JAMA*. 1961; 176: 255-8.

12 Craig AB Jr. Summary of 58 cases of loss of consciousness during underwater swimming and diving. *Med Sci Sports*. 1976; 8: 171-5.

13 Pollock NW, Vann RD, Denoble PJ, Freiberger JJ, Dovenbarger JA, et al. *Annual diving report*, 2007 edition. Durham, NC: Divers Alert Network; 2007. p. 61-8, 100-3.

14 Donald KW. *Oxygen poisoning in man*. Admiralty Experimental Diving Unit Report number XVI, 1946; 172-81.

15 Simpson G, Ferns J, Murat S. Pulmonary effects of ‘lung packing’ by buccal pumping in an elite breath-hold diver. *SPUMS J*. 2003; 33:122-6.

16 Lindholm P, Nyren S. Studies on inspiratory and expiratory glossopharyngeal breathing in breath-hold divers employing magnetic resonance imaging and spirometry. *Eur J Appl Physiol*. 2005; 94: 646-51.

17 Jacobson FL, Loring SH, Ferrigno M. Pneumomediastinum after lung packing. *Undersea Hyperb Med*. 2006; 33: 313-6.

18 Overgaard K, Friis S, Pedersen RB, Lykkeboe G. Influence of lung volume, glossopharyngeal inhalation and $P_{ET}O_2$ and $P_{ET}CO_2$ on apnea performance in trained breath-hold divers. *Eur J Appl Physiol*. 2006; 97: 158-64.

19 Seccombe LM, Rogers PG, Mai N, Wong CK, Kritharides L, Jenkins CR. Features of glossopharyngeal breathing in breath-hold divers. *J Appl Physiol*. 2006; 101: 799-801.

20 Loring SH, O’Donnell CR, Butler JP, Lindholm P, Jacobson F, Ferrigno M. Transpulmonary pressures and lung mechanics with glossopharyngeal insufflation and exsufflation beyond normal lung volumes in competitive breath-hold divers. *J Appl Physiol*. 2007; 102: 841-6.

21 Potkin RT, Cheng V, Siegel R. Effects of glossopharyngeal insufflation on cardiac function: an echocardiographic study in elite breath-hold divers. *J Appl Physiol*. 2007; 103: 823-7.

22 Liner MH, Andersson JPA. Pulmonary edema after competitive breath-hold diving. *J Appl Physiol*. 2008; 104: 986-90.

23 Novalija J, Lindholm P, Loring SH, Diaz E, Fox JA, Ferrigno M. Cardiovascular aspects of glossopharyngeal insufflation and exsufflation. *Undersea Hyperb Med*. 2007; 34: 415-23.

24 Lindholm P, Ekborn A, Oberg D, Gennser M. Pulmonary edema and hemoptysis after breath-hold diving at residual volume. *J Appl Physiol*. 2008; 104: 912-7.

25 Germonpre P, Balestra C, Musimu P. Passive flooding of paranasal sinuses and middle ears as a method of equalisation in extreme breath-hold diving. *Br J Sports Med*. 2008; Epub ahead of print.

26 Lindholm P, Gennser M. Aggravated hypoxia during breath-holds after prolonged exercise. *Eur J Appl Physiol*. 2005; 93: 701-7.

27 Lindholm P, Conniff M, Gennser M, Pendergast D, Lundgren C. Effects of fasting and carbohydrate consumption on voluntary resting apnea duration. *Eur J Appl Physiol*. 2007; 100: 417-25.

28 Song SH, Kang DH, Kang BS, Hong SK. Lung volumes and ventilatory responses to high CO_2 and low O_2 in the ama. *J Appl Physiol*. 1963; 18: 466-70.

29 Nygren-Bonnier M, Lindholm P, Markstrom A, Skedinger M, Mattsson E, Klefbeck B. Effects of glossopharyngeal pistoning for lung insufflation on vital capacity in healthy women. *Am J Phys Med Rehabil*. 2007; 86: 290-4.

30 Nygren-Bonnier M, Gullstrand L, Klefbeck B, Lindholm P. Effects of glossopharyngeal pistoning for lung insufflation in elite swimmers. *Med Sci Sports Exerc*. 2007; 39: 836-41.

31 Davis FM, Graves MP, Guy HJ, Prisk GK, Tanner TE. Carbon dioxide response and breath-hold times in underwater hockey players. *Undersea Biomed Res*. 1987; 14: 527-34.

32 Binks AP, Vovk A, Ferrigno M, Banzett RB. The air hunger response of four elite breath-hold divers. *Respir Physiol Neurobiol*. 2007; 159: 171-7.

33 Lemaitre F, Polin D, Joulia F, Boutry A, Le Pessot D, et al. Physiological responses to repeated apneas in underwater hockey players and controls. *Undersea Hyperb Med*. 2007; 34: 407-14.

34 Dujic Z, Ivancev V, Heusser K, Dzamonja G, Palada I, et al. Central chemoreflex sensitivity and sympathetic neural outflow in elite breath-hold divers. *J Appl Physiol*. 2008; 104: 205-11.

35 Feiner JR, Bickler PE, Severinghaus JW. Hypoxic ventilatory response predicts the extent of maximal breath-holds in man. *Respir Physiol*. 1995; 100: 213-22.

36 Moosavi SH, Golestanian E, Binks AP, Lansing RW, Brown R, Banzett RB. Hypoxic and hypercapnic drives to breathe generate equivalent levels of air hunger in humans. *J Appl Physiol*. 2003; 94: 141-54.

37 Lindholm P, Lundgren CEG. Alveolar gas composition before and after maximal breath-holds in competitive divers. *Undersea Hyperb Med*. 2006; 33: 463-7.

38 Fitz-Clarke JR. Adverse events in competitive breath-hold diving. *Undersea Hyperb Med*. 2006; 33: 55-62.

39 Krack K, Stepanek M, Cruickshank M. Safety techniques and problem management in recreational and competitive freediving. In: Lindholm P, Pollock NW, Lundgren CEG, eds. *Breath-hold diving*. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006. p. 82-95.

40 Edmonds CW, Walker DG. Snorkelling deaths in Australia, 1987-1996. *Med J Aust*. 1999; 171: 591-4.

41 Ridgway L, McFarland K, Stewart IB, Bulmer AC. ‘Sambas’, ‘Mooglies’ and other acute effects of apnea. In: Lindholm P, Pollock NW, Lundgren CEG, eds. *Breath-hold diving*. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006. p. 39-45.

42 Lindholm P. Loss of motor control and/or loss of consciousness during breath-hold competitions. *Int J Sports Med*. 2007; 28: 295-9.

43 Butler FK. A proposed 60 second limit for breath-hold diving. In: Lindholm P, Pollock NW, Lundgren CEG, eds. *Breath-hold diving*. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006. p. 64-74.

44 Vann RD, Freiberger JJ, Caruso JL, Denoble PJ, Pollock NW, et al. *Report on decompression illness, diving fatalities*

and Project Dive Exploration: DAN's annual review of recreational scuba diving injuries and fatalities Based on 2003 data; 2005 edition. Durham, NC: Divers Alert Network; 2005. p. 91-8, 129-31.

45 Vann RD, Freiberger JJ, Caruso JL, Denoble PJ, Pollock NW, et al. *Annual diving report*, 2006 edition. Durham, NC: Divers Alert Network; 2006. p. 59-63, 92-3.

46 Pollock NW. Development of the DAN breath-hold incident database. In: Lindholm P, Pollock NW, Lundgren CEG, eds. *Breath-hold diving*. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. Durham, NC: Divers Alert Network; 2006. p. 46-55.

Neal W Pollock, PhD, is a Research Associate at the Center for Hyperbaric Medicine and Environmental Physiology, Duke University Medical Center and a member of the Research Department of Divers Alert Network, Durham, NC, USA
Address for correspondence:
Center for Hyperbaric Medicine and Environmental Physiology
Duke University Medical Center
PO Box 3823
Durham, NC 27710, USA
Phone: *+1-(0)919-684-2948, ext 225*
Fax: *+1-(0)919-493-3040*
E-mail: *<neal.pollock@duke.edu>*

Dr Pollock was the Guest Speaker at the 2007 SPUMS Annual Scientific Meeting at Tutukaka, New Zealand.

Oxygen toxicity in recreational and technical diving

Andrew Fock and Ian Millar

Key words
Oxygen, toxicity, technical diving, mixed gas, review article

Abstract

(Fock A, Millar I. Oxygen toxicity in recreational and technical diving. *Diving and Hyperbaric Medicine*. 2008; 38: 86-90.)

It is increasingly common for recreational scuba divers to use breathing mixtures enriched with additional oxygen ('nitrox' or 'enriched air nitrogen') and for technical divers to be exposed to elevated partial pressures of oxygen for prolonged periods of time. The National Oceanic and Atmospheric Administration oxygen exposure limits have traditionally been used by the recreational diving industry and technical diving communities. Review of the original research into oxygen toxicity brings into question the validity of these limits and would suggest revised limits with a maximum partial pressure of oxygen of 162 kPa (1.6 Ata) and 142 kPa (1.4 Ata) at depth and the use of the repetitive air excursion (REPEX) limits for single and repetitive exposures. Suitable conservatism in case of the need for recompression therapy is recommended.

Introduction

The use of breathing mixtures containing high levels of oxygen ('nitrox', 'enriched air nitrogen' for scuba diving has become routine over the last decade. More recently, the advent of technical diving has seen the use of these mixtures as well as pure oxygen to accelerate decompression. Training agencies for both recreational and technical diving have traditionally used the central nervous system (CNS) limits prescribed by the National Oceanic and Atmospheric Administration (NOAA).[1] These describe a relationship between time and an exposure to a particular partial pressure of oxygen (PPO_2) and are provided for both single exposures and daily exposures. However, with the advent of technical diving, where decompression times may exceed five hours, many divers are routinely exceeding these limits apparently without ill effect. Therefore, it would seem timely to review the origins of these limits as well as newer data on oxygen toxicity more relevant to this style of diving.

Manifestations of oxygen toxicity

At a clinical level, the toxic effects of oxygen are most apparent in the lung, brain and eye. This should not be surprising, given the lung's direct exposure to oxygen, the very high blood flow and vaso-reactivity of the CNS and the unique avascular physico-chemical structure of the lens of the eye. In the lung, oxidative damage results in inflammation, capillary leakiness and ultimately fibrosis. The mechanisms of acute CNS toxicity are extremely complex and incompletely understood. In overview, it is thought that increased reactive oxygen species produced through the metabolism of molecular oxygen cause an imbalance between neurotransmitters, triggering uncoordinated electrical depolarisation (an excellent review is provided by Clark and Thom[2]). This often manifests as loss of consciousness with a grand mal-type convulsion and may commence abruptly, with or without preceding symptoms. The occurrence of such an event whilst diving is likely to be fatal, therefore a good understanding of the CNS oxygen tolerance limits is vital if high PPO_2 is to be used. With respect to the eye, prolonged exposure to high PPO_2 has been observed to cause a reversible narrowing of the field of vision, whilst in the field of hyperbaric medicine, repeated daily exposure to hyperbaric oxygen for 20–30 sessions or more can induce myopia due to oxidative biochemical change in the lens.[3] Fortunately this myopia usually reverses spontaneously over several months after treatment is completed.

Historical background

Bert, in his seminal work on oxygen in 1878, clearly demonstrated that, whilst oxygen is essential to life, it is lethal at high pressure.[4] He exposed a number of species to high PPO_2 noting convulsions as a manifestation of CNS toxicity. This later became known as the Paul–Bert effect. In 1899, Lorrain Smith reported a series of experiments on rats exposed to raised PPO_2.[5] Smith detailed the pulmonary changes and noted that early changes were reversible, as well as the fact that higher pressures were associated with an earlier onset of symptoms. The pulmonary changes associated with high oxygen exposure are now commonly referred to as the Lorrain Smith effect.

By 1907 when JS Haldane was conducting experiments, which were to lead ultimately to the first successful diving tables, the works of Smith and Bert were well known.[6] In 1908, Haldane both recommends that air diving be limited to 50 fathoms (90 metres' sea water (msw)) to avoid oxygen toxicity and mentions the possibility of using oxygen to accelerate decompression.[6] In the case of the latter, it was felt at the time that the technical difficulties of using oxygen in decompression outweighed any possible benefit. Haldane also confirmed that duration and depth were related to the risk of CNS symptoms resulting from oxygen exposure.

World War Two experience

By the late 1930's the United States Navy (USN) was experimenting with oxygen for both deep diving and recompression therapy.[7,8] At this time it was generally believed that exposures to 100% oxygen at 304 kPa (3 Ata) were usually well tolerated, a limit that was similarly supported in the Royal Navy (RN). After the success of the Italian "human torpedoes" in damaging British battleships at Alexandria in 1941, the British sought to create a similar capability. The bubble-less and decompression-less features of closed-circuit oxygen rebreathers made them ideal for such covert missions. However, after a series of unexplained episodes of unconsciousness associated with the use of oxygen rebreathers in the early stages of World War Two, the RN embarked on an extensive series of human experiments to definitively determine the oxygen exposure limits for divers.[9]

These experiments, conducted by Kenneth Donald, involved more than 2,000 exposures and generally used convulsions as the end point for each experiment. In 60% of cases lip twitching was the first sign of CNS oxygen toxicity; however, in approximately 10% the first sign was a convulsion, often without any preceding symptoms (Table 1).

While CNS oxygen toxicity susceptibility did in general increase with pressure, there was such a large day-to-day variability in the time to convulse for an individual at any given pressure that it was difficult to meaningfully score the differences in susceptibility between individuals. In addition to this variability in individual susceptibility on a day-by-day basis there was also substantial inter-individual variability. However, there did appear to be a minimum threshold of 172 kPa (1.7 Ata) below which convulsions were not seen despite exposures of up to six hours.[10] Donald noted that subjects were less tolerant to oxygen if immersed as compared to in a dry chamber. Susceptibility to toxicity was also increased by exercise, if the water temperature was low or if carbon dioxide levels were elevated.

Donald also found that the addition of nitrogen to the breathing gas mixture increased divers' tolerance to increased partial pressures of oxygen. On the basis of Donald's work, the Royal Navy promulgated operational limits for its divers of 172 kPa for pure oxygen and to a PPO_2 of 203 kPa (2.0 Ata) for nitrox mixtures.[10]

Post World War Two

The USN also conducted a series of trials in the period immediately after World War Two. There was criticism of the RN studies based on the belief that the type of rebreather equipment used would have allowed accumulation of CO_2 and this would have reduced the RN divers' oxygen tolerance.

Table 1
First reported symptoms of CNS oxygen toxicity
(modified from Donald K[9])

Symptoms	Number of cases	Percentage
Convulsions	46	9.2
Twitching lips	303	60.6
Vertigo	44	8.8
Nausea	43	8.6
Respiratory disturbance	19	3.8
Dyspnoea	8	
Cough	6	
Other	5	
Twitching, other than lips	16	3.2
Generalised jactitations	7	
Other	9	
Sensations of abnormality	16	3.2
Drowsiness	7	
Numbness	3	
Other	6	
Visual disturbances	5	1
Acoustic hallucinations	3	0.6
Paraesthesia	2	0.4

Extraordinarily, it was also suggested that there was some question as to the 'quality' of the RN dives and the divers conducting them.[11] Donald countered by pointing out that subsequent analysis of the equipment had not shown CO_2 accumulation, and that a substantial number of his subjects had gone on to win a Victoria Cross and other awards for bravery![10] The initial trials conducted by the USN produced higher oxygen tolerances but in hindsight it would appear that inadequate oxygen purging of their rebreather units may have allowed retention of nitrogen. This may explain the apparently higher oxygen tolerances reported.

Subsequent USN experimentation using open-circuit equipment resulted in progressive revisions to the USN oxygen limits. However, the data used to determine these limits were in general taken from very small numbers of trials and, in some cases, the exposures accepted (depth-time combination) in the tables seem at odds with the experimental data. In some cases, symptoms were observed at or before the time limits finally recommended.[11] As late as 1986, USN oxygen tolerance tables allowed up to 10 minutes at 253 kPa (2.5 Ata) and 240 minutes at 162 kPa. In contrast, the nitrox tables used by the USN were far more conservative, allowing only 30 minutes at 162 kPa PPO_2.

Recreational diving

Recreational oxygen exposure limits are generally based on the NOAA tables for oxygen exposure limits (Table 2).[1] These were reputedly derived from the USN nitrox tables but the actual experimental basis for them remains elusive. Hamilton has stated that these recommendations "*represent an operation decision, not research results*".[12] The NOAA recommendations limit the maximum oxygen exposure to 162 kPa for a maximum of 45 minutes at that pressure. They allow a maximum of 720 minutes at 61 kPa (0.6 Ata). As limits of tolerance, these recommendations seem at odds with the published CNS exposure data where definite symptoms are used as an endpoint. However, in recent large studies of Israeli military divers, softer or more subjective signs of possible oxygen toxicity were accepted as end points.[13] If these symptoms are accepted as endpoints of CNS oxygen toxicity, limits lower than those originally proposed by Donald or the USN may have some justification especially in the recreational setting.

Table 2
NOAA oxygen exposure limits[11]
with permission (1 Ata = 101.3 kPa)

PPO_2 Ata	Single exposure mins	Daily limit mins
1.6	45	150
1.5	120	180
1.4	150	180
1.3	180	210
1.2	210	240
1.1	240	270
1.0	300	300
0.9	360	360
0.8	450	450
0.7	570	570
0.6	720	720

For recreational diving the recommended maximum inspired PPO_2 at depth is usually limited to 143 kPa and for decompression to 162 kPa. Based on the available evidence, it would seem that acute CNS toxicity would be unlikely to occur in divers using these limits provided that there is strict adherence to prescribed gas composition and depth of use.

Pulmonary oxygen toxicity

In contrast to CNS oxygen toxicity, pulmonary oxygen toxicity has received little attention as a risk for recreational diving. However, modern trends in technical diving have seen dive times exceeding six hours with a considerable proportion of that time spent at partial pressures of oxygen in excess of 142 kPa to accelerate decompression. As a result, pulmonary effects of oxygen also now need to be considered in this setting. The symptoms of pulmonary oxygen toxicity are relatively consistent in contrast to acute CNS toxicity. When fully developed they resemble those of a viral upper respiratory tract illness with a dry hacking cough and retro-sternal chest discomfort. Both the pain and the coughing are markedly aggravated by deep inspiration. While initial changes are easily reversible (though individuals show marked variability in recovery time), severe toxicity may result in permanent lung damage. As with CNS oxygen toxicity, there appear to be considerable variations between individuals as to their pulmonary oxygen tolerance.

Pulmonary tolerance to high levels of oxygen has been shown by several researchers to be increased by the inclusion of low oxygen breathing periods.[10,11] Lambertsen et al demonstrated that if oxygen breathing was interrupted by five-minute periods of normoxia after each 20-minute high PPO_2 exposure this more than doubled the tolerable oxygen breathing time.[14]

Unit of pulmonary toxicity dose (UPTD)

As a medical therapy oxygen at partial pressures up to 51 kPa (0.5 Ata) is generally well tolerated for continuous periods of many days. Above this level oxygen toxicity results in a gradual reduction in vital capacity (VC) with increasing exposure. The oxygen exposure that risks a chosen reduction in VC is described by a hyperbolic relationship between PPO_2 and duration of exposure. Bardin and Lambertsen described this relationship mathematically.[15] They defined what they termed a 'unit of pulmonary toxicity dose' (UPTD) as the degree of pulmonary oxygen toxicity incurred from breathing 100% oxygen for one minute.

Mathematically, UPTD is defined as

$$UPTD = t((PPO_2 - 0.5)/0.5)^{0.83}$$

Where t is time in minutes, and PPO_2 is the partial pressure of oxygen.[15]

Using this methodology, their exposure data indicated that dives incurring 615 UPTD would be expected to sustain a 2% reduction in VC and dives incurring 1425 UPTD would be expected to sustain a 10% reduction in VC. The former is considered the limit for routine diving and the latter for therapy of life-threatening decompression illness.[10] These limits were based upon a small sample of subjects and there is significant variability in what actually occurs in any particular diver. Nevertheless, the UPTD tables provide a well-tried formula for limiting pulmonary risk.

Using the UPTD system to assess typical recreational rebreather diving reveals there should be minimal risk of developing pulmonary toxicity for dives of average duration. As an example, a closed-circuit rebreather (CCR) dive to a maximum depth of 67 msw for 30 minutes' bottom time requires 71 minutes at a PPO_2 of 131 kPa (1.3 Ata) and then 34 minutes at 162 kPa during decompression. This will incur 105 UPTD + 65 UPTD = 170 UPTD for the dive (CNS = 116% of NOAA limit). If two such dives were performed in a day, this would equate to 340 UPTD per day. However, should the diver require a therapeutic recompression using a Royal Navy Treatment Table 62, a further 645 UPTD would be incurred resulting in a total exposure of 985 UPDT, still within the acceptable limits. If 1425 UPTD is accepted as the daily maximum, then it would seen prudent to limit the daily diving exposure to somewhat less than 780 UPTD.

Maximal oxygen exposure will be associated with multi-day programmes of multiple, long-duration dives per day. The applicability of UPTDs to such scenarios is uncertain as no allowance is made for 'surface intervals' or cumulative exposure. In the late 1980s, Hamilton et al working with NOAA investigated the effects of prolonged exposure to raised PPO_2 in sea-floor habitats (generally shallow saturation diving with intermittent deeper excursions).[12] Due to the long exposures to elevated levels of oxygen, this work seems better constructed for application to recreational technical expeditions. Using the same calculation method as Bardin et al, UPTDs were renamed as oxygen tolerance units (OTUs) and were assumed to reflect total body oxygen toxicity. It was proposed that if exposures were kept below the described 'REPEX' (REPetitive air EXcursion) limits and a maximum PPO_2 of 152 kPa, then CNS toxicity issues would take care of themselves. OTUs are calculated on a cumulative basis, e.g., if planning an eight-day expedition, the REPEX table would allow a total of 2,800 OTUs over the eight-day period. This would allow 350 OTUs per day or 175 OTUs per dive if two dives per day were planned.

With respect to eye toxicity, it has been traditionally thought that there is little risk when diving within limits designed to avoid both CNS and pulmonary toxicity. Lambertsen et al demonstrated, visual field contraction, thought to be due to retinal vasospasm, after 2.5–3 hours of exposure to 304 kPa (3.0 Ata).[11] Likewise, the hyperbaric oxygen exposures associated with myopic change to the lens usually involve a PPO_2 ranging from 203 to 284 kPa (2.0–2.8 Ata) for 1.5 to 2 hours per session, daily for several weeks.[3]

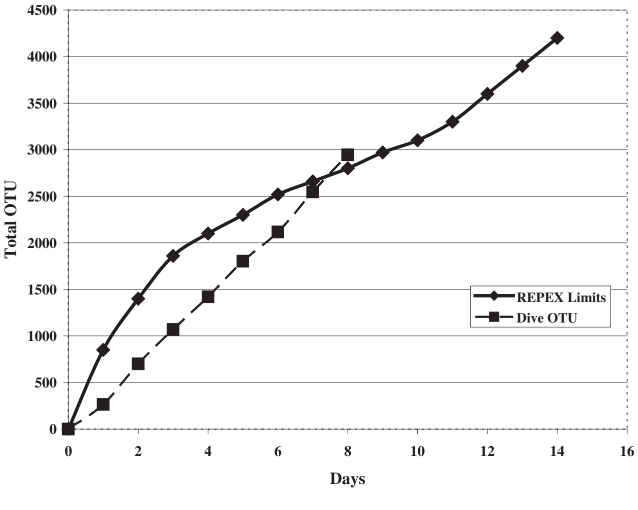
It would seem, therefore, that there should be little risk of pulmonary or eye toxicity with normal recreational technical diving. However, during a recent study of technical divers, the author noted symptoms suggestive of pulmonary oxygen toxicity in 50% of the divers while well below the REPEX exposure limits.[16] While these symptoms developed before the REPEX limits were approached, the cumulative OTUs in this group of recreational technical divers did approach the REPEX limits towards the end of the expedition indicating that cumulative oxygen exposures may become significant in this type of diving (Figure 2). In addition, a number of divers reported transient visual symptoms suggestive of a change in refraction. Such changes in refractive index in a recreational CCR diver have been reported previously.[17]

Summary

There would appear to be little supporting evidence of significant symptoms of CNS toxicity developing below a threshold of 162 kPa PPO_2 despite substantial exposures exceeding the NOAA limits. Exposures beyond PPO_2 of 172 kPa may result in convulsions at any time and without warning.

With the increasing popularity of technical diving using CCRs that maintain a relatively high PPO_2 throughout the

Figure 2
Allowable cumulative oxygen dose: REPEX limits and cumulative oxygen dose (OTU) for expedition divers (see text for explanation)



dive (commonly 131 kPa), the REPEX limits may be more relevant than the NOAA limits. Divers conducting such dives should be mindful of the potential for cumulative effects of multi-day diving on the lungs and the potential need for a therapeutic recompression when calculating daily exposure allowances and plan their dives accordingly.

For the diver conducting a single prolonged dive where pulmonary oxygen toxicity may become an issue, there may be a case for switching to a low PPO_2 for five-minute periods during the latter stages of long decompression profiles where high-oxygen mixes are used. Any such reduced oxygen periods would need to be taken into account in decompression calculations and gas mixtures should be selected with the aim of avoiding potential counter-diffusion problems where helium-based diluents are used.

There is a case for further studies that objectively assess changes in vision and lung function in divers undergoing repetitive, high-oxygen exposure, recreational diving.

References

1 Joiner JT, editor. *NOAA Diving Manual*. 4th ed. Flagstaff AZ: Best Publishing; 2001. p. 1-16.

2 Clark J, Thom S. Oxygen under pressure. In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving*, 5th ed. Edinburgh: Saunders; 2003. p. 358-408.

3 Evanger K, Haugen OH, Irgens A, Aanderud L, Thorsen E. Ocular refractive changes in patients receiving hyperbaric oxygen administered by oronasal mask or hood. *Acta Ophthalmol Scand*. 2004; 82: 449-53.

4 Bert P. *La pression barametrique: researches de physiologie experimentale*. 1878. Translated from the French by Hitchcock MA, Hitchcock FA. Published as: Barometric pressure researches in experimental physiology. In: *Key documents of the biomedical aspects of deep sea diving selected from the world's literature 1608–1982*. Durham, NC: Undersea and Hyperbaric Medical Society; 1983. CD-ROM. p. 2508-60.

5 Lorrain Smith J. The pathological effects due to increase of oxygen tension in the air breathed. *Journal of Physiology (London)*.1899; 24: 19-35.

6 Boycott D, Damant G, Haldane J. The prevention of compressed-air illness. *J Hyg*. 1908; (8): 342-443.

7 Behnke AR. USS Squalus: medical aspects of the rescue and salvage operations and the use of oxygen in deep sea diving. *US Navy Medical Bulletin*. 1939. In: *Key documents*, Undersea and Hyperbaric Medical Society; 1983. CD-ROM. p. 860-9.

8 Behnke AR, Shaw LA, Messer AC, Thomson RA, Motley EP. The circulatory and respiratory disturbances of acute compressed air illness and the administration of oxygen as a therapeutic measure. *Am J Physiol*. 1936; 114: 525-33.

9 Donald KW. Oxygen poisoning in man. *BMJ*. 1947; (May 17th): 667-717.

10 Donald K. *Oxygen and the diver*. Hanley Swan, Worcs: The SPA Ltd; 1992.

11 Lambertsen CJ, Clark JM, Gelfand R, Pisarello JB, Cobbs WH. Definition of tolerance to continuous hyperoxia in man: An abstract report of predictive studies V. In: Bove AA, Bachrach AJ, Greenbaum LJ, editors. *Underwater and hyperbaric physiology IX*. Bethesda, Ma: Undersea and Hyperbaric Medical Society; 1987. p. 717-49.

12 Hamilton RW, Kenyon DJ, Peterson RE, Butler GJ, Beers DM. *REPEX: development of repetitive excursions, surfacing techniques, and oxygen procedures for habitat diving*. NURP Technical Report 88-1A. Rockville, MD: NOAA, US Department of Commerce; 1988.

13 Arieli R, Shochat T, Adir Y. CNS toxicity in closed-circuit oxygen diving: symptoms reported from 2,527 dives. *Aviat Space Environ Med*. 2006; 77: 526-32.

14 Lambertsen CJ. Extension of oxygen tolerance in man: philosophy and significance. *Exp Lung Res*. 1988; 14(Suppl): 1035-58.

15 Bardin H, Lambertsen CJ. *A quantitative method for calculating pulmonary oxygen toxicity. Use of the "Unit of Pulmonary Toxicity Dose" (UPTD)*. Environmental Medicine Report. Philadelphia: University of Pennsylvania; 1970.

16 Fock AW. Health status and diving practices of a technical diving expedition. *Diving and Hyperbaric Medicine*. 2007; 36: 179-85.

17 Butler FK Jr, White E, Twa M. Hyperoxic myopia in a closed-circuit mixed-gas scuba diver. *Undersea Hyperb Med*. 199; 26: 41-5.

Dr Andrew Fock, FANZCA, Dip DHM, is a Senior Staff Specialist, and
Ian Millar, FAFOM, Dip DHM, is Medical Director in the Hyperbaric Services, The Alfred Hospital, Melbourne

Address for correspondence:
Dr Andrew Fock
The Alfred Hospital, Commercial Road, Prahan
Melbourne, Australia 3004
Phone: *+61-(0)3-9276-2269*
Fax: *+61-(0)3-9076-3052*
E-mail: *<a.fock@alfred.org.au>*

This review article is based on a presentation by Dr Fock at the SPUMS ASM, New Zealand, 2007.

Cochrane corner

Recompression and adjunctive therapy for decompression illness: a systematic review of randomised controlled trials

Michael Bennett, Simon J Mitchell, Jan P Lehm and Jason Wasiak

Key words
Decompression illness, decompression sickness, recompression, non-steroidal anti-inflammatories, helium, Cochrane library

Abstract

(Bennett M, Mitchell SJ, Lehm JP, Wasiak J. Recompression and adjunctive therapy for decompression illness: a systematic review of randomised controlled trials. *Diving and Hyperbaric Medicine*. 2008; 38: 91-8.)

Introduction: Decompression illness (DCI) results from bubble formation in the blood or tissues following the breathing of compressed gas. Recompression is the universally accepted standard for the treatment of DCI, but a number of strategies have been suggested in order to improve the outcome.

Methods: We performed a systematic search of the literature in December 2007 for randomised controlled trials of DCI therapy, and made an analysis of pre-determined clinical outcomes.

Results: Two randomised controlled trials satisfied the inclusion criteria. Pooling of data was not possible. There was a reduction in the number of compressions required with the addition of the non-steroidal anti-inflammatory drug (NSAID) tenoxicam to routine recompression therapy ($P = 0.01$) but no evidence of improved effectiveness (relative risk (RR) of residual symptoms 1.04, $P = 0.58$). The risk of multiple recompressions was lower with heliox than with an oxygen treatment table (RR 0.56, 95% CI 0.31 to 1.00, $P = 0.05$).

Conclusions: There is no randomised evidence concerning the effectiveness of recompression for DCI. Either the addition of an NSAID or the use of heliox may reduce the number of recompressions required, but neither strategy is shown to improve the chance of recovery. The application of either of these strategies may be justified. The modest number of patients studied demands a cautious interpretation of the findings. There is a case for large randomised trials of high methodological rigour in order to define any benefit from the use of different breathing gases during recompression therapy.

This article is a summary of a Cochrane review published in The Cochrane Library, Chichester, UK: John Wiley & Sons, Ltd (www.thecochranelibrary.com). The relevant material is reproduced with permission. Cochrane reviews are regularly updated as new evidence emerges and in response to comments and criticisms. The Cochrane Library should be consulted for the most recent version of these reviews. Please note that the results of a Cochrane review can be interpreted differently, depending on people's perspectives and circumstances. The conclusions are the opinions of the authors, and are not necessarily shared by The Cochrane Collaboration.

Introduction

Decompression illness (DCI) is the term given to the clinical manifestations of bubble formation in the blood or tissues following a reduction in ambient pressure.[1] DCI most commonly occurs in relation to compressed-air or mixed-gas diving, but it may also arise in aviators following rapid ascent to altitude or cabin decompression, and in astronauts participating in 'space walks'.[2] The term covers two different problems: arterial gas embolism (AGE) caused by the presence of bubbles in the arterial blood vessels; and decompression sickness (DCS) caused by bubbles in the veins and tissues.

Bubbles may cause harm through mechanical distortion of tissues, vascular obstruction or stimulation of immune mechanisms that lead to tissue oedema, haemoconcentration and hypoxia. Arterial blood vessels are a particular target for damage by intravascular bubbles, where they disrupt the luminal surfactant layers, damage the endothelium and stimulate intraluminal blood elements (particularly white blood cells and platelets) to clump together and obstruct the flow within the vessel. Secondary interactions between these elements result in leaking vessels and further reductions to flow.[3–5]

The two pathological entities (AGE and DCS) are difficult to distinguish clinically and are treated with similar strategies.[6,7] It is, therefore, accepted practice to make the clinical diagnosis of 'DCI' in the understanding that one or both of the two pathologies may be operating. We will use the generic term DCI in this review except when we refer to the specific pathological mechanisms that cause AGE and DCS.

Clinically, DCI has many possible manifestations, from mild, vague constitutional symptoms to sudden loss of consciousness, paralysis or death.[8] The most important target tissues are the central nervous system and the musculoskeletal system, with musculoskeletal pain and constitutional symptoms similar to those of a viral illness being the most common complaints.[8,9] Without an objective method of determining whether they are the result of bubble formation, these mild symptoms will sometimes result in misdiagnosis.

Severe DCI is now uncommon in the developed world, but remains a significant problem for poorly trained indigenous commercial divers around the developing world.[2,8] While the overall incidence of DCI has not been determined, a number of studies have reported both incidence and prevalence of DCI and its long-term effects in individual diving populations. In one prospective study involving indigenous sea harvesters the proportion of divers who reported ever having DCI was 94.4%, and 10% had residual signs of spinal injury. In another indigenous group mortality was estimated at four per cent of divers per year.[10,11] In contrast, the incidence of DCI among recreational divers in Canada was estimated at 0.01% of dives over 14 months.[12]

The historical development of recompression treatment tables is well described by Moon and Gorman.[2] Pol and Wattelle first proposed recompression (whilst breathing air) as a treatment for DCI in 1854, but it was not used systematically in practice until 1896 during the construction of the Hudson River Tunnel.[13] The mortality of 25% of cases recorded prior to institution of recompression was dramatically reduced with recompression. In a subsequent tunnel project in New York, Keays demonstrated a symptom recurrence rate of 13.7% in workers with DCI who were treated with analgesics and 'stimulants' compared to 0.5% in those treated with recompression.[14] Recompression on air became the standard therapy for DCI until the introduction of 100% oxygen breathing during recompression in 1944, following the work of Yarbrough and Behnke.[15]

Many variations of recompression on oxygen, air and helium–oxygen mixtures have been proposed and used since; and indeed, recompression in some form remains the mainstay of treatment for DCI. A review of the effectiveness of the United States Navy oxygen treatment tables suggests complete relief of symptoms in 50% to 98% of individuals, apparently depending on the severity of illness and period of time elapsed between development of DCI and recompression.[16] In addition, a number of 'first aid' and adjunctive therapies have been applied in the hope of improving rates of complete resolution. Strategies suggested include the maintenance of a horizontal position (to discourage distribution of intravascular bubbles into the cerebral circulation), 100% oxygen administration at one atmosphere and the administration of intravenous or oral fluids, corticosteroids, anticoagulants, non-steroidal anti-inflammatory drugs, lignocaine and diazepam. These strategies (and others) have been summarized by Moon.[2] It is important to consider that any one of these strategies might modify the outcome of DCS and AGE in either direction.

Recompression whilst breathing nitrogen-free mixtures greatly enhances the movement of nitrogen out of any bubbles down a steep diffusion gradient as well as directly reducing bubble volume in accordance with Boyle's Law. The use of high oxygen fractions also delivers a greatly increased partial pressure of oxygen to the tissues. Typically, recompression involves pressurization to between two and six atmospheres absolute (ATA; 203–608 kPa), for periods between two hours and several days. The optimal treatment strategy for differing clinical presentations is not apparent. By far the most commonly used regimen is the United States Navy Treatment Table 6 (USN T6), which involves compression to 2.8 ATA (284 kPa) breathing 100% oxygen, followed by a stepwise decompression over four hours and 45 minutes.[17]

We present here a systematic review of the randomised clinical evidence for the benefits and harms of all therapies used in the treatment of DCI.

Methods

It was our intention to identify and review all randomised and quasi-randomised controlled trials concerning the use of any strategy for the treatment of DCI. Specific search strategies were developed to identify eligible reports from database inception to August 2005 in MEDLINE, EMBASE, the Cochrane Central Register of Controlled Trials (CENTRAL) and the Database of Randomised Controlled Trials in Hyperbaric Medicine (DORCTIHM). The latter is a specifically targeted database of clinical evidence in the field (http://www.hboevidence.com). All searches were re-run in December 2007, and a further search was conducted of the Rubicon Foundation database (http://www.rubicon-foundation.org) at that time, but no further studies were identified.

Medical subject headings (MeSH) and main key words used were 'decompression sickness', 'embolism, air' and 'hyperbaric oxygenation' with variants of the main key words, free-text terms and all adjuvant treatments mentioned above also applied. No restrictions to language were made. Relevant hyperbaric textbooks, journals and conference proceedings were searched by hand. Experts in the field were contacted for published, unpublished and ongoing randomised controlled trials (RCTs). Additional trials were sought from the citations within obtained papers.

We pre-determined the following clinically important outcomes for assessment, and all included studies must have reported at least one of these: mortality at any time, severe functional disability rate, complete recovery rate, a functional recovery scale (e.g., Royal New Zealand Navy (RNZN) Recovery Score,[18] Dick and Massey Score,[19] functional outcome scale[20]) or the number of recompression sessions required. We also recorded the time to complete recovery, time to return to diving, activities of daily living (ADL), quality of life and any adverse events following therapy when reported.

Two reviewers independently assessed the electronic search results and selected potentially relevant studies. Disagreements were settled by examination of the full paper and the opinion of a third reviewer. To assess methodological quality and detect potential sources of bias we followed the guidelines set out by the Cochrane Handbook for Systematic Reviews of Interventions.[21] This method assesses factors related to applicability of findings, validity of individual studies, and study design characteristics such as double blinding and adherence. Two authors independently assessed the methodological quality of the selected studies and ranked allocation concealment as A (adequate), B (unclear), C (inadequate) or D (not used). We resolved any differences of opinion by discussion and consensus.

If any relevant data were missing from trial reports, we attempted to contact the authors. To allow an intention-to-treat analysis we extracted the data reflecting the original allocation group where possible. Disagreements were again settled by consensus.

STATISTICAL ANALYSIS

Following agreement, the data were entered into Review Manager® 4.2.1. (Cochrane Collaboration, Oxford, UK). For dichotomous outcomes such as mortality at a single time point, we calculated Relative Risks (RR) with 95% confidence interval (CI). A statistically significant difference from control was assumed when the 95% CI of the RR did not include the value 1.0.

All analyses were made on an intention-to-treat basis where possible; where not possible, this is clearly stated. Where the 95% CI for the absolute risk difference did not cross zero, we calculated the number needed to treat (NNT) from the standard recompression event rate and the experimental group rate. The 95% CI was calculated from the 95% CI of the risk difference between the groups.

We performed sensitivity analyses for missing data from the outcome ‘complete recovery’ in Bennett et al[22] by comparing best- and worst-case scenarios at discharge and six weeks. For the best-case scenario, all missing patients in the tenoxicam group were assumed to have recovered while all those in the placebo group were assumed not to have recovered. The worst-case scenario employed the reverse assumptions. We also considered subgroup analysis based on the subtype of DCI, severity grade, gas burden, time elapsed between completion of last dive and treatment, time elapsed from appearance of first symptom to treatment and dose of oxygen received.

Results

THE INCLUDED STUDIES

We identified 14 publications apparently dealing with the use of recompression or adjunctive therapy for the treatment of DCI. Initial examination confirmed six were investigations concerning divers, but for problems other than DCI; two were reviews without new data; one was a treatment guideline; one was a comparative trial with retrospective controls; one was a trial involving pre-dive treatment with a range of adjunctive agents intended to modify any subsequent illness; and one was a report of a planned trial. These reports were excluded, leaving two publications of possible randomised comparative trials. After appraisal of the full reports we included both these trials.[22,23] No new studies were found on a repeat search in December 2007.

The authors were aware of two planned RCTs but both have been abandoned at the time of writing the original review. One proposed the investigation of helium–oxygen mixtures versus oxygen-only recompression (Jonas Hink, personal communication, 2006), whilst the other proposed investigation of the addition of intravenous lignocaine to recompression for serious neurological DCI (James Francis, personal communication, 2004). The details of the two included trials are summarised in Table 1.

Bennett et al enrolled 180 divers presenting for management of DCI, but excluded those with a clinical diagnosis of AGE. They were randomised with stratification by clinical disease severity to either routine recompression therapy or routine recompression therapy with the addition of a non-steroidal anti-inflammatory drug (tenoxicam). In the active therapy arm, tenoxicam 20 mg was administered at the first air break during the first recompression treatment and daily for seven days, while in the control arm a placebo medication was administered on the same schedule. In the absence of complete recovery with the initial treatment, once-daily recompressions were continued until either complete recovery was achieved, or there was no sustained improvement over two consecutive days. Results were given for 164 of the 180 enrolled (91%). This trial reported complete recovery of symptoms and signs measured at completion of recompression therapy and at six weeks, mortality and the number of recompressions administered.

Drewry et al enrolled 88 patients with a clinical diagnosis of DCI and randomised them either to an initial recompression schedule of 100% oxygen breathing at 2.8 ATA or to a schedule involving breathing 50% oxygen with 50% helium at 2.8 ATA. Both arms had treatment option available if initial response was less than 80% improvement. This study utilised the same criteria for cessation of repeat recompression therapy as outlined above for the Bennett et al trial. This trial has been reported to date only in the form of interim results in an abstract. Eighteen of the 88 participants (20.5%) were withdrawn from analysis due to failure to meet entry criteria (retrospectively) or because of protocol violations, and a further 14 had not reached final follow up. Therefore only 56 participants (64% of those enrolled) had outcomes reported in the abstract. This trial reported the proportion of participants who required multiple compressions prior to discharge.

Table 1. Summary of included trials

Study	Methods	Participants	Interventions	Outcomes	Notes
Drewry 1994	Randomised controlled trial with blinding of investigators and participants. Sealed envelope method with stratification for presentation within 48 hours or at more than 48 hours.	88 patients presenting with DCI (clinical diagnosis) and requiring recompression therapy.	Control: intravenous hydration and recompression breathing 100% oxygen at 18 msw. • If 80% or more improvement after 45 minutes, then USN T6 recompression table is completed. • If less than 80% improvement, then proceed to 30 msw breathing 50% oxygen with 50% nitrogen. Complex aglorithm if there is still poor response, with maximum compression to 50 msw. Active: intravenous hydration and recompression breathing 50% oxygen and 50% helium at 18 msw. • If 80% or more improvement after 45 minutes, then completed 18 msw maximum depth table breathing heliox with no air breaks. • If less than 80% improvement, then proceed to 30 msw breathing 50% oxygen with 50% helium. Complex algorithm if there is still poor response, with maximum compression to 50 msw breathing 20% oxygen and 80% helium.	Proportion of participants requiring second recompression due to incomplete resolution of clinical symptoms or signs.	Trial only reported in an abstract. Not analysed by intention to treat (18 withdrawals due to protocol violations and 14 others with results not reported). The first report did not give any results. Allocation concealment: B
Bennett 2003	Randomised controlled trial with blinding of all participants. Analysed by intention to treat. Central computer code held by pharmacy.	180 participants with 'clinical' DCI (excluding CAGE) from three centres.	Control: recompression on physician choice table (88% had USN T6), placebo medication at first air break and daily for seven days, recompression as clinically indicated to plateau of symptoms or complete resolution plus one further treatment. Active: as above, but active medication with tenoxicam 20 mg per dose.	Death; outcome functional score 1 to 4; number of compression cycles required.	High methodological quality. Allocation concealment: A

CLINICAL OUTCOMES

Major clinical outcomes of interest are summarised in Table 2 and those of greatest interest are discussed below. Data from the two included studies could not be pooled and are described individually.

Bennett et al reported no significant difference in the proportion of participants who were completely recovered at discharge or six weeks later (80% with placebo versus 83% with tenoxicam at six weeks).[22] However, the result at six weeks was sensitive to the outcome of those lost to follow up, with a best-case analysis suggesting that the chance of recovering completely at six weeks was improved with tenoxicam: relative risk (RR) of complete recovery with tenoxicam was 1.19, 95% CI 1.01 to 1.39, P = 0.03.

In order to achieve these outcomes, the placebo group required a median of three recompression treatments (range one to eight), while the tenoxicam group required a median of two treatments (range one to six), and this difference was reported as significant (P = 0.01, 95% CI 0 to 1). Of the placebo group, 61% required more than two treatments whilst only 39% of the treatment group required more than two treatments. A stratified analysis by the severity grade of DCI on presentation suggested this treatment effect was present across the range of severities tested. The analysis suggested a need to treat five patients in order to reduce the number of compressions required by one patient (NNT 5, 95% CI 3 to 18).

Drewry et al similarly reported that the proportion of participants requiring multiple recompressions was significantly smaller in the oxygen and helium group (heliox) versus the oxygen group (36% versus 65%, P = 0.03).[23] Analysis in this review suggests the chance of multiple recompressions may be lower with heliox (RR 0.56, 95% CI 0.31 to 1.00, P = 0.05) and that we would need to treat four individuals with helium and oxygen in order to have one extra individual requiring only a single recompression (NNT = 4, 95% CI 2 to 31).

Adverse events were reported by Bennett et al. Six participants had problems during initial recompression: three (one on tenoxicam, two on placebo) complained of aural barotrauma, two (one on tenoxicam, one on placebo) developed premonitory signs of cerebral oxygen toxicity and one tenoxicam patient complained of nausea not resolved by removal from oxygen breathing at depth (pressure).

Discussion

This review has included data from two trials investigating the treatment of DCI, and we believe these represent all randomised human trials in this area, both published and unpublished, at the time of searching the databases. Unsurprisingly, we did not find randomised controlled trial evidence to support or refute the effectiveness of recompression versus no recompression for the management of DCI. Recompression is a universally accepted therapy for DCI and for ethical reasons is most unlikely to be subject to randomised investigation against sham therapy in the future. The two trials considered in this review involved a modest total of 268 patients and investigated alternative recompression strategies [23] and an NSAID drug as an adjunctive therapy to standard recompression [22] respectively. The results could not therefore be pooled for meta-analysis.

The Drewry et al trial was never reported at completion and is probably underpowered to find a clinically significant difference between the two recompression strategies.

Table 2
Summary of outcomes (RR = relative risk, MD = median difference, *statistically significant outcomes)

Study; outcome measure	N		Outcome rate		Efficacy data$^{\#}$	95%CI	P-value	NNT
Drewry 1994	**Heliox**	**Nitrox**	**Heliox**	**Nitrox**	**RR**			
Need for more than one recompression	25	31	9 (36%)	20 (65%)	*0.56	0.31 to 1.00	0.05	4 [2 to 31]
Bennett 2003	**Tenoxicam**	**Placebo**	**Tenoxicam**	**Placebo**	**RR**			
Complete recovery at discharge	84	84	53 (63%)	59 (70%)	0.90	0.72 to 1.11	0.33	
Complete recovery at 6 weeks	84	80	70 (83%)	64 (80%)	1.04	0.90 to 1.20	0.58	
Need for more than one recompression	90	90	35 (39%)	55 (61%)	*0.65	0.48 to 0.88	0.005	5 [3 to 18]
Median number of treatments administered	90	90	2 (1–6)	3 (1–8)	MD 1	0 to 1	0.01	

There is a significant difference in the reported number of participants enrolled in each arm of this study (25 versus 31) and although this may be due to chance we consider the potential for selection bias to be high. While a preliminary 1992 report on trial methodology described a sequential analysis strategy with a stopping rule based on a significant difference in health outcome between the groups at one month ($P = 0.05$ or less), it is not clear this rule was invoked.[24] Indeed, only the proportion of participants who required multiple recompressions was reported and there are no data describing health outcomes at any stage.

The proportion of participants requiring more than one recompression was significantly reduced by the use of an aggressive helium and oxygen recompression regimen in which treatment depth and duration was determined by symptom response.[23] The impact of the heliox regimen should be interpreted carefully in the context of local patient characteristics and the expected rate of multiple compressions. While calculation of the NNT with heliox using the control event rate in this study (65% required multiple compression) is four, this estimate is sensitive to the actual event rate in practice at other treatment facilities. For example, data from 591 cases of DCI reported by the Divers Alert Network in 2001 suggested the proportion receiving multiple compressions was 50%.[17] Using this as the control event rate and an RR of 0.56 as our best estimate of effect suggests an NNT of five.

Also of potential importance is the consideration that the treatment protocol was quite complex for both arms of the study and ultimately allowed for the participants to enter a saturation treatment that may have lasted for several days. More information is needed on the actual profiles used and the clinical outcome of participants in this trial. This is important because it is possible that any benefit for heliox treatment may have arisen from an interaction with complex, long, high-pressure recompression protocols that might be impractical in many facilities.

The trial by Bennett et al was powered to detect a difference between groups in the proportion of participants with incomplete resolution (30% placebo versus 20% tenoxicam predicted). We can therefore be reasonably confident that the addition of tenoxicam to recompression does not in fact result in a clinically significant improvement in the effectiveness of therapy.

The proportion of participants requiring more than two recompressions before discharge was significantly reduced by the addition of the NSAID tenoxicam to a standard recompression treatment. Bennett et al chose the dichotomous outcome ‘one or two treatments versus more than two treatments’ because the standard practice in many Australasian institutions is to continue recompression treatments until resolution of symptoms plus one further recompression session, or until symptoms plateau for two consecutive recompression sessions. Thus, for many physicians, two recompression sessions is a minimal treatment course. Analysis suggested a modest treatment-sparing effect with an NNT of five patients to reduce the number of recompression treatments required by at least one. Similar considerations concerning the interpretation of NNT apply here, particularly as world practice suggests that single recompression therapy remains common. Once again, using the DAN data for comparison and the effect estimate from the study (RR 0.65), only 30% of patients received more than two compressions, suggesting an NNT with tenoxicam of 10 rather than five.

An informal economic analysis based on the results of Bennett et al[22] and using data from a contemporaneous cost analysis in the main contributing hyperbaric facility, suggests there may be modest cost savings associated with the administration of tenoxicam as an adjunctive measure for DCI.[25] These data suggest a saving of $AUD 720 (one session of HBOT for DCI) for every five patients treated for DCI (95% CI every 3 to 18 patients), whilst the cost of a single week course of tenoxicam is estimated at $AUD 6.50 for each patient.[26]

One problem with research in this area is diagnostic uncertainty. There are no reliable diagnostic tests or clinical criteria for DCI and it is likely that all clinical trials will be contaminated by an unknown number of ‘cases’ that do not suffer from a bubble-related injury. In general, this will tend to minimize the apparent effectiveness of specific, targeted therapies while magnifying the effect of symptomatic therapies with broad, non-specific activity. The included studies are both pragmatic and likely to reflect the efficacy of interventions in the presence of this diagnostic uncertainty.

There are a few major adverse effects of recompression (pulmonary barotrauma, acute cerebral oxygen toxicity or death related to chamber fire) and short courses of non-steroidal drugs (renal failure or significant gastric bleeding), and while these are all rare enough not to be seen in the trials included in this review, they should be included in consideration of any benefit of these therapies. In practice it is likely that a beneficial effect strong enough to be clearly identified in clinical trials would overwhelm the consideration of such rare events. There are, however, a number of more minor complications that may occur commonly and Bennett et al reported six individuals with minor adverse effects.[22] None of the six was withdrawn from therapy.

While we have made every effort to locate further unpublished data, it remains possible that this review is subject to a positive publication bias, with generally favourable trials more likely to achieve reporting.

Conclusions

Recompression therapy is universally accepted as standard practice for the treatment of DCI. While there is considerable evidence for good outcomes following recompression, this practice is not based on any RCT evidence. There is some evidence that the addition of an NSAID to breathing 100% oxygen during recompression reduces the number of recompression sessions required to treat DCI, but no evidence for an improvement in the rate of complete recovery. Similarly, there is some evidence that helium and oxygen breathing during recompression may reduce recompression requirements, though the methodological problems in the single trial examining the use of helium and oxygen breathing should be noted. The use of an NSAID is likely to be associated with a modest reduction in the cost of therapy. Thus, the application of either of these strategies may be justified. The small number of studies and the modest numbers of patients included in this review demand a cautious interpretation.

Given the natural history of severe DCI and the well-documented clinical response to recompression, it is unlikely that any comparison of recompression therapy against a sham alternative can be justified. There is, however, a strong case for large RCTs of high methodological rigour in order to define the extent of benefit (if any) from the use of different breathing gases and pressure profiles during recompression therapy. Specifically, information is required on the subset of disease severity that may justify the use of complex and expensive treatment tables. The diagnosis and classification of DCI is particularly problematic with the milder forms of the disease. Formal economic analysis is required to quantify the cost benefit of treatment with NSAIDs and heliox. Any future trials would need to consider adequate sample sizes to detect important differences in clinical outcome, careful definition of target cases, appropriate adjunctive therapies and the careful elucidation of any adverse effects.

Acknowledgements

This paper is a summary of a Cochrane systematic review [**Bennett MH, Lehm JP, Mitchell SJ, Wasiak J. Recompression and adjunctive therapy for decompression illness (Cochrane Review). In: The Cochrane Library (Issue 2, 2006). CD005007. Chichester, UK: John Wiley & Sons, Ltd**.].

We would like to thank John Carlisle, Nathan Pace, Peter Kranke, Richard Moon, Tom S Neuman, James Vorosmarti, Robyn Walker, Janet Wale, Kathie Godfrey and Marcus Müllner for their help and editorial advice during the preparation of that review. We are also very grateful to Jane Cracknell of the Cochrane Anaesthesia Review Group for orchestrating the process.

Conflicts of interest

The authors declare they have no conflict of interest with regard to the material presented in this work. This work has received no external funding.

References

1 Brubakk AO. The effect of bubbles on the living body. *SPUMS J.* 1999; 29: 221-7.
2 Moon RE, Gorman DF. Treatment of the decompression disorders. In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving*, 5th edition. Edinburgh: Saunders; 2003. p. 600-50.
3 Helps SC, Gorman DF. Air embolism of the brain in rabbits pretreated with mechlorethamine. *Stroke.* 1991; 22: 351-4.
4 Hills BA, James PB. Microbubble damage to the blood-brain barrier: relevance to decompression sickness. *Undersea Biomed Res.* 1991; 18: 111-6.
5 Nossum V, Koteng S, Brubakk AO. Endothelial damage by bubbles in the pulmonary artery of the pig. *Undersea Hyperb Med.* 1999; 26: 1-8.
6 Francis TJ, Pearson RR, Robertson AG, Hodgson M, Dutka AJ, Flynn ET. Central nervous system decompression sickness: latency of 1070 cases. *Undersea Biomed Res.* 1988; 15: 403-7.
7 Smith DH, Francis TJR, Pethybridge RJ. Concordance: a problem with the current classification of diving disorders. *Undersea Biomed Res.* 1992; 18 Suppl: 40.
8 Francis TJR, Mitchell SJ. Manifestations of decompression disorders. In: Brubakk AO, Neuman TS, editors. *Bennett and Elliott's physiology and medicine of diving*, 5th edition. Edinburgh: Saunders; 2003. p. 578-9.
9 Rudge FW. Decompression sickness presenting as a viral syndrome. *Aviat Space Environ Med.* 1991; 62: 60-1.
10 Bourke A, Verwork C, Dawson R. A study of diving practices and the incidence of decompression sickness in a population of indigenous diving fishermen in the Phillipines (ii Noc Nocan). *Undersea Hyperb Med.* 1998; 25 Suppl: 32.
11 Cross MR, Dawson R. Diving diseases research centre's diving fishermen project. In: Lepawsky M, Wong R, editor(s). *Empirical diving techniques of commercial sea harvesters: 50th Workshop of the Undersea and Hyperbaric Medical Society*. Kensington: Undersea and Hyperbaric Medicine Society; 1998.
12 Ladd G, Stepan V, Stevens L. The Abacus Project: Establishing the risk of recreational scuba death and decompression illness. *SPUMS J.* 2002; 32: 124-8.
13 Moir EW. Tunnelling by compressed air. *Journal of the Society of Arts.* 1896; 44: 567-85.
14 Keays FL. Compressed air illness, with a report of 3,692 cases. *Department of Medicine Publications*, Cornell University Medical College. 1909; 2: 1-55.
15 Yarbrough OD, Behnke AR. The treatment of compressed air illness using oxygen. *J Indust Hygrog Toxicol.* 1939; 21: 213-8.
16 Thalmann ED. Principles of US Navy recompression treatments for decompression sickness. In: Bennett PB, Moon RE, editor(s). *Diving accident management.* Kensington: Undersea and Hyperbaric Medical Society; 1996. p. 75-95.
17 Divers Alert Network. Report on decompression illness, diving fatalities and Project Dive Exploration. Durham: Divers Alert Network; 2001.
18 Mitchell S, Holley T, Gorman D. A new system for scoring severity and measuring recovery in decompression illness. *SPUMS J.* 1998; 28: 84-94.
19 Dick AP, Massey EW. Neurologic presentation of decompression sickness and air embolism in sport divers. *Neurol.* 1985; 35: 667-71.
20 Bennett MH. The retrieval of diving injuries in New South

Wales. *SPUMS J*. 1995; 25: 142-7.
21 Higgins JPT, Green S, editors. Cochrane Handbook for Systematic Reviews of Interventions 4.2.5 [updated May 2005]. In: *The Cochrane Library* Issue 3, 2005. Chichester, UK: John Wiley & Sons, Ltd.
22 Bennett M, Mitchell S, Dominguez A. Adjunctive treatment of decompression illness with a non-steroidal anti-inflammatory drug (tenoxicam) reduces compression requirement. *Undersea Hyperb Med*. 2003; 30: 195-205.
23 Drewry A, Gorman DF. A progress report on the prospective randomised double blind controlled study of oxygen and oxygen-helium in the treatment of air-diving decompression illness. *Undersea Hyperb Med*. 1994; 21 Suppl: 98.
24 Drewry A, Gorman DF. A preliminary report on a prospective randomized, double-blind, controlled study of oxygen and oxygen-helium in the treatment of air-diving decompression illness. *SPUMS J*. 1992; 22: 139-43.
25 Gomez-Castillo JD, Bennett MH. The cost of hyperbaric therapy at the Prince of Wales Hospital, Sydney. *SPUMS J*. 2005; 35: 194-8.
26 MIMS Australia. MIMS Online. http://www.mims.com.au/ 2007.

Michael Bennett, MD, FANZCA, MM (Clin epi), is Associate Professor, Department of Diving and Hyperbaric Medicine, Prince of Wales Hospital and University of NSW, Australia
Simon J Mitchell, PhD, FANZCA, is Senior Lecturer in Anaesthesia, Faculty of Medicine and Health Sciences, The University of Auckland, New Zealand
Jan P Lehm, MD, FANZCA, is a Senior Staff Specialist, Diving and Hyperbaric Medicine, Prince of Wales Hospital and University of NSW, Australia
Jason Wasiak, PhD, is Senior Research Officer, Victorian Adult Burns Service, The Alfred Hospital, Victoria, Australia
Address for correspondence:
Associate Professor Michael Bennett
Department of Diving and Hyperbaric Medicine
Prince of Wales Hospital
Barker Street, Randwick
NSW 2031, Australia
Phone: *+61-(0)2-9382-3880*
Fax: *+61-(0)2-9382-3882*
E-mail: *<m.bennett@unsw.edu.au>*

Articles reprinted from other sources

Time to treatment for decompression illness [Executive summary]

Prepared by North Sea Medical Centre for the Health & Safety Executive 2007
Werner Stipp

Executive summary

Hyperbaric oxygen treatment (HBO) is the standard and definitive treatment for decompression illness (DCI). HBO involves the delivery of 100% oxygen inside a treatment chamber at a pressure of more than one atmosphere.

Normobaric oxygen means administration of 100% oxygen at atmospheric pressure with tight-fitting mask, ideally with a reservoir bag or a demand system, to a patient (diver). Normobaric oxygen should never be regarded as a substitute for HBO in divers with DCI.

There has been some debate regarding the relative importance of speed vs. quality of treatment for divers with decompression illness (DCI) arising from diving at work operations. Although there is consensus amongst diving doctors that there is no substitute for quality supportive medical care in a seriously injured diver, there is conflicting evidence in the medical literature on whether DCI is more responsive to early rather than late treatment with hyperbaric oxygen (HBO). The main aim of this study was to investigate the influence of time to treatment with HBO in divers with neurological DCI.

The Health and Safety Executive's Approved Code of Practice (ACOP) for commercial diving projects inland/inshore under the Diving at Work Regulations 1997, provides guidelines regarding the availability of hyperbaric chambers to ensure prompt treatment in the event of a diver developing DCI. The guidance states that a compression chamber should be within 2 hours' travelling distance for dives over 10 and up to 50 metres with either no planned in-water decompression; or with planned in-water decompression of up to 20 minutes. For inland/inshore diving with no planned in-water decompression, and if the diving depth is less than 10 metres, the ACOP states that the compression chamber should be within 6 hours' travelling distance from the diving site. For dives with planned in-water decompression greater than 20 minutes, a compression chamber is required on site.

Firm medical evidence is needed to allow the HSE to review, and if necessary amend, the current guidance in this area.

This study provides evidence that early HBO treatment in divers with neurological DCI is associated with a better outcome. An additional analysis evaluating the current ACOP provides evidence that divers who are compliant with the ACOP, i.e. divers with DCI having HBO within the time limits specified above (see above), have a better outcome when compared to divers who are non-compliant. This study therefore provides medical evidence that the time limits as specified in the current ACOP should remain in place.

An interesting observation in this study is that normobaric oxygen administered to the diver before HBO tends to protect the diver against a delay in treatment with HBO. There is a suggestion in the analysis of these study data that divers with DCI who did not receive normobaric oxygen are less responsive to HBO treatment after 350 minutes (or approximately six hours) of surfacing from the incident dive.

Diving contractors and diving supervisors, professional and amateur divers, as well as medical staff, need to be informed and educated on the importance of early hyperbaric oxygen treatment in divers with DCI.

The author recommends that a revised ACOP should re-emphasize the importance of administering normobaric oxygen in divers who develop symptoms and signs suggestive of DCI.

Of note is that HBO gives complete resolution of DCI in the majority of DCI cases (relatively few divers had residual symptoms or signs of neurological DCI after all HBO sessions). Prompt HBO will result in earlier resolution of DCI symptoms and signs.

Knowledge of symptoms and signs of the illness in amateur and professional divers is important, but according to research is not sufficient to change patient behaviour to ensure that patients seek specific treatment at an early stage. A well laid out time-to-treatment action plan (TTT action plan) on what to do when a diver develops suspicious symptoms will be more effective in ensuring divers seek prompt HBO treatment. It is recommended that a TTT action plan should be included in each diving plan. Transport arrangements need to form part of a TTT action plan.

The questionnaire used in this study could form the basis of the development of a clinical diving incident reporting system to the HSE, which could be undertaken by doctors with medical responsibility for diving operations. Such a reporting system may help the HSE to identify diving operations/practices that have a high incidence of DCI (and a poor response to HBO treatment), which in turn could be used to initiate preventative action. The time taken to HBO treatment could be included in each incident report.

Further research is necessary to identify divers who are more susceptible to DCI at the pre-employment medical.

Reprinted with kind permission from Stipp W. Research Report 550 *Time to treatment for decompression sickness*. Prepared by North Sea Medical Centre. Norwich: HSE Books, Her Majesty's Stationery Office; 2007.

Key words
Decompression illness, decompression sickness, diving at work, accidents, hyperbaric oxygen therapy, outcome

---

Continuing Medical Education

An unconscious diver

Mike Bennett found this US CME exercise that he thought might be of interest to readers.
<http://www.medscape.com/viewprogram/14680?src=mp&spon=32&uac=31987CT>
To access the article, click on this Web address, or cut and paste it into a browser window.

This article notification service provided by <http://www.medscape.com>
Physician optimized MEDLINE
Free online CME
25+ medical specialty sites
100+ online medical journals
Conference coverage
Daily medical news
Free e-mail is available to Medscape members – the perfect solution for the mobile professional.

Cost-effectiveness and budget impact of adjunctive hyperbaric oxygen therapy for diabetic foot ulcers [Abstract]

Chuck AW, Hailey D, Jacobs P, Perry DC

Background: Hyperbaric oxygen therapy (HBOT) has been proposed as an adjunct to standard methods of care for diabetic foot ulcers (DFU). Its use may decrease the risk of infection and lower extremity amputations (LEAs). As part of a Canadian assessment, we estimated the cost-effectiveness and budget impact of HBOT in this application.
Methods: We developed a decision model comparing adjunctive HBOT with standard care alone. The population was a 65-year-old cohort with DFU. The time horizon was 12 years taken from a Ministry of Health perspective. The health states were a healed wound with or without a minor LEA, an unhealed wound with no related surgery, and a major LEA. Efficacy data were based on outcomes reported in studies included in a literature review. Cost and capacity needs for treating DFU patients in Canada were estimated using prevalence data from the literature, and cost and utilization data from government records.
Results: The 12-year cost for patients receiving HBOT was CND$40,695 compared with CND$49,786 for standard care alone. Outcomes were 3.64 quality-adjusted life-years (QALYs) for those receiving HBOT and 3.01 QALYs for controls. Estimated cost to treat all prevalent DFU cases in Canada was CND$14.4–19. 7 million/year over 4 years. If seven-person HBOT chambers were used, a further nineteen to thirty-five machines would be required nationally.
Conclusions: Adjunctive HBOT for DFU is cost-effective compared with standard care. Additional HBOT capacity would be needed if it were to be adopted as the standard of care throughout Canada.

University of Alberta and Institute of Health Economics

Reprinted with kind permission from Chuck AW, Hailey D, Jacobs P, Perry DC. Cost-effectiveness and budget impact of adjunctive hyperbaric oxygen therapy for diabetic foot ulcers. *Int J Technol Assess Health Care*. 2008; 24: 178-83.

Key words
Hyperbaric oxygen, hyperbaric facilities, wounds, diabetes, economics

---

Editorial comment

Physicians working in hyperbaric medicine constantly battle against lack of main-stream medical recognition for HBOT as a legitimate treatment modality. In our centre we also frequently hear clinicians saying that so-and-so patient was not referred because HBOT is “too expensive”. This Canadian study, taken from the perspective of a Ministry of Health, demonstrates that HBOT is, in fact, cost-effective in treating diabetic foot ulcer (DFU). Clearly in modelling health delivery services of any sort quite a number of assumptions have to be made based on the available data, and the accuracy of these determine how robustly the model behaves. When the parameters of this model were changed in favour of routine care, HBOT remained the dominant strategy. Modelling the costs of DFU with and without HBOT was conducted by Wheen in 1994 based on costs in Auckland, New Zealand, at that time.[1] The short-term savings were estimated to be NZ$7,333 per patient despite a surprisingly low estimate of the costs of major amputation being assumed. Neither was any allowance made for the costs of rehabilitation or the ongoing costs of wound care in non-healing patients, so this is probably a conservative estimate of the true cost savings for DFU in that setting. In the Hull study from 1999 to 2001, the real cost savings in the first year were GBP2,960 per patient treated in favour of HBOT as adjunctive therapy to routine care.[2] In all the randomised studies of HBOT for DFU published thus far, small and variable in their quality as they are, there has been a consistent trend to improved healing and fewer major amputations. One wonders just how much evidence is required before HBOT becomes an accepted component of DFU care by our medical colleagues. Certainly not all patients with DFU are suitable for HBOT; in the Canadian study the assumption was made that only about a quarter were so, based on the published literature. What is important is that HBOT is integrated into a multidisciplinary approach to what represents a very large health care cost to the community.

References

1 Wheen L. The effectiveness and cost of oxygen therapy of diabetic foot wounds. *SPUMS J*. 1994; 24: 182-90.
2 Abidia A, Laden G, Kuhan G, Johnson BF, Wilkinson AR, et al. The role of hyperbaric oxygen therapy in ischaemic diabetic lower extremity ulcers: a doule-blind randomised-controlled trial. *Eur J Vasc Endovasc Surg*. 2003; 25: 513-8.

Book reviews

Annual Diving Report, 2006 Edition: DAN report on decompression illness, diving fatalities and Project Dive Exploration: 2006 edition (based on 2004 data)

Durham, NC: Divers Alert Network; 2006
Soft cover, 101 pages
No ISBN number
Available from DAN America, 6 West Colony Place, Durham NC 27705, USA.
<www.DiversAlertNetwork.org>
Phone: +1-919-684-2948
Fax: +1-919-490-6630
E-mail: <dan@DiversAlertNetwork.org>

The 2006 Annual DAN Diving Report is the latest edition of their regular review of recreational scuba diving and breath-hold diving injuries and fatalities, this time updated to include 2004 data. Previous editions have been reviewed in this journal. This review of the 2006 report comments on the new data and on changes from the previous edition.

One hundred and sixty diving deaths were reported to DAN in 2004, 88 involving US and Canadian residents. The number of US and Canadian diving fatalities has remained fairly constant for two decades now. Ten of these 88 fatalities did not have an autopsy. Australian and New Zealander readers may find this surprising as an autopsy would almost always occur in their countries if the body was recovered. It may be especially surprising as we hear of the litigious nature of the USA. Females who died had a median age of 53 years and males 47 years. Where information was available, 15% of fatalities had heart disease and 9%, hypertension. Three-quarters were overweight (BMI > 25 kg.m^{-2}) or obese, 45% having a BMI > 30 kg.m^{-2}. A recent USA National Survey showed 30% of adults aged over 20 had BMI > 30 kg.m^{-2}, so obesity may be a factor for death while diving (Figure 1). However, weight tends to increase with age and the diving population might be heavier and older than the population as a whole. The addition of such comparative data from other populations is a new feature to this edition and adds considerably to the interest for the reader. Could BMI be added to Project Dive Exploration (PDE) data to measure the obesity of a sample of recreational divers?

Figure 1
Classification of fatalities by body mass index (N = 49)

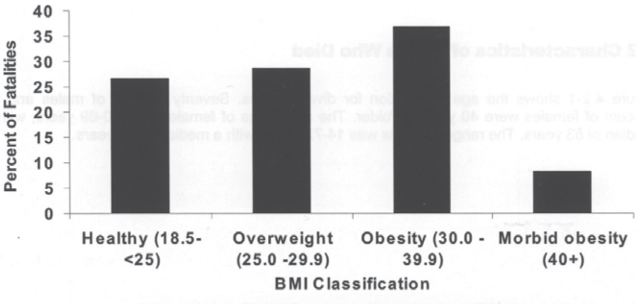


Figure 2
Annual diving death incidence rates per 100,000 divers for DAN and BSAC members

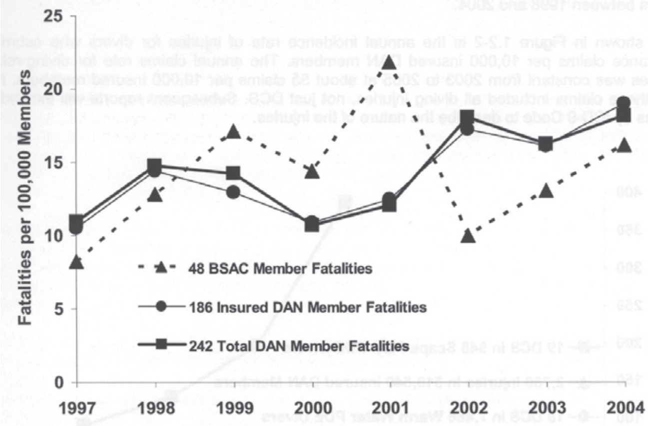
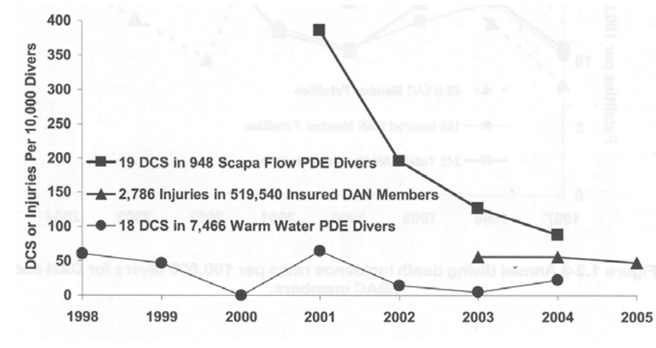


Figure 3
Annual DCS incidence rates per 10,000 dives at Scapa Flow and in the Caribbean among divers enrolled in Project Dive Exploration



The annual diving death rate per 100,000 divers for DAN and British Sub-Aqua Club members is between 10 and 20, and is increasing at about 1 death per 100,000 per year (Figure 2). This is the same rate as deaths in motor vehicle accidents in the USA (14.24 per 100,000 per year, Fatality Analysis Reporting System 2006). Divers are thus just as likely to die in a car as diving, but most American divers must average hundreds of hours per year in their car and dive for only 10–50 hours per year.

The annual decompression sickness (DCS) incidence rates per 10,000 dives at Scapa Flow show a significant decrease from 40 in 2001 to 10 in 2004, while Caribbean rates remained under 5. The corresponding rates per 10,000 divers (rather than dives) were 400 dropping to 100 at Scapa Flow and less than 50 in the Caribbean (Figure 3). These rates are measured in the selected population of divers who log all dives with PDE. PDE now holds data on 105,000 dives from 1,500 divers over 9 years. There were no major changes in the data from previous reports.

A new feature of this edition is the distribution of fatalities by phase of the dive. One of the truisms I have quoted to many would-be divers is that diving deaths mostly occur on the surface. This is not true according to the 2004 data! Sixty per cent of divers lost consciousness underwater. Only 25% were on the surface after the dive, and a few before the dive. The disabling agents in 50% of dives were emergency ascent, entrapment and natural disease (Figure 4). The initial triggering events were insufficient gas (14%), rough seas and current (10%), natural disease (9%), entrapment (9%) and equipment problems (8%) (Figure 5).

There has been a decrease in the number of injury reports to DAN over the last two years due to regulatory changes affecting their ability to collect clinical data (Health Insurance Portability and Accountability Act, 1996, Title II). DAN has introduced a web-based reporting system called the Medical Services Call Center. This serves primarily to benefit clinical management but it also captures the reporting information. Hopefully, this will allow recovery from the damage caused by HIPAA. New Zealand is another country that suffers from over-zealous interpretation of its Privacy Act in ways that the Government never intended. Researchers need to point out to statutory and regulatory bodies that harm done to the pursuit of knowledge is as unethical as disregard for individual privacy.

The mean age of injured divers was 39 years, with some divers over 90 years old! No medical conditions were over-represented in the injured divers. Rapid ascent and omitted decompression were associated with injury. Pain and sensory symptoms were most common, more often located in the hands, head and arms. Malaise, confusion, respiratory trouble and motor weakness tended to start within minutes of the dive whereas pain and parasthesiae took an hour or so to develop. Forty-two per cent gained complete relief from symptoms with treatment, 28% improved, 7% had no response and the data were missing in 23%.

The chapter on breath-hold diving is still evolving and the data remain less complete than the information for scuba diving. This short chapter includes a section on diving wisely that is not consistent with the remainder of the publication, which does not try to prescribe safe practice for scuba diving.

Figure 3
Disabling agents in dive fatalities (n = 88)

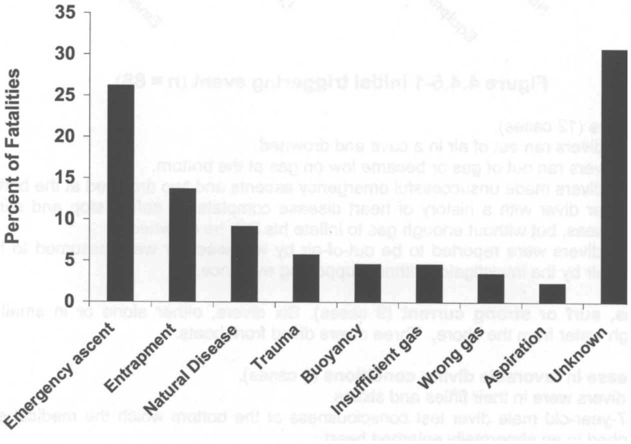
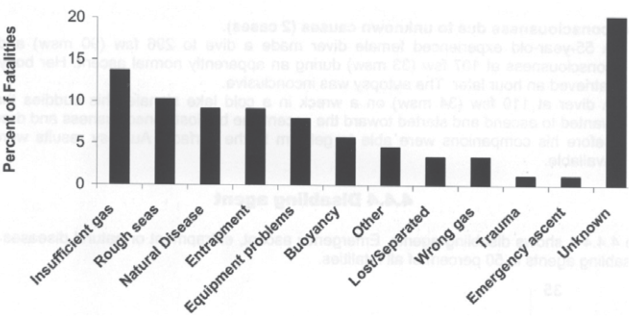


Figure 4
Initial triggering events in dive fatalities (n = 88)



The DAN 2006 Report concludes with case reports that document the sad parade of predictable and preventable injury and death. DAN is again to be congratulated for their efforts to improve our data on diving injury and death. Do all readers involved with hyperbaric units contribute injury reports? Diving deaths are clearly not reported from many countries including many of those around the Mediterranean. Maybe the increased collaboration demonstrated by this journal will result in improved international reporting of morbidity and mortality.

Graham McGeoch
Consultant in Hyperbaric Medicine, Christchurch Hospital

Figures reproduced with kind permission from *Annual Diving Report 2006 Edition*. DAN Report on decompression illness, diving fatalities and Project Dive Exploration: 2006 edition (based on 2004 data). Durham, NC: Divers Alert Network; 2006.

Key words
Book review, accidents, incidents, deaths, decompression illness, recreational diving, DAN - Divers Alert Network

Treading water: Robert Hewitt's survival story

Rob Hewitt with Aaron Smale

Soft cover, 130 pages
ISBN 978-1-869693-18-3
Wellington: Huia Publishers; 2007
39 Pipitea Street, PO Box 17-335
Wellington, New Zealand
Website: <www.huia.co.nz>

In early February 2006, Rob Hewitt, aged 39 and 19 years a Royal New Zealand Navy diver, was lost at sea on his first-ever civilian, recreational dive-charter trip, off Mana Island, near Wellington. Seventy-five hours later he was found floating not far from where he was last seen, dressed only in his wetsuit trousers, hallucinating but alive. During the intervening three days, having been caught initially in an underwater rip current, he was carried first North and then back South by the strong tides that sweep unpredictably through Cook Strait, for a total of about 60 km. During that time an intensive air, land and sea search had been fruitless and it was only by chance that he was spotted by old navy diving mates.

This short book is not only the story of this extraordinary feat of survival at sea in approximately 15°C waters, but of the man himself, his family and the challenges that life presents to young Māori men in the modern era (epitomised in the title of the second chapter, "Grappling with identity"). This is a simple tale, honestly told, not only of the courage and endurance of which humans are capable in extreme circumstances, but also of a man's imperfections and the strength of family ties and the spiritual values held dear by Māori. Rob repeatedly invokes Tangaroa, the Māori guardian of the sea, and Tawhirimatea, god of the winds and storms, as well as drawing strength from family and his faith in God. Whilst long survivals at sea have been recorded in warmer, tropical waters, no-one to this reader's knowledge has survived an ordeal of this length in temperate waters.

Some claim not to believe his story, but the medical evidence for his prolonged immersion was there for all to see on admission to the Emergency Department at Wellington Hospital. Yet, in less than 24 hours, he was out of hospital and back, a changed man, in the embrace of his whanau.

I took this book to bed one evening, planning just to start it; by 1 o'clock in the morning, I had read it cover to cover. Is there a better recommendation for a book than that?

Mike Davis,
Editor, DHM

Key words
Book review, immersion, diving accidents, autobiography, general interest

The poetry doctor

Diving madness

You've got to be mad to go diving,
To go where you can't even breathe?
And if you stay too long down under,
You can't even choose when you leave?

OK, you take your air with you,
In a tank that's strapped to your back?
Is your time spent constantly watching
To ensure that there isn't a lack?

You say you have a computer
That tells you how long you can spend,
So when you finish your diving
You trust it is safe to ascend?

And hey, you get this narcosis
That's greater the more you have sunk?
So as you slowly go deeper
You're suddenly daft and act drunk?

And yeah, your body is pressured,
Its air spaces squeezed on descent,
And if you surface too quickly
Your lungs burst and you're heavenly sent!

You play with dangerous creatures?
They bite, poison or sting
Causing pain, weakness, infection,
Convulsion, arrest or bleeding?

No way I'll ever go diving,
Risking a bend or attack.
I'm going to stay dry and breathe easy,
In the madness I know,
...In Iraq.

I am presently in Iraq working another mission with Médecin Sans Frontières (MSF or "Doctors Without Borders"). I am the Medical Director of a Burns, Plastic and Trauma hospital treating victims of the ongoing violence. We are taking some of the burden off the overloaded Iraqi medical system. There is plenty of work with daily bombs and bullets, most of which never get reported by media. It is like living in a hornet's nest!

But sitting here telling my Iraqi colleagues and friends about my interest in diving medicine has been interesting. Recreational diving is not big here. They show a mixture of amazement, amusement and astonishment at my stories and this poem evolved from their reactions.

John Parker
<www.thepoetrydoctor.com>

Letters to the Editor

Accident rates at a busy diving centre

Dear Editor,

The Poor Knights Islands in Northland, New Zealand, is a world-famous, temperate-water, diving tourism destination, popularised many years ago by Jacques Cousteau. By far the largest dive operator there is *Dive! Tutukaka,* with five vessels carrying up to 30 divers, operating on a regular basis throughout the year. *Dive Tutukaka* is required to keep a detailed, daily vessel manifest. Thus, the number of divers is known accurately and all incidents are recorded by the Skipper or the Chief Divemaster on board. Although all dives are logged (time in, time out and maximum depth for every diver) and kept permanently, these data were not utilised for this brief report. Each customer does two dives on a trip and there are between one and four divemasters on board who may do one, two or more dives a day (van der Hulst G, unpublished observations). Thus the accident rate per diver is known, and it is assumed that the rate per dive is very close to half this figure. In addition, under health and safety regulations all non-diving injuries both on shore and on board are documented, but these will include some non-divers.

For the three financial years between July 2005 and 14 June 2008, 32,302 customers dived with *Dive! Tutukaka*, approximately 63,000 dives (a small minority did only one dive). Over the same period, there were an estimated 7,600 dives conducted by the divemasters. The injuries documented during this time are shown in Table 1. There were seven cases of decompression illness (DCI), a rate of about 1 per 10,000 divers (0.5 per 10,000 dives). Two of the seven DCI cases involved serious neurological injury. There was one further possible case of DCI who did not seek medical advice. If this diver is included then the rate is 1.14 per 10,000 divers. More minor diving injuries and incidents occurred at a rate of approximately 2 per 10,000 divers.

Non-diving injuries occurred rarely, the most common being various musculo-skeletal injuries to staff, requiring time off work. Many of these were secondary to lifting and carrying heavy diving equipment, particularly dive tanks. This indicates an area where improved practices by staff could be achieved.

We believe these injury data are robust and provide an accurate picture of a single, mainstream, international tourism diving centre in temperate waters, and indicate a low rate of injury, comparable to the international literature.

Michael Davis, MD, Christchurch Hospital, and
Kate Malcolm, Dive! Tutukaka, Northland, New Zealand
E-mail: *<mike.davis@cdhb.govt.nz>*

Table 1
Dive! Tutukaka incidents July 2005 to June 2008.
(figures in parenthesis are customer injuries)

Diving injuries	**Divers**
Ear barotrauma (Bt)[*]	5 (3)
External ear infection	1
Tooth Bt	1
Pulmonary Bt[†]	3
Decompression illness[‡]	7 (4)
Other (panic, rapid ascent)	3 (3)
Total	20

Non-diving injuries	**Ship-board**	**Dock/Dry land**
Musculo-skeletal strains	3 (1)	10
Lacerations	4	0
Eye – petrol/solvent	0	2
Chest injury	2 (2)	0
Total	9 (3)	12

[*] 3 customers with ear Bt
– vertigo and balance problems, ?inner ear Bt
– tympanic membrane rupture
– tooth and middle ear (possible DCS)

[†] 2 pulm Bt cases were admitted to the local base hospital

[‡] 2 DCI cases involved serious neurological injury
1 other possible case of DCI did not seek medical help

Key words
Letters (to the Editor), accidents, recreational diving, decompression illness, decompression sickness, data

---

Monarchy and the Republic

Dear Editor,

I must have missed the news item that Lee Kwan Yu had been made King of Singapore (Royal Singapore Navy).[1] Last time I was in Singapore, admittedly last year, the money was marked Republic of Singapore. When Jimmy How ran the naval diving unit more than 20 years ago he was in the REPUBLIC of Singapore Navy!

John Knight
Life Member and previous Editor, SPUMS Journal

Editor's comment: The present Editor apologises for any offence to Drs Chong and Tan of the Republic of Singapore Navy that may have been given, and assures readers he is not a monarchist.

Reference

1 Chong SJ, Tan TW. Cerebral arterial gas embolism in a diver using closed-circuit rebreather diving apparatus. *Diving and Hyperbaric Medicine*. 2008; 38: 46-7.

Key words
Letters (to the Editor), corrections

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 medically qualified, and be a current financial member of the Society of at least two years' standing.
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 facility. The list of approved facilities providing two-week courses is provided on the SPUMS website.
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. Accompanying this written report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–4 above.

Additional information – prospective approval of projects is required

The candidate must contact the Education Officer in writing (e-mail is acceptable) to advise of their intended candidacy, 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, and that the candidate is the first author, where there are more than one.

The Academic Board reserves the right to modify any of these requirements from time to time. The Academic Board consists of:
Associate Professor David Smart, Education Officer, Associate Professor Mike Davis, Dr Simon Mitchell.

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

Key words
Qualifications, underwater medicine, hyperbaric oxygen, research

---

Minutes of the SPUMS Executive Committee Meeting held at Holiday Inn, Melbourne Airport on 04 November 2007

Opened: 1009 hr

Present: Drs C Acott (President), R Walker (Immediate Past-President), S Sharkey (Secretary), G Williams (Treasurer), D Smart (ANZHMG Rep), V Haller (Public Officer), D Vote (Committee Member), G Hawkins (Committee Member)

Apologies: Drs M Davis (Editor), C Lee (Committee Member), F Sharp (Education Officer)

1 Minutes of the previous meeting
Dr Acott moved that the minutes of the SPUMS Executive Meeting held on 01 September 2007 be accepted as a true record; seconded by Dr G Hawkins, with no amendments.

2 Matters arising from the previous minutes
2.1 ASM 2008: (Item 3.2–3.4 of previous minutes covered in standard agenda item) **Closed**

2.2 Manual subscription costs: Committee endorsed extra charge to members using manual membership application/renewal of $15. (Item 4.4.1 previous minutes) **Closed**

2.3 Mass emailing: Dr Hawkins reported that he is yet to meet with SQUIZ technical team (Item 4.4.2 previous minutes) **Ongoing**

2.4 An issue will be currency of e-mail addresses for members. There is a requirement for letter to be sent to members requesting notification of current e-mail addresses for this purpose. **New action: Dr Acott** to ask Steve Goble to action

2.5 Education Committee membership: (Item 6.1 previous minutes) Dr Sharp unavailable to clarify role of Professor Gorman and interest from others in joining the Committee. **Ongoing**

2.6 Recognition of international diving medicine qualifications by SPUMS for purposes of the Diving Doctors List: (Item 7.2 previous minutes) Original correspondence and Dr Acott response to be provided for publication in the Journal in 2008. **Ongoing**

2.7 Response to Dr Lang letter: (Item 7.3 previous minutes) **Closed**

2.8 ASM Convenor Manual update: (Item 8.2 previous minutes) Intended as a guideline with some specific direction. Some specific content was reviewed and suggestions made. **Action: Dr Acott** to forward amended draft to the Secretary for distribution

2.9 Committee member job descriptions: Committee members to e-mail to Secretary (Item 8.3 previous minutes) **Ongoing**

2.10 Tendering for ASM: (Item 8.4 previous minutes) **Ongoing**

2.11 Committee elections: (Item 8.6 previous minutes) President, Secretary, Education Officer and two Committee Members up for re-election at AGM 2008. **Closed**

3 Annual Scientific Meeting

3.1 ASM 2008

3.1.1 50 registrants are booked. Dr Acott reported on the scientific programme planned so far. The programme gaps include ARC Resuscitation Guideline update; case reports and diabetes mellitus ("What if" scenarios and duty of care issues).

3.1.2 All guest lecturers have agreed to an honorarium to cover their own expenses for attendance. For the Society it is anticipated that this will have the advantages of improved recruitment of guest lecturers and better control of cost.

3.1.3 Automatic external defibrillator not yet purchased; waiting for availability of new model with rechargeable batteries. No further communication regarding the joint donation with DAN for Kimbe Hospital.

3.2 ASM 2009

Dr Smart reported that Pearl Pacific Harbour resort is provisionally booked. Bruce Spiess as guest lecturer is confirmed. Some travel warnings in Fiji were recently downgraded. Some potential ethical and weather concerns raised by committee members are acknowledged, but the Committee has endorsed a plan to proceed. A final decision will be made in March 2008.

3.3 ASM 2010

3.3.1 Dr Haller was excused from the meeting for this discussion due to potential conflict of interest.

3.3.2 Dr Hawkins reported that proposal was still a joint ASM with Asian Hyperbaric and Diving Medical Association. Location is yet to be decided through further discussion with the AHDMA. The Committee discussed issues affecting compatibility of the two groups that will need to be considered. Some proposed guest speakers were also discussed.

4 Treasurer's report

4.1 Dr Williams reported on known journal costs that need to be shared with EUBS. It was also acknowledged that there are some hidden costs that are not discretely identifiable at present. The Committee agreed that EUBS should be requested to provide known costs and 20% additional for hidden costs. It was agreed that this would be regularly reviewed. **Action: Dr Williams** to forward detail to Dr Davis

4.2 Dr Williams reported that current balances were approximately $86,000 in the general account and approximately $13,500 in the ASM 2008 account with the deposit having been paid.

4.3 Arrangements for a SPUMS business credit card are in progress. The Committee endorsed a plan for the SPUMS Treasurer Dr Guy Williams to have a business credit card with an initial AUD$6,000 limit. Also agreed was an expenditure limit of $500 without approval of the Committee. **Action: Dr Williams** to facilitate CC arrangements

4.4 AMEX, Diners and ANZ facilities should be closed shortly.

4.5 The Committee endorsed the fee increases previously discussed and forwarded by e-mail from Dr Williams recently.

5 Journal report

5.1 Dr Davis sent his apologies but Dr R Walker spoke to this agenda item regarding their recent attendance at the EUBS meeting in Egypt.

5.2 Dr Walker described some excellent diving and a huge volume of divers. However personal safety in this location is an issue and there are relevant travel warnings. She could not recommend this venue for the SPUMS ASM.

5.3 Dr Walker reported on a range of issues that were discussed with EUBS at the meeting. These included EUBS membership; EUBS ASM organisation; journal costs and financing arrangements; some journal content issues and the membership of the editorial board.

5.4 The Committee discussed a requirement that a lawyer be engaged to provide advice/draw up an agreement or contract regarding the journal arrangements. **Agreed**

5.5 Dr Walker also suggested that SPUMS need to consider documenting our editorial and advertising policy.

5.6 Editorial board meetings: Although much of the work could be achieved electronically, face-to-face meetings will need to be factored into costs. It would be an evolving issue.

5.7 There will be a requirement for an editorial board member to attend both SPUMS and EUBS meetings. Costs of airfares and accommodation will need to be met by Journal but with registration cost being met by the respective societies' meetings.

5.8 The Committee also needs to consider committee member attendance at EUBS to represent SPUMS, separate to the journal issues and at SPUMS' cost. **Action: to be discussed** at next face-to-face meeting

5.9 EBSCO proposals: The Committee agreed that we were not prepared to progress these proposals at this stage due to ongoing negotiations with EUBS.

5.10 Rubicon database arrangements are in progress.

6 Education Officer's report

Dr F Sharp unavailable to clarify the role of Professor Gorman on the Education Committee and any interest from others in joining the Committee. **Ongoing**

7 Correspondence

Several items of e-mail and written correspondence were discussed.

8 Other business

8.1 Diabetes mellitus and SPUMS Diving Medical: The Committee discussed a range of issues for consideration. Definitive progress is dependent on the report from the subcommittee, which is currently tasked to review the guidelines for Diabetes.

8.2 Dr Smart departed at 1415 hr.

8.3 Dr Walker is to present at the upcoming Travel Medicine conference in February in Melbourne and would welcome any input for this presentation.

9 Next meeting

The next meeting is planned for early March 2008.

Closed: 1439 hr

ANZCA Certificate in Diving and Hyperbaric Medicine

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

Eligibility criteria are:

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

2 Completion of training courses in Diving Medicine and in Hyperbaric Medicine of at least 4 weeks' total duration. For example, one of:
  a ANZHMG course at Prince of Wales Hospital Sydney, **and** Royal Adelaide Hospital or HMAS Penguin diving medical officers course **OR**
  b Auckland University Diploma in Diving and Hyperbaric Medicine.

3 **EITHER:**
  a Completion of the Diploma of the South Pacific Underwater Medicine Society, including 6 months' full-time equivalent experience in a hyperbaric unit and successful completion of a thesis or research project approved by the Assessor, SPUMS.
  b **and** Completion of a further 12 months' full-time equivalent clinical experience in a hospital-based hyperbaric unit which is approved for training in Diving and Hyperbaric Medicine by the ANZCA.

  OR:
  c Completion of 18 months' full-time equivalent experience in a hospital-based hyperbaric unit which is approved for training in Diving and Hyperbaric Medicine by the ANZCA
  d **and** Completion of a formal project in accordance with ANZCA Professional Document TE11 "Formal Project Guidelines". The formal project must be constructed around a topic which is relevant to the practice of Diving and Hyperbaric Medicine, and must be approved by the ANZCA Assessor prior to commencement.

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

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

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

Dr Margaret Walker, FANZCA
Chair, ANZCA/ASA Special Interest Group in Diving and Hyperbaric Medicine

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY
38^{TH} Annual Scientific Meeting
24 May – 30 May 2009
Venue: To be advised

THEMES

Diving, Flying and Space Exploration

Future Synergies in Diving Accident Management

Ear Injuries and ENT Workshop

The ENT workshop will cover ENT diagnostic dilemmas in divers, practical case examples of ear injuries, principles and practical use of tympanometry

Keynote Speaker

Professor Bruce Spiess, MD, FAHA

Bruce Spiess is Professor and Chief of Cardiothoracic Anaesthesia and Director of Research in the Department of Anaesthesiology at Virginia Commonwealth University. As Director of the Virginia Commonwealth University Reanimation Engineering Shock Center (VCURES) he is researching perfluorocarbons as blood substitutes and their potential in treating decompression illness and gas embolism. Professor Spiess also conducts research into decompression sickness and submarine escape with the USN, and with NASA on decompression sickness in astronauts.

Abstracts: Abstracts should be submitted before 31 March 2009 as a Word file of up to 250 words (excluding references – 4 only) and with only one figure. Intending speakers are reminded that it is SPUMS policy that their presentation is published as a full paper in *Diving and Hyperbaric Medicine.* The Editor will contact speakers prior to the meeting.
Papers should reflect the theme of the conference: diving, flying (including aeromedical retrieval), space exploration, future synergies in diving accident management, systems of care and treatment.

Convenor: Associate Professor David Smart
Education Officer SPUMS
GPO Box 463 HOBART 7001
Tasmania, AUSTRALIA
E-mail: <dsmart@iinet.net.au>
Phone: +61-(0)3-6222-8193
Fax: +61-(0)3-6222-7268
Mobile: +61-(0)419-508-577

34th Scientific Meeting of the European Underwater & Baromedical Society

Graz, Austria, 3 to 6 September 2008

Organized in collaboration with the Dept of Surgery, Division of Thoracic and Hyperbaric Surgery, the University Clinic of Anesthesiology and Intensive Care Medicine of the Medical University of Graz.

We are looking forward to welcoming you in Graz, the capital of Styria, elected European cultural capital in 2003, and the "green heart of Austria"! The old town has been included into the UNESCO World Cultural Heritage List.
The Graz Hyperbaric Centre is part of the ancient Medical University, now a 1500-bed hospital, and is one of the largest hyperbaric facilities in Central Europe.

Venue: Main Auditorium at Graz University Hospital, Auenbrugger Platz 36

Main topics

Hyperbaric medicine:

- Interdisciplinary application of HBO therapy in burn injury, critical care, neurological disorders, oncology, paediatrics, radiotherapy and traumatology
- Critical incidence reporting – discussion of cases
- Nursing the HBO therapy patient – a challenge?

Diving medicine:

- Advances in diving research
- Validation of decompression profiles
- Restart of diving after neurological DCI
- Special environmental conditions: high altitudes, cold water
- Diving with the handicapped

Poster discussions will be included within the several sessions after a "mini-presentation" by the authors.
Preliminary programme: For the latest updates, please visit <www.eubs2008.org>

Satellite meetings, social events, and prices are shown on the conference website.

Sponsors: The Austrian Society of Diving and Hyperbaric Medicine (ÖGTH) & DAN EUROPE

Hotel Reservation: via Graz Tourism Agency
Website: <http://www.graztourismus.at>
E-mail: <info@graztourismus.at>
Phone: +43-(0)316-807547
Refer to EUBS 2008 when booking, please. Please do not hesitate to contact us if you need further assistance:

Conference office: Martina Neuhold, Auenbrugger Platz 29, Graz
Phone: +43-(0)316-385-81923 or +43-(0)664-859-6146
Fax: +43-(0)316-385-3267
E-mail: <info@eubs2008.org

Presidium: Univ. Prof. Dr Freyja Maria Smolle-Jüttner, Dr Beatrice Ratzenhofer-Komenda, Dr Winfried Beuster
Scientific Committee: Diving Medicine: A. Marroni, Italy; A. Taher, Egypt
Hyperbaric Medicine: J. Desola, Spain, Ph. James, U.K.; E. Jansen , Denmark; J. Kot, Poland; D. Mathieu, France; Y. Melamed, Israel
Poster presentations: M. Cimsit, Turkey; L.Ditri, Italy ; Th. Mesimeris, Greece
Organizing Committee: Heiko Aschbacher, Sabine Gabor, Alexej Pokorny, Astrid Preininger, Heiko Renner, Beatrice Ratzenhofer-Komenda.

EUBS European Underwater and Baromedical Society

EXECUTIVE COMMITTEE (as of January 2008)

PRESIDENT
Professor Alf O Brubakk
NTNU, Dept Circulation & Imaging
N-7089 Trondheim, Norway
Phone: +47-73-598904
Fax: +47-73-597940
E-mail: <alf.o.brubakk@ntnu.no>

VICE PRESIDENT
Dr Peter Germonpré
Centre for Hyperbaric Oxygen Therapy
Military Hospital Brussels
B-1120 Brussels, Belgium
Phone: +32-2-2644868
Fax: +32-2-2644861
E-mail: <peter.germonpre@mil.be>

IMMEDIATE PAST PRESIDENT
Dr Noemi Bitterman
Technion, Israel Institute of Technology
Technion City
Haifa 32000, Israel
Phone: +972-4-8294909
Fax: +972-4-8246631
E-mail: <noemib@tx.technion.ac.il>

PAST PRESIDENT
Dr Ramiro Cali-Corleo
Hyperbaric Unit, St. Luke's Hospital
G'Mangia, Malta
Phone: +356-21-234765
Fax: +356-21-372484
E-mail: <irocali@daneurope.org>

HONORARY SECRETARY
Dr Joerg Schmutz
Foundation for Hyperbaric Medicine
Kleinhuningerstrasse 177
CH-4057 Basel, Switzerland
Phone: +41-61-631306
Fax: +41-61-6313006
E-mail: <joerg.schmutz@hin.ch>

MEMBER AT LARGE 2007
Dr Phil Bryson
DDRC, The Hyperbaric Medical Centre
Tamar Science Park, Research Way
Derriford, Plymouth
Devon, PL6 8BU, United Kingdom
Phone: +44-1752-209999
Fax: +44-1752-209115
E-mail: <phil.bryson@ddrc.org>

MEMBER AT LARGE 2006
Professor Maide Cimsit
Department Underwater and Hyperbaric Medicine
Istanbul Faculty of Medicine
80620 Istanbul, Turkey
Phone: +212-5313544
E-mail: <cimsit@istanbul.edu.tr>

MEMBER AT LARGE 2005
Dr Armin Kemmer
BG-Unfallklinik, c/o GTÜM e.V.
Prof. Küntscher-Str. 8
D-82418 Murnau, Germany
Phone: +49-8841-482167
Fax: +49-8841-482166
E-mail: <armin@kemmers.de>

HONORARY TREASURER & MEMBERSHIP SECRETARY
Ms Patricia Wooding
16 Burselm Avenue
Hainault, Ilford
Essex, IG6 3EH, United Kingdom
Phone & Fax: +44-20-85001778
E-mail: <patriciawooding@btinternet.com>

NEWSLETTER EDITOR
Dr Peter HJ Mueller
PO Box 1225
D-76753 Bellheim, Germany
Phone: +49-7272-74161
Fax: +49-7272-774511
E-mail: <pete@ejuhm.de>

Nominations for election as EUBS Executive Committee Member-at-Large 2008

For the term 2008–2010, the following candidates have been accepted by the EUBS Executive Committee. CVs and ballot forms will be circulated by mail. Please return the ballot form using the enclosed envelope.

Andreas Møllerløkken

Address: Rosenborggt 33b, N-7014 Trondheim, Norway
Phone: +47 97 68 40 36
E-mail: <andreas.mollerlokken@ntnu.no>
Date of birth: 15.05.1974
Marital status: Married, one child

Work experience:

2008	Researcher, Department of Circulation and Medical Imaging, Faculty of Medicine, NTNU
2003–2008	PhD student, Medical Technology, Department of Circulation and Medical Imaging, Faculty of Medicine, NTNU
2003	Teacher, Lesjaskog skule
2002	Teacher Education NTNU, part 2, Anna van Rijn College, The Netherlands
2001	Teacher Education NTNU, part 1, Sunnland Ungdomsskole, Trondheim
1997–2003	Axel Bruun AS, Trondheim

Education:

2003–2008	PhD Medical Technology
2001–2002	Programme for Teacher Education, NTNU
1995–2001	Cand. Scient, Biology, NTNU
1994	Officer's training school, Trandum
1993	University of Trondheim
1990–1993	College, Trondheim Cathedral school

Awards:

2007	FRIDA award.
2005	Zetterstrom Award for best poster, EUBS, Barcelona

Publications:

1. Møllerløkken A, Gutvik C, Berge V, Jørgensen A, Løset A, Brubakk AO. Recompression during decompression and effects on bubble formation in the pig. *Aviat Space Environ Med*. 2007; 78: 557-60.
2. Møllerløkken A, Gutvik C, Måsøy S-E, Brubakk AO. Where do bubbles form?. *Eur J Underwater Hyperb Med*, 2007; 8: 26-7.
3. Møllerløkken A, Nossum V, Hovin W, Gennser M, Brubakk AO. Recompression with oxygen to 160 kPa eliminates vascular bubbles, but does not prevent endothelial damage. *Eur J Underwater Hyperb Med*. 2007; 8 (1&2): 11-16.
4. Løset A, Møllerløkken A, Berge V, Wisløff U, Brubakk AO. Post-dive bubble formation in rats: Effects of exercise 24 h ahead repeated 30 min before the dive. *Aviat Space Environ Med*. 2006; 77: 905-8.
5. Møllerløkken A, Berge V, Jørgensen A, Wisløff U, Brubakk AO. Effect of a short-acting NO donor on bubble formation from a saturation dive in pigs.. *J Appl Physiol*. 2006; 101: 1541-5.
6. Møllerløkken A, Gutvik C, Tunstad H. Trygt opp fra dypet. Gemini [Avis] 14.06.2006
7. Møllerløkken A, Brubakk AO, Wisløff U. The effect of hyperbaric oxygen on aerobic capacity in rat. *Eur J Underwater Hyperb Med*. 2005; 6: 5-9.

Lectures:

1. Invited lecture EUBS 2007: Exercise and diving
2. Where do bubbles form? EUBS 2007
3. Ultrasound for animal studies. Ultrasound for monitoring decompression: Theory and practice. NTNU
4. Bubblegrade vs. number of bubbles. 32nd Annual Scientific Meeting of the EUBS 2006.
5. Who am I and what do I do? Mid-Scandinavian winter meeting in extreme environmental physiology.
6. Recompression during decompression reduce bubble formation in the pig: further support for a gas phase model of decompression. 31 Annual Meeting of the European Underwater & Baromedical Society.
7. Amis 2000, our new research tool? R&D diving, December 2005.
8. In-water recompression as first aid. Dykkeseminaret 2005.
9. Pigs without bubbles. Dykkeseminaret 2004.

Poster presentations:

1. Gutvik, Christian; Møllerløkken, Andreas; Brubakk, Alf O. Difference in bubble formation using deep stops is dependent on bottom time: experimental findings and theoretical support. Dykkeseminaret; 14–15.11.2007
2. Møllerløkken, Andreas; Gutvik, Christian; Måsøy, Svein-Erik; Brubakk, Alf O. Where do bubbles form? Dykkeseminaret; 14–15.11.2007
3. Gutvik, Christian; Møllerløkken, Andreas; Brubakk, Alf O. Parameter Estimation on the Copernicus Bubble Model Using Human Doppler Data. UHMS ASM 2006.
4. Møllerløkken, Andreas; Nossum, Vibeke; Hovin, Wenche; Brubakk, Alf O. Recompression with oxygen to 160 kPa eliminates vascular gas bubbles in the pulmonary artery, but does not prevent injury to the endothelium and the cns. 31st Annual Meeting of the European Underwater & Baromedical Society 2005.
5. Møllerløkken, Andreas; Brubakk, Alf O; Lundsett, Nina. The effect of nitric oxide on vascular bubble formation in pigs. EUBS 2004.

Peter Knessl Dr med.

Anaesthesiology FMH, Emergency Medicine SGNOR, Diving Medicine SUHMS

Address: Steinechtweg 18, CH-4452 Itingen / BL, Switzerland

Phone: +41-44 -716-7105 (work)
+41-61- 971-6778 (private)

E-mails: <pknessl@bluewin.ch>
<p.knessl@spitalsanitas.ch>

Born: Prague / CS 19. February 1950

Medical study: Charles University Prague & Basel University

1976	Medical Diploma: Basel University
1991	Anaesthesiology: Basel
1980-1991	Postgrad.Training: Surgery, Urology, Cardiac Surgery, Cardiology, Anaesthesiology REGA (Rescue)
1983-1984	HBO: University Hospital, Basel
Present:	Consultant in Anaesthesia, Sanitas Hospital Kilchberg / ZH

Courses: ACLS / CH, ATLS / GB
MED / GB, DMP / CH
Hyperbaric Team Training / San Antonio / Tx

Publications:

Co-authorship: Fitness to Dive (several versions)
Medical Assessment of Working Divers
Non-indexed journal articles, abstract at UHMS 2000

Societies:

Anaesthesiology & Emergency Medicine:
ESA, ESRA, SGAR, SAOA, SGNOR
Diving & Hyperbaric Medicine:
UHMS; EUBS, SPUMS, ICHM
SUHMS (Committee Member since 94, Educational Affairs)
Aerospace Medicine:
ASMA

Languages:

a) German, English, Czech, Slovak (& “Swiss” German)
b) French, Italian, Hebrew, some Russian (conversation only)

Family status: Married, two adult sons

Proposed modifications of Constitution and Bylaws

In order to facilitate voting and interactive response from EUBS members, it is proposed that the Constitution and Bylaws of the Society be modified in order to make secure internet voting and polling possible. The Articles and Rules to be modified are listed below, with indication of the proposed changes. Please use the Ballot Sheet that will be sent separately to you and send it in an anonymous blank envelope, enclosed in a normal envelope, to the honorary Secretary, Joerg Schmutz, BEFORE July 20, 2008.

Proposed modifications:

CONSTITUTION

ARTICLE VIII - Amendments

Amendments of this Constitution may be proposed by the Executive Committee or by the petition of any twenty (20) members presented to the Executive Committee at least one hundred (100) days before the annual meeting. All amendments so proposed shall be distributed by the honorary Secretary to the membership at least sixty (60) days before the annual meeting with or without the recommendation of the Executive Committee. Voting shall be by postal *or secure internet* ballot and such ballots must be posted to the Secretary at least thirty (30) days before the annual meeting. The approval of at least three-quarters of the members in good standing of the Society who vote upon the proposed amendment shall be required for its passage. No amendment shall be made to the Constitution which shall cause the Society to cease to be Charity-at-Law.

BYLAWS

RULE I - Nominations and Elections

At least one hundred (100) days in advance of the annual meeting, the Executive Committee shall prepare for approval a slate of nominees for all elected officers of the Society and for replacement of those members-at-large of the Executive Committee whose term of office will end at the annual meeting. Additional nominations, if sponsored by at least fifteen (15) members, may be made by petition to the honorary Secretary of the Society at least one hundred

(100) days in advance of the annual meeting provided that such petition include the name of the nominee, the office for which nominated, and nominee's written consent to serve if elected, and the signatures of the fifteen (15) sponsors.

At least sixty (60) days prior to the annual meeting, the honorary Secretary shall report the recommendations of the Executive Committee and all other nominations received by petition in a format suitable for ~~postal~~ balloting. All paid up members shall be ~~sent this ballot and shall be~~ eligible to vote. Each member who desires to vote shall ~~mark the ballot to indicate clearly his choices in the election, shall date and sign the ballot, and shall post it to the honorary Secretary~~ *complete and send the ballot according to the instructions given* at least thirty (30) days prior to the annual meeting. If there has been more than one nominee for an office, the President shall, *in the case of a postal ballot,* appoint two tellers to open and count all ballots received by the honorary Secretary; this counting shall be conducted prior to the annual meeting. Elections shall be by simple majority. The honorary Secretary shall announce the results of the balloting at the annual meeting, and the new officers and members-at-large of the Executive Committee shall assume office immediately thereafter.

RULE IX - Amendments

Amendments to these Bylaws may be proposed by the Executive Committee or by petition of any fifteen (15) members presented to the Executive Committee at least one hundred (100) days before the annual meeting. All proposed amendments shall be distributed to the membership by the Secretary at least sixty (60) days before the annual meeting with or without recommendations of the Executive Committee. Voting shall be by postal *or secure internet* ballot and such ballots must be posted to the Secretary at least thirty (30) days before the annual meeting. The approval of at least two-thirds of the members of the Society who vote upon the proposed amendment shall be necessary for its passage.

No amendment shall be made to the Bylaws which shall cause the Society to cease to be a Charity-at-law.

Important financial information for EUBS members

Membership fees

Dear Colleagues

It is reminder time again for Membership Fees; the membership fees 2008 are due no later than June 30th.

I look forward to receiving this years fee. Please remember to send me your "new membership" or "renewal" form which can be obtained from the EUBS website. Payments can be made by Visa Card, MasterCard/EuroCard, by EuroCheque, or by using the secure Paypal option on the EUBS website.

Thank you,

Ms P Wooding
EUBS Treasurer/Membership Secretary
E-mail: <patriciawooding@btinternet.com>

Auditors

As is customary for non-profit organisations, the accounts of the Society should be audited yearly by an independent auditor. In the past, the financial statements have been accepted in good faith and proved to be correct. However, a procedure for appointing an auditor has been started and this will be conducted yearly from now on. The auditor will be selected during the Annual General Meeting. For 2007, the books will be audited by Sarah Munday of DDRC. Our EUBS Treasurer will prepare a financial statement, which will be available at the start of the Annual Scientific Meeting.

Increase in membership dues

As has been discussed and approved at the 2007 Annual General Meeting, the Journal merger and the more active role that the Society wants to take in providing services to its members and assistance to the Annual Meeting, will necessitate an increase in membership dues. The exact amount will be proposed at the 2008 Annual General Meeting.

Because of the new financial responsibilities that EUBS now faces, it is important that the membership dues are paid by the members as early as possible. Therefore, membership dues will be due before February 1st of each new year, instead of June.

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

<www.hboevidence.com>

Situations vacant

Christchurch Hospital, New Zealand. Hyperbaric Medicine + Anaesthesia or Emergency Medicine Specialist

Vacancies #: 6308 + 6946 (Anaesthesia) or (Emergency Medicine)
Closing date: Applications still being accepted

The Hyperbaric Medicine Unit (HMU), Christchurch Hospital has a 0.4 FTE position to replace a retiring member of the senior staff. This vacancy will be combined with either Anaesthesia or Emergency Medicine sessions to create a full-time specialist position.

CDHB is a busy tertiary referral centre in South Island of New Zealand, with close links to the University of Otago Christchurch School of Medicine and Health Sciences situated on the Christchurch Hospital site. Surgical services include all the main surgical specialties, whilst the Department of Medicine covers all major sub-specialties. There is a regional Spinal Injuries Unit and a Bone Marrow Transplant Unit, and the Emergency Department is the busiest in New Zealand.

HMU is administered within the Anaesthetic Department and is currently being assessed by the ANZ College of Anaesthetists for approval for resident training in hyperbaric medicine. The HMU provides a full range of hyperbaric services for the Canterbury District Health Board (CDHB), and is a referral centre for other DHBs in South Island and some parts of North Island. Clinical practice is based on the UHMS and ANZHMG guidelines. We operate a 4 ATA-capable rectangular multiplace chamber providing around 1,300 treatments per year. Our patients range from ambulatory through critically ill, and we provide a 24/7 emergency service [visit <www.cdhb.govt.nz/hbu/>].

Applicants should have appropriate training and experience in hyperbaric medicine, and an Emergency Medicine or Anaesthesia post-graduate qualification recognised for vocational registration by the Medical Council of New Zealand. Foreign graduates will need to meet all immigration and medical council requirements. A successful appointee in Anaesthesia would preferably have generalist skills with a focus on day surgery, acute theatre work, preassessment, and elective orthopaedics. Flexibility in covering other lists is also required and the ability to work in obstetrics would be an advantage.

Christchurch ("The Garden City") is a university city (Canterbury, Lincoln and Otago Universities) of about 365,000 people. It is situated on the East Coast of South Island close to the Banks Peninsula and the commercial harbour town of Lyttelton, and is an hour's drive from the Southern Alps. A wide range of outdoor recreational activities are readily accessible locally and throughout South Island [visit <www.ccc.govt.nz>].

For the position description contact:
Human Resources, Christchurch Hospital
Phone: +64-(0)3-364-0198 or +64-(0)3-364-0133
E-mail: <hradmin@cdhb.govt.nz>

Fremantle Hospital, Australia. Director – Diving & Hyperbaric Medicine

The Department of Diving & Hyperbaric Medicine at Fremantle Hospital is the State referral centre for hyperbaric medicine in Western Australia and has been operating since 1989. Applications are invited from suitably qualified medical practitioners registrable in the state of Western Australia for the position of Director, Hyperbaric Medicine.

Full-time or part-time (minimum of 5 sessions) and opportunities exist to negotiate sessions within other specialties.

Terms and conditions of service are in accordance with the Western Australian Government Health Industry/AMA Medical Practitioners Agreement 2007.

Essential Criteria include: Specialist qualification registrable in Australia, e.g., FANZCA, FACEM or similar; adequate airway skills (if not in possession of FANZCA, a minimum of 6 months' experience in anaesthesia) and a DipDHM or equivalent.

Other experience required: Experience with multiplace and monoplace chambers; Critical care patients in a hyperbaric environment; Teaching of junior staff and medical students; Conduct of diving and hyperbaric medicine courses, e.g., medical officers', DMTs, Nurses' courses; Research; Publications; Continued medical education/Maintenance of professional standards/Quality Improvements.

Applications, detailing qualifications, previous experience and the names and addresses of three professional referees should be forwarded to Manager Medical Administration, Fremantle Hospital, PO Box 480, Fremantle, Western Australia 6959.

Further information could be obtained from the current Director of Hyperbaric Medicine, Dr Robert M Wong: 08-9431-2233 or <robert.wong@health.wa.gov.au>.

Closing date: 29 August 2008

The Hyperbaric Research Prize

The Hyperbaric Research Prize encourages the scientific advancement of hyperbaric medicine and will be awarded annually whenever a suitable nominee is identified. It will recognise a scholarly published work or body of work(s) either as original research or as a significant advancement in the understanding of earlier published science. The scope of this work includes doctoral and post-doctoral dissertations. The Hyperbaric Research Prize is international in scope. However, the research must be available in English.
The Hyperbaric Research Prize takes the form of commissioned art piece and US$10,000 honorarium.

For detailed information please contact:
Baromedical Research Foundation
5 Medical Park, Columbia, SC 29203, USA
Phone: +1-803-434-7101
Fax: +1-803-434-4354
E-mail: <samir.desai@palmettohealth.org>

Third Congress of US–Japan Panel on Aerospace-Diving Physiology & Technology, and Hyperbaric Medicine (3rd New UJNR)

Dates: 7 to 8 November 2008
Venue: Grand Plaza Nakatsu Hotel, Nakatsu City, Japan
Website: <www.maruroku.co.jp/grandplaza/>
Registration: 20,000 yen
Sponsors: Japanese Society of Hyperbaric and Undersea Medicine <http://www.coara.or.jp/~gensin/3rdcongress/> and Undersea and Hyperbaric Medical Society
Abstract submissions: 15 January–31 July 2008

For further information contact the Congress office:
Kawashima Orthopaedic Hospital, 14-1 Miyabu, Nakatsu city, Oita prefecture, Japan, 871-0012
Phone: +81-979-24-0464
Fax: +81-979-24-6258
E-mail: <newujnr_3rdcongress@yahoo.co.jp>

Hyperbaric Technicians & Nurses Association

2008 ASM/AGM

Challenging HBO traditions:
Occupational diversity under pressure

Venue: SeaWorld Resort, Gold Coast
Dates: 14-17 August
Workshop Faculty: Francois Burman, I-DAN
Robert Sheffield, Texas
Invited Speakers: Dr Michael Strauss, California
Dr Martin Sayer, Scotland.
Hosts: The Wesley Centre for Hyperbaric Medicine
www.wesleyhyperbaric.com.au
Enquiries: <HTNA2008@htna.com.au> or
<htnaasm@bigpond.com>

The future of diving: 100 years of Haldane and beyond

International Symposium

Dates: 18 to 19 December 2008
Venue: Trondheim, Norway

In 1908 Haldane and co-workers published their paper “The prevention of compressed-air illness”, that has formed the basis of modern decompression procedures. It is our belief that diving will be of increasing importance in the future. Climatic changes, lack of food and an increasing need for energy will force better use of our underwater resources. This movement will force a development of new and improved technologies for surviving, working and playing underwater, allowing us to dive deeper and stay longer. Still, however, physiology will be a limiting factor, increasing the need for better understanding of the effect of the underwater environment on man.

For further information contact: Alf O Brubakk
E-mail: <alfb©ntnu.no>

Asian Hyperbaric & Diving Medical Association

DMAC-EDTC Level 1 & IIa

Dates: 9 to 13 December 2008
Venue: Langkawi Island, Malaysia (tentative)

A course for experienced diving medical examiners and diving medicine physicians. This two-part course covers advanced aspects of diving medicine not usually detailed in recreational and military courses. The major emphasis will be on mixed-gas, deep and saturation diving operations.

Course Directors: Professor David Elliott
Dr Jurg Wendling
Course Coordinator: Dr Tony Lee

Sponsor: Hyperbarichealth
For background information visit:
<http://www.dmac-diving.org/courses/>
Contact: <hyperbarichealth@gmail.com>
Fax: +61-(0)3-9558-0216 or +605-242-8533

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

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

2008 ROYAL AUSTRALIAN NAVY MEDICAL OFFICERS' UNDERWATER MEDICINE COURSE

Dates: 10 to 21 November 2008
Venue: HMAS Penguin, Sydney
Cost: $1,833.00 (tbc)

The Medical Officers' Underwater Medicine Course seeks to provide the medical practitioner with an understanding of the range of potential medical problems faced by divers. Considerable emphasis is placed on the contra-indications to diving and the diving medical, together with the pathophysiology, diagnosis and management of the more common diving-related illnesses.

For information and application forms contact:
The Officer in Charge, Submarine & Underwater Medicine Unit, HMAS PENGUIN,
Middle Head Road, Mosman, 2088 NSW, Australia
Phone: +61-(0)2-9960-0572
Fax: +61-(0)2-9960-4435
E-mail: <Scott.Squires@defence.gov.au>

UNDERSEA & HYPERBARIC MEDICAL SOCIETY
Annual Scientific Meeting 2008

Dates: 26 to 28 June 2008
Venue: The Salt Lake City Marriott Downtown, Salt Lake City, Utah

A pre-course '*Decompression and the Deep Stop*' will be offered on June 24-25 and a '*Wound Healing*' pre-course will be offered on June 25.

Register online: <www.regonline.com/UHMS-SLC08>
For more information follow the link:
<http://www.uhms.org/MeetingsEvents/2008AnnualScientificMeeting/tabid/97/Default.aspx>

British Hyperbaric Association
The 2008 Annual Meeting, 20-23 November 2008

BHA

Venue: King's College Conference Centre, University of Aberdeen, Aberdeen

Guest speakers: Professor John Yarnold, Institute of Cancer Research, Mr Richard Shaw, University of Liverpool, and Professor Richard Moon, Duke University

For further information and on-line registration go to the BHA2008 website:
<http://www.hyperchamber.com/BHA2008/index.html>
For more information on the BHA go to:
<www.hyperbaric.org.uk>

ROYAL ADELAIDE HOSPITAL DIVER MEDICAL TECHNICIAN (DMT) & DIVING MEDICAL OFFICER COURSES 2008

DMT courses

November/December 2008
Unit 1: 24 – 28 November
Unit 2: 1 – 5 December
Unit 3: 8 – 12 December

DMT refresher courses 2008
27 – 31 October

There are no further Medical Officer courses in 2008

For more information contact:
Lorna Mirabelli
Senior Administrative Assistant
Hyperbaric Medicine Unit, Royal Adelaide Hospital
Phone: +61-(0)8-8222-5116
Fax: +61-(0)8-8232-4207
E-mail: <Lmirabel@mail.rah.sa.gov.au>

Hyperbaric Medicine
A Team Course for Health Care and Diving Professionals

Dates: 13 to 17 October 2008
Venue: Whipps Cross University Hospital
Cost: £475

40 hours of theory and practical experience with a multiplace chamber incorporating the British Hyperbaric Association (BHA) Core Curriculum. Approved for CHT and CHRN/ACHRN by The National Board of Diving & Hyperbaric Medical Technology (NBDHMT). Approved for 15 CEPD points by the RCA.

Course Director: Roly Gough-Allen

For information and application forms contact:
Ms Tricia Wooding
Phone: +44-0208-539-1222
Fax: +44-0208-539-1333
or download the information from our website:
<www.londonhyperbaric.com>

E-mail: <mail@londonhyperbaric.com>
Post to: London Hyperbaric Medicine Ltd
Whipps Cross University Hospital
Leytonstone
London E11 1RG

Instructions to authors – full version

(revised May 2008, this version can be found along with the journal key word list on the websites)

Diving and Hyperbaric Medicine, as the combined journal of the South Pacific Underwater Medicine Society and the European Underwater and Baromedical Society, seeks to publish papers of high quality on all aspects of diving and hyperbaric medicine in the interests of furthering knowledge amongst diving medical professionals, interested physicians of all specialties, and members of the diving industry.

Contributions should be sent to:
The Editor, Diving and Hyperbaric Medicine
C/o Hyperbaric Medicine Unit, Christchurch Hospital
Private Bag 4710, Christchurch, New Zealand
E-mail: <spumsj@cdhb.govt.nz>

Requirements for manuscripts

Diving and Hyperbaric Medicine welcomes contributions that meet the following requirements:

Original articles (maximum 3,000 words, plus 30 references)
These articles should generally be subdivided into the following sections: an **Abstract** of no more than 250 words, **Introduction**, **Methods**, **Results**, **Discussion**, **Conclusions**, **Acknowledgements** and **References**. Acknowledgements should be brief.

Review articles (maximum 5,000 words, plus 50 references); include an abstract.

Case reports, **Brief reports** and **Work in progress reports** (maximum 1,500 words, plus 15 references); include an abstract.

Educational articles, **commentaries** and **case reports** for '**The diving doctor's diary**', '**World as it is**', '**Opinion**' or '**Historical**' occasional sections may vary in format and length, but should be a maximum of 3,000 words and generally comply with the requirements below.

Letters to the Editor (maximum 500 words, plus 5 references)

Articles longer than specified above will be considered, but require strong justification with regard to length.
Inclusion of more than five authors in any one manuscript requires justification.

Documents should be submitted electronically on CDRom or as attachments to e-mail. The preferred format is Microsoft Office Word 2003. Paper submissions will also be accepted, but may incur a fee for transposition into electronic format.

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. One author must be identified as correspondent, with their full postal address, telephone and fax numbers, and e-mail address supplied. A **covering letter** must be included, signed by all authors, acknowledging this as their own work, that they all agree to submission to DHM and declaring any financial, commercial or other conflicts of interest.

A maximum of five **key words** best describing the paper should be chosen from the list on the SPUMS or EUBS websites, <www.spums.org.au> or <www.eubs.org>. Use of new key words must be justified and may be overruled.

Text should be double-spaced, using both upper and lower case. Headings should conform to the current format in *Diving and Hyperbaric Medicine*:

Section heading
SUB-SECTION HEADING 1
Sub-section heading 2

All pages should be numbered, but no other text should appear in the header and footer space of the document. Do not use underlining. No running title is required.

English spelling will be in accordance with the *Concise Oxford Dictionary*, 11th edition revised. Oxford: Oxford University Press; 2006. Adequate English is a prerequisite for acceptance of the paper. However, editorial assistance will be provided to authors for whom English is not their first language.

Measurements are to be in SI units (mmHg are acceptable for blood pressure measurements) and normal ranges should be included where appropriate. Authors are referred to Baron DN, McKenzie Clarke H, editors. *Units, symbols and abbreviations. A guide for biological and medical editors and authors*, 6th edition. London: Royal Society of Medicine; 2008. Atmospheric and gas partial pressures should be presented in kPa rather than ATA or bar (ATA/bar/mmHg may be provided in parenthesis on the first occasion). Water depths should be presented in metres' sea (or fresh) water (msw or mfw).

Abbreviations may be used once they have been shown in parenthesis after the complete expression. For example, "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 October 2007. Website for details: <http://www.icmje.org/index.html>). In this system references appear in the text as superscript numbers at the end of the sentence **after** the full stop.[1,2] The references are numbered in order of quotation (including those in tables). Index Medicus abbreviations for journal names are to be used (<http://www.nlm.nih.gov/tsd/serials/lji.html>). Examples of the exact format are given below for a journal article and for a chapter in a book. If a referenced journal uses continuous page numbers in each volume, the issue number should not be given. When there are five or fewer authors, all authors are listed; when there are more than five authors, the first five will be listed, followed by "et al." Examples of other types of references can be found at the ICMJE website referred to above, or in previous issues of *Diving and Hyperbaric Medicine*.

1 Freeman P, Edmonds C. Inner ear barotraumas. *Arch Otolaryngol*. 1972; 95: 556-63.
2 Balestra C, Germonpré P, Marroni A, Cronjé FJ. *PFO and the diver*. Flagstaff, AZ: Best Publishing Company; 2007.
3 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.
4 Royal Geographical Society. *The RGS-IGB Expedition Health and Safety Survey*. Available at <http://www.rgs.org/category.php?Page=mainpublications> Accessed March 30, 2005.

Titles of quoted books and journals should be in italics. Capital letters are used only at the start of the article or book title and for proper names. For journal articles, there should be a full stop after the journal name, a space after the semi-colon and after the colon, and a full stop after the page numbers. Verifying the accuracy of references is the responsibility of authors.

Personal communications should appear as such in the text and not be included in the reference list, e.g., (Other AN, personal communication, YEAR).

Illustrations, figures and tables

These should **NOT** be embedded in the manuscript, but submitted as separate, individual electronic files. Each figure and table must be mentioned within the text of the article, e.g., 'Rates of decompression illness by demographic are presented in Table 1…', 'Differences in rates of decompression illness were not significant (Table 1)', etc.

The approximate positions of tables and figures should also be identified in the text. No captions or symbols should appear in the body of the table or image. Legends should generally contain fewer than 40 words and must be listed on a separate page at the end of the main text file.

Table data may be presented either as normal text with tab-separated columns (preferred) or in table format. No gridlines, borders or shading should be used. References appearing in tables should continue the sequence of references in the main text of the article in accordance with the position of the table in the text.

Illustrations and figures should be submitted as separate electronic files in TIFF, high-resolution JPEG or BMP format. JPEGs must be saved at their maximum size and compression avoided. Files of 10 Mb or larger should be submitted on CDRom. Authors are advised to convert their illustrations to grayscale to ensure that contrast within the image is sufficient for clarity when printed. Any graphs or histograms created in Excel should be sent within their original Excel file, including the data table(s) from which they were produced.

Special attention should be given to font sizes within a diagram. These should be sufficiently large to be legible should the diagram be resized for single-column reproduction. The preferred font is Times New Roman.

Posted photographs should be glossy and can be either black-and-white or colour. Magnification should be indicated for photomicrographs, and consideration given to the positioning of labels on diagnostic material as this can greatly influence the size of reproduction that can be achieved in the published article.

Colour is available only when essential and is at the author(s)' expense (approx. A$750 for a single A4 page).

Any manuscript not complying with the above requirements will be returned to the author for revision before it will be considered for publication.

Consent and ethical approval

Studies on human subjects must comply with the Helsinki Declaration of 1975 and those using animals must comply with National Health and Medical Research Council Guidelines or their equivalent in the country in which the work was conducted. A statement affirming Ethics Committee (Institutional Review Board) approval should be included in the text. A copy of that approval should be available if requested. Patient details must be removed and photographs made unrecognizable unless written consent for their publication has been obtained from the patient(s).

Copyright

Manuscripts must be offered exclusively to *Diving and Hyperbaric Medicine*, unless clearly authenticated copyright exemption accompanies the manuscript. Obtaining permission to use tables or figures, etc, from other published work is the responsibility of the author(s), and evidence of this is required before publication.

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

SPUMS and EUBS Annual Scientific Meetings

Diving and Hyperbaric Medicine has published articles based on many of the presentations from SPUMS ASMs. Presenters, including the Guest Speaker(s), are reminded that this is an explicit condition of their participation in the SPUMS meetings. Speakers at EUBS meetings, both those giving keynote addresses and those presenting previously unpublished work are strongly encouraged to submit papers to DHM. All such articles are subject to the above requirements and to peer review.

Zetterström Award

The author(s) of the scientific poster winning the Zetterström Award at the EUBS ASM explicitly agree to submit an article based on their poster to *Diving and Hyperbaric Medicine*. This paper is subject to the above requirements and to peer review.

SPUMS Diploma dissertations

SPUMS policy is to encourage diplomates to publish their dissertation in *Diving and Hyperbaric Medicine*. Advice on preparing a dissertation for submission to DHM is available from the Editor or the Education Officer on request.

Synopses or summaries of master's or doctoral theses will also be considered in order to draw the diving and hyperbaric medical and scientific community's attention to the work of young researchers.

Publication schedule

All submitted manuscripts will be subject to open peer review by a member of the Editorial Board and at least one external reviewer. Reviewer comments will be provided to authors with any recommendations for improvement before publication or if the article is rejected. *Diving and Hyperbaric Medicine* believes that a transparent review process is indicated in such a small specialty. Reviewers are very often aware of the origin of manuscripts and, in the interests of fairness, the authors are therefore provided the names of reviewers of their articles.

The review process takes approximately 3–6 weeks and papers are generally scheduled for publication in order of final acceptance. The Editor retains the right to delay publication in the interests of the journal. Accepted contributions will be subject to editing.

Proofs of articles to be published will be sent to authors in PDF format by e-mail in the month before publication. Authors are expected to check the proofs very carefully and inform the editorial office of any minor corrections they require within five days. Corrections should be listed in an e-mail sent to the journal address <spumsj@cdhb.govt.nz>, or annotated electronically in the pdf file.

Following publication, one complimentary copy of *Diving and Hyperbaric Medicine* will be sent to the corresponding author of each contributory paper. A PDF copy of their article will be available to the corresponding author on request. Additional copies of the journal issue containing the article are not available for purchase unless requested at the time final proofs are checked by the corresponding author, and will be at a charge to the authors.

Erratum

In the paper by Havnes et al, (Havnes MB, Møllerløkken A, Brubakk AO. The effect of two consecutive dives on bubble formation and endothelial function in rats. *Diving and Hyperbaric Medicine*. 2008; 38: 29-32.) the headings for columns 3 and 4 of Table 1 on page 30 were placed the wrong way around. Table 1 should read as below. We apologise for this error.

Table 1
The compression and decompression rates and depth of the dive profiles together with the observation period. The two dives in groups C and D were separated by a 24 hr surface interval.
***The rats that died after the dive did not have an hour observation period**

Group (n)	Compression rate kPa.min^{-1}	Dive depths kPa	Decompression rate kPa.min^{-1}	Observation period hr*
Group A (8)	0	0	0	0
Group B (7)	200	700	50	1
Group C (8)	200	400 + 700	50	1
Group D (7)	200	550 + 700	50	1

DIVER EMERGENCY SERVICES PHONE NUMBERS

AUSTRALIA
1-800-088-200 (in Australia, toll-free)
+61-8-8212-9242 (International)

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

SOUTH-EAST ASIA
+65-750-5546 (Singapore Navy)
+63-2-815-9911 (Philippines)
+605-681-9485 (Malaysia)
852-3611-7326 (China)
010-4500-9113 (Korea)
+81-3-3812-4999 (Japan)

EUROPE
+39-06-4211-8685 (24-hour hotline)

LATIN AMERICA
+1-919-684-9111 (may be called collect; Spanish and Portuguese)

SOUTHERN AFRICA
0800-020-111 (in South Africa, toll-free)
+27-11-254-1112 (International, may be called collect)

The DES numbers are generously supported by DAN

DAN Asia-Pacific DIVE ACCIDENT REPORTING PROJECT

This project is an ongoing investigation seeking to document all types and severities of diving-related accidents. Information, all of which is treated as being confidential in regard to identifying details, is utilised in reports on fatal and non-fatal cases. Such reports can be used by interested people or organisations to increase diving safety through better awareness of critical factors. Information may be sent (in confidence unless otherwise agreed) to:

DAN Research
Divers Alert Network Asia-Pacific
PO Box 384, Ashburton VIC 3147, Australia
Enquiries to: <research@danasiapacific.org>

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-AP website: <www.danasiapacific.org>
They should be returned to:
DIMS, 30 Park Ave, Rosslyn Park, South Australia 5072, Australia.

DISCLAIMER

CONTENTS

Diving and Hyperbaric Medicine Volume 38 No. 2 June 2008

Editorial

61 **The Editor's offering**

Original articles

62 **Comparative incidences of decompression illness in repetitive, staged, mixed-gas decompression diving: is 'dive fitness' an influencing factor?**
Martin DJ Sayer, Jim Akroyd and Guy D Williams

68 **Changes in lung function in Republic of Singapore Navy divers**
Si Jack Chong, Teck Wei Tan and Jordan Yu Jin Lim

71 **Review of scuba diving fatalities and decompression illness in Australia**
John Lippmann

Review articles

79 **Breath-hold diving: performance and safety**
Neal W Pollock

86 **Oxygen toxicity in recreational and technical diving**
Andrew Fock and Ian Millar

Cochrane corner

91 **Recompression and adjunctive therapy for decompression illness: a systematic review of randomised controlled trials**
Michael Bennett, Simon J Mitchell, Jan P Lehm and Jason Wasiak

Articles reprinted from other sources

98 **Time to treatment for decompression illness [Executive summary]**
Stipp W

100 **Cost-effectiveness and budget impact of adjunctive hyperbaric oxygen therapy for diabetic foot ulcers [Abstract]**
Chuck AW, Hailey D, Jacobs P, Perry DC

SPUMS notices & news

105 **Diploma of Diving and Hyperbaric Medicine requirements**

105 **Minutes of the SPUMS Executive Committee Meeting held on 04 November 2007**

107 **ANZCA Certificate in Diving and Hyperbaric Medicine**

108 **SPUMS ASM 2009, Pacific Harbour, Fiji**

EUBS notices & news

109 **EUBS 34th ASM 2008, Graz**

110 **EUBS Executive Committee**

111 **Nominations for election as EUBS Executive Committee Member-at-Large 2008**

112 **Proposed modifications of Constitution and Bylaws**

113 **Important financial information for EUBS members**

Letters to the Editor

104 **Accident rates at a busy diving centre**
Michael Davis and Kate Malcolm

104 **Monarchy and the Republic**
John Knight

Book reviews

101 **DAN Annual Diving Report, 2006 Edition**

103 **Treading water: Robert Hewitt's survival story**
Rob Hewitt with Aaron Smale

Situations vacant

114 **Situations vacant**

Courses and meetings

115 **Courses and meetings**

Instructions to authors

117 **Full version**

Diving and Hyperbaric Medicine is indexed on SCIE and EMBASE

Printed by Snap Printing, 166 Burwood Road, Hawthorn, Victoria 3122