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The safety record of science diving

Acute oxygen toxicity during hyperbaric therapy

Reverse diving profiles: a riposte

Diving's black box

More on jellyfish

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Invited commentary

The international safety record for scientific diving

Martin Sayer

Key words
Scientific diving, safety, decompression sickness, epidemiology, editorial

This issue sees the publication of two papers with a common element in that they review the safety records of scientific diving programmes undertaken in Australia and the United States.[1,2] Earlier this year, an analogous review was made of a single institution's scientific diving operations in the UK and the abstract of that paper is also reproduced.[3] Such detailed published appraisals of a specific sector of the diving-at-work industry are rare, especially for three comparable reviews to have been conducted in similar depth in different national programmes. In this commentary I will contrast the safety trends of the three studies in a way that presents an international evaluation of the relative risk levels for the scientific diving sector as a whole.

As with any meta-analysis of data sets that have been developed in isolation, there will be difficulties in making exact comparisons or when trying to combine the information into single estimates. At least Carter et al and Sayer and Barrington had the relatively straightforward task of examining records from single institutes. Lang's work has had to make some assumptions because of a lack of consistency in some of the reporting phraseology made during two long-term, multi-institute assessments.

In their inter-sectorial comparisons, Sayer and Barrington argue that the unit of 'a dive' does not necessarily convey the true risk to the individual as differences in diving practices will produce varying ratios of person dives to dives. For the UK study that ratio was just over 1.8 but this value could potentially vary considerably within and between the other studies. Conceivably, the US data expressed as 'dives' could refer to the number of divers per person. The study of Carter et al does relate their findings to the 'person dive' level. However, the overall lack of clarity in the reporting terminology between the three studies does influence the levels of certainty in some of the joint incident rates calculated below.

The Australian study does not give a detailed breakdown of the actual maximum depths dived to but the diving was restricted to depths shallower than 30 metres' sea water (msw) or 15 msw depending on the level of qualification because of the statutory limits for scientific diving in that country. The UK study does not discriminate between depth classes deeper than 30 msw but the statutory maximum for diving on scuba at work in the UK is 50 msw. The maximum depths reported from the US were in excess of 50 msw. Looking at dive numbers only, and making some allowance for conversions of depths from feet to metres, indicates that the types of diving being undertaken by the scientific sectors in the US and UK are remarkably similar (Table 1). The only major difference is in depths shallower than 19 msw, where the majority of US diving is performed shallower than 9 msw whereas most of the UK diving is done between 10 and 19 msw. Summing the dives performed shallower than 19 msw produces a very similar trend, with 87% of the US dives and 88% of the UK dives being in this depth range. This similarity in trend is also shown in the proportion of dives undertaken in the depth ranges of 20–29 msw (10% in both) and 30+ msw (3% and 2% by US and UK scientific divers respectively). By subtraction, this means that the proportion of scientific dives performed shallower than 30 msw is 97% in the US, 98% in the UK and 100% in Australia.

This overview examines both the rates of decompression illness (DCI) and those of serious diving incidents. Lang questions whether some of the incidents reported as "pressure accidents" in his pre-1981 data set refer specifically to incidents of DCI or not. I have assumed here that they do but they are also grouped, along with the deaths, within the "serious accidents" category. The relative sizes of the three studies means that any 'international' risk factor that is constructed will be heavily influenced by the US study. The lack of any incidents in the Australian account and only a single incident in the UK study produce their own statistical problems when attempting to apportion risk rate. That notwithstanding, combining the three data sets produces a total of 508,771 dives in which there were 7 deaths, 21 cases of DCI and, by summation, 28 serious diving incidents. This produces rates of 0.06 and 0.04 respectively for serious incidents and DCI cases per 1,000 dives. The incident rates from this analysis for scientific diving are lower than those previously reported for military personnel (0.14 serious incidents per 1,000 dives),[4] amateur recreational divers in the UK (DCI only, 0.07),[5] recreational divers in the Caribbean (DCI only, 0.09),[6] recreational divers in western Canada (serious incidents, 0.12)[7] and wreck divers in cold water (serious incidents, 0.25–0.49).[8]

Table 1. A comparison by maximum depth of the types of scientific diving undertaken in the US (Lang)[2], UK (Sayer and Barrington)[3] and Australia (Carter et al)[1]

Depth range (msw)	US (%)	UK (%)	Australia (%)
0–9	49.20	31.90	
10–19	37.93	56.40	
0–19	87.13	88.30	
20–29	10.10	9.60	
0–30	97.22	97.90	100.00
30+	2.78	2.10	0.00

The assumption made from all three studies is that the vast majority of scientific diving operations are performed using scuba equipment and equipment configurations that have, in general, been developed for and employed by the recreational diving sector. Although scientific diving may have been a driving developmental sector during the advent of scuba, the massive expansion of the recreational sector in recent decades has accelerated development and, as a consequence, made scuba equipment inexpensive and easily accessible. So the question raised by these studies is that if the diving techniques and equipment are common to both sectors, why is the scientific safety record better than the recreational one? There are a number of possible explanations for this that are consistent from the three studies, any one of which may be the most significant.

A theme common to all three accounts is that the scientific diving programmes are conducted under some form of centralised regulation. In the US, this is defined by the Department of Labor's Occupational Health and Safety Administration but implemented through the American Academy of Underwater Sciences. Australia and New Zealand have an Occupational Diving Standard with a sector-specific Scientific Diving Standard, while in the UK scientific diving has a sector-specific Approved Code of Practice under the Diving at Work Regulations. There are many regulatory differences between each of the national approaches but the aim in each case is to ensure that all scientific diving is conducted to standards that minimise the potential for accidental injury and/or illness and to set minimum training and operational competencies. Of course, it could be argued that these aims are also common to the recreational sector. However, it is the level of post-training dive management that is significantly different to that for recreational diving. Sayer has previously detailed how risk is managed in UK scientific diving operations,[9] and although the same level of formalistic risk analysis may not be required in the other two national programmes, the basic control mechanisms are similar for all three countries. That is: there are defined management structures for diving operations, usually with a distinct level of supervision; dive depth may be limited totally and additionally restricted depending on experience; the method of managing decompression may be prescribed; and there will be an age-determined medical requirement.

In general, the type of diving required by science rarely involves excessive physical exertion and it will usually not be dominated by the same commercial demands that other diving-at-work sectors may have. Although it is tempting to suggest that dive duration does not need to be maximal for the depths being dived this may not be the same for all three nationalities. There was some variation in average dive times, from about 32 minutes in the UK, to 41 in the US, and 52 in Australia. This could be explained by the predominate depth range being deeper in the UK but is much more likely caused by the types of science being done and the clarity and temperature of the water being worked in. Although much of the Australian scientific diving was classified as multi-day this may not be true for the US and UK. However, it is possible that the near-total proportion of dives being shallower than 30 msw in all three programmes is not typical of recreational diving.

In all three cases there was a high use of tables to control decompression, from 100% in the UK and Australian programmes to about 50% usage in the US. The Australian programme employed DCIEM tables and the UK the RNPL 11 up to 2002 and Bühlmann 1986 tables since then. The theories that drive decompression-table and computer development are evolving constantly and both approaches will have their relative merits. However, the use of tables does force divers to plan further in advance with pre-agreed depth and duration schedules. This should reduce factors such as unplanned staged decompression and problems with gas supply. The counter-argument is that the vast majority of scientific dives involve returning to the same location to perform the same task in order to increase the levels of statistical acceptance. In these cases, maximum depths are often planned in advance, the dive profile is inevitably square-wave and so decompression management could be controlled by either table or computer. Whatever the method of control, the rates of no-stop dives are very high in scientific diving: greater than 99.5% in the US, 95.6% in Australia and, although not reported, probably close to 100% in the UK. In addition, there are obvious attempts to increase the safety margin through statutory safety stops, employing more conservative decompression tables and increasing the surface-interval durations.

The final comparison to make between the scientific and recreational diving sectors is demography. Lang's is the only study that mentions age and suggests that the majority of scientific diving in the US is performed at the under- and post-graduate levels making the predominant age group 18–34 years. Increasing age has been identified as a DCI risk factor as Carter et al point out, with the physical and physiological consequences of getting older being, of course, multi-factorial. But, irrespective of age, all three programmes are based on rigorous levels of medical examination of the divers that may intensify with increasing age. Conversely, the recreational sector appears now to have adopted self-certification as the predominant method of medical supervision.

In conclusion, the close timing of publication of these three accounts has delivered a special opportunity to appraise a whole sector of the diving industry at a pan-national scale. In general, the safety record for scientific diving in all three programmes is extremely good and is much higher than would have been anticipated considering a near-total use of scuba. It is not clear as to whether the often-quoted incident rate of 1 in 100,000 dives for the scientific sector refers to the number of dives *per se* or the number of person dives. In either case, however, the rate appears to be too low compared with the evidence provided here. In future, anyone wishing to be conservative could employ rates of 1 in 18,000 dives for serious incidents and 1 in 25,000 dives for DCI for the sector. Alternatively, if the UK value of 1.8 person dives per dive is used, then rates of 1 in 32,400 and 1 in 45,000 dives for serious incidents and DCI respectively would be generated.

There is great importance attached to incident rates as they can influence insurance premiums as well as be useful for informing employers as to what the acceptable levels of risk are for a specific at-work activity. Whereas there may be national schemes to collate data, these may be incomplete, or even if they are complete they are obviously infrequently published. Collectively assessing the three reports has demonstrated the potential value of evaluating national trends within an international context. Perhaps it may be too optimistic to believe that this approach could lead to an international database for scientific diving with a standard reporting format. But then, when you consider the statistic-driven mentality of the scientist, who knows?

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The Editor's offering

One of the problems that has dogged epidemiological studies of diving safety is knowing accurately the incidence or prevalence of the matter at hand, be it fatalities, decompression sickness, etc. Assembling such data for scientific diving from three international sources in a single issue of the Journal was a unique opportunity. In place of my usual, frivolous editorial, Martin Sayer has provided commentary on the papers from the Australian Institute of Marine Sciences and the Smithsonian in the USA as well as his own UK data.

Michael Davis

Front cover photograph by George Steinmetz, courtesy of Smithsonian Institution

Original articles

The clinical incidence of central nervous system oxygen toxicity at 284 kPa (2.8 ATA)

David Wilkinson, Sally Wright and Steven Goble

Key words
Hyperbaric oxygen, toxicity, hyperbaric facilities

Abstract

(Wilkinson D, Wright S, Goble S. The clinical incidence of central nervous system oxygen toxicity at 284 kPa (2.8 ATA). *SPUMS J*. 2005; 35: 120-4.)
Introduction: Central nervous system (CNS) oxygen toxicity is a recognised complication of hyperbaric oxygen treatment (HBOT), manifest most profoundly as a seizure. Reports have varied in the frequency of this complication.
Methods: A retrospective review of the computerised database of the Hyperbaric Medicine Unit at the Royal Adelaide Hospital was performed from 1986 to 2003. Symptoms attributed to CNS oxygen toxicity and the occurrence of seizure were both recorded for all patient treatments at 284 kPa (2.8 ATA).
Results: 1,395 patients received a total of 6,084 treatments at 284 kPa. Symptoms of CNS toxicity occurred in 64 treatments (1%) and seizure in 17 (0.3%). Incidence of seizure was significantly higher for emergency medical indications as compared with non-emergency medical indications. The highest incidence was found in the 1,493 treatments for decompression sickness (DCS) with symptoms in 32 (2%) and seizure in eight (0.5%). A gender disparity was observed, with an increased incidence of seizure in female divers that was not statistically significant. Of the eight seizures, seven occurred during the first treatment giving a risk of seizure during the first treatment for DCS of 1.80% or 1 in 55 patients.
Conclusions: An incidence of CNS oxygen toxicity at 284 kPa has been described for one hyperbaric facility. There is an increased risk of seizure in emergency compared with non-emergency medical treatments. There appears to be an increased risk of seizure in female divers and during the first recompression treatment for DCS.

Introduction

Hyperbaric oxygen treatment (HBOT) exposes a patient to potentially toxic levels of oxygen with effects on many organ systems. Within the central nervous system (CNS) oxygen toxicity can become manifest in a myriad of symptoms, or more dramatically as a seizure. The incidence of such complications has been difficult to interpret. Published papers have treated different patients under different conditions leading to a range of seizure incidence from 5 per 52,758 treatments (0.009%) to 3% of patients.[1,2] No other study has specifically reported the incidence of CNS oxygen toxicity with 284 kPa (2.8 ATA) exposures.

Methods

Research ethics committee approval was obtained for a retrospective review of the computerised treatment records of the Hyperbaric Medicine Unit from 1 January 1986 to 1 October 2003. For all patient exposures to an oxygen partial pressure of 284 kPa, database entry of symptoms attributable to CNS oxygen toxicity and occurrence of seizure were recorded. Treatment was provided in one of two twin-lock, multi-place chambers: either a 1.8-metre-diameter cylindrical chamber (Drägerwerk, Germany; 1985) or, since becoming available in 1994, a rectangular chamber (Cowan Manufacturing/Fink International, Australia; 1994). Oxygen was delivered by a built-in breathing circuit using either a head hood on continuous flow or a demand-regulator Scott™ mask (both Amron International, Escondido, CA, USA).

The clinical indications for HBOT treatment were recorded as diving or non-diving, and the non-diving medical indications divided into emergency and non-emergency categories. An emergency was considered to be a condition associated with a clinically significant alteration in normal physiology and included carbon monoxide, gas and smoke inhalation, acute infection, mucormycosis, thermal burn, traumatic and ischaemic injury and iatrogenic gas embolism. Non-emergency indications included chronic infection and osteomyelitis, non-healing wounds, radiation tissue injury, spider bite and other.

Results

A total of 1,395 patients received 6,084 treatments with oxygen at 284 kPa. Symptoms of CNS toxicity occurred in 64 treatments (1.05%) and seizure in 17 treatments (0.28%) (Table 1). Table 1 summarises the clinical indications for HBOT treatment together with the frequency of CNS oxygen toxicity (reported symptoms or seizures) in each category.

Table 1
Conditions treated and the frequency of CNS toxicity symptoms and seizures

Indication	Patients	Treatments	CNS symptoms	%	Seizures	%
Decompression sickness	388	1,493	32	2.14	8	0.54
CAGE (Diving)	23	90	-	-	-	-
Iatrogenic gas embolism	16	53	-	-	2	3.77
Carbon monoxide, gas/smoke inhalation	502	1,497	18	1.2	3	0.20
Acute infection	233	853	4	0.47	2	0.23
Chronic infection, osteomyelitis	39	660	1	0.15	-	-
Thermal burns	56	393	2	0.51	1	0.25
Traumatic, ischaemic injury	47	261	1	0.38	-	-
Radiation tissue injury	30	357	1	0.28	-	-
Wound healing	30	172	-	-	-	-
Mucormycosis	6	120	1	0.83	1	0.83
Spider bite	13	44	4	9.10	-	-
Other	12	91	-	-	-	-
Medical (emergency)	860	3,177	26	0.82	9	0.28
Medical (non-emergency)	124	1,324	6	0.45	-	-

Of 388 divers treated for DCS, eight experienced seizures over the 18 years of review. While noting an increased incidence of seizure in divers with decompression sickness (DCS) compared to medical indications, analysis of proportions failed to demonstrate statistical significance (χ^2 = 7.5, df = 3, p $\leq$0.10). When looking at the medical treatments in isolation, seizure risk is significantly increased for emergency compared with non-emergency indications (χ^2 = 3.76, df = 1, p = 0.05).

To investigate any change in incidence of seizure in divers over time, they were chronologically arranged and divided into successive cohorts of 100 (the number of seizures in successive cohorts were three, three, one and one). Analysis suggested no significant change in incidence between successive groups (χ^2 = 1.8, df = 3, p < 1). The characteristics of the eight divers who experienced these eight seizures are found in Table 2. Among 302 male divers a total of four seizures were experienced, while only 86 female divers experienced a total of four seizures among them. This trend towards increased seizure incidence in females did not reach statistical significance (χ^2 = 3.67, df = 1, p = 0.55). Of note, seven of the eight seizures occurred during the first exposure to oxygen at 284 kPa.

Table 2
Characteristics of divers with decompression sickness (DCS) experiencing seizure

Age (years)	Sex	Treatment number	Treatment profile	Time of seizure
36	Male	1 of 1	18:60:30	Not stated
21	Female	1 of 2	USN 6	Not stated
22	Female	1 of 1	18:60:30	25 min
29	Female	1 of 3	USN 6	41 min
27	Male	1 of 3	USN 6	43 min
32	Male	1 of 1	18:60:30	35 min
22	Female	2 of 3	18:60:30	Not stated
40	Male	1 of 5	USN 6	55 min

Discussion

This study provides an incidence for symptoms and seizures attributable to CNS oxygen toxicity for hyperbaric chamber exposures to an oxygen partial pressure of 284 kPa. There is an issue of reliability in the reporting of symptoms of oxygen toxicity. Reported symptoms included nausea, feeling light-headed, agitation, shakes, feeling faint, sweating, tinnitus and numb lips. By their nature, such symptoms are not specific for oxygen toxicity and may be due to many other things; however, clinical practice does not advocate waiting for progression to seizure to confirm the diagnosis. If the symptoms are self-limited they may be considered trivial and not be reported by the patient, nor entered in the database. On the other hand, the incidence of seizure should be a reliable measure of CNS oxygen toxicity because seizure is an objective sign most likely to be due to oxygen toxicity and very likely to be recorded in the treatment record. It is reassuring to observe that the incidence of symptoms did loosely follow the trend observed with seizure. These results also suggest that the risk of seizure due to oxygen toxicity is not uniform for all indications. Subsequent discussion will separately consider diving and medical indications.

Treatment of DCS at 284 kPa has an incidence of 2% for symptoms of CNS toxicity, and 0.5% for seizure. Of note is the gender disparity favouring seizure in female divers. Only one other group has reported a gender influence on the incidence of seizure in a published study and subsequent abstract.[3,4] The abstract reported an increased sample size of 2,303 recompressions in 1,073 patients with decompression illness. Oxygen partial pressures were in the range of 243–294 kPa and included US Navy Treatment Table 6 as well as other mixed-gas, deep tables. The incidence was a surprisingly comparable 2% for symptoms and 0.6% for seizure. Again, the researchers found that the risk of seizure in the female divers was 2.9 times that for males although this did not reach statistical significance either. For all the investigation into the myriad factors considered to be a risk for oxygen toxicity, no other clinical or laboratory research has been published on the influence of gender, and this indicates a need for further work.

The other striking feature of this study is the 'first-treatment effect' with seven of the eight seizures occurring during the first exposure. This gives an incidence of seizure during the first treatment for DCS of 1.8% or 1 in 55 divers. Corroborating evidence for an increased risk during the first treatment has not been published. Gender aside, are there any other patient factors that might influence the risk of seizure, particularly during the first exposure? One plausible theory is that DCS produces a neurological injury rendering the diver more susceptible to CNS toxicity – it would seem reasonable that bubbles passing through the cerebral circulation should have a significant impact. It was for this reason that the terminology of DCS and cerebral artery gas embolism (CAGE) was used to describe divers in this study.

If acute neurological injury is believed to increase the risk for CNS oxygen toxicity, one would expect to see evidence for this in diving-related CAGE. In this study, there was a zero incidence for symptoms and seizures in divers with CAGE, although small numbers may be responsible. However, contrast this with two seizures in 53 treatments for iatrogenic gas embolism. In any case, such a neurological injury would have to recover quickly as the risk appears to relate to the first treatment only. Of the eight divers who experienced seizure, five received subsequent HBOT treatment without further seizure.

Patient factors do not adequately explain the seizure risk. Other factors that may influence the development of oxygen toxicity include method of oxygen delivery (and carbon dioxide, CO_2, elimination) and the chamber environment itself. All treatments were undertaken at an ambient pressure of 284 kPa with the intention of delivering 100% oxygen; however, oxygen delivery may vary with the use of either mask or hood. The use of the rigid Scott mask requires attention to the fit of the mask around the face and proper fastening of the straps. Any gaps will allow air entrainment and unpublished data from this unit have demonstrated that the mask can deliver variable inspired oxygen content (80–95%), whereas the hood system provides reliably greater than 96% oxygen. This is consistent with published experience.[5]

With this in mind, it would be expected that use of the hood, with its higher oxygen content and therefore higher oxygen partial pressure, should carry an increased risk of CNS toxicity. This in fact appears not to be the case, as all seizures occurred in divers using the mask, although it must be remembered that 90% of all DCS treatments used the mask. Perhaps the mask alters risk via an effect on another known risk factor: CO_2. While the volume of the mask is small, re-breathing of CO_2 will occur to some degree although its significance is uncertain. Alternatively, as the mask delivers oxygen by demand valve, its use may unconsciously provoke 'skip-breathing' by the diver resulting in CO_2 retention and increased seizure risk.

The chamber environment is different for the two chambers available. A maximum pressure tolerance of 304 kPa for the larger rectangular chamber (and so no ability to use deeper treatment tables than the US Navy Treatment Table 6) meant 80% of recompressions were performed in the smaller cylindrical chamber, including 85% of all first treatments. All seizures occurred in the cylindrical chamber. The smaller chamber does not have space for an air-conditioning unit as used in the larger chamber, and swings in temperature and humidity occur with compression and decompression. A higher risk for seizure may be due to inadequate control of ambient temperature during operation. Alternatively, perhaps the smaller chamber size creates an enhanced sense of claustrophobia and anxiety in the diver, raising the risk of oxygen toxicity secondary to arousal of the sympathetic nervous system.

The medical indications for HBOT identified a patient-related effect on incidence of seizure. While dividing the medical indications into emergency and non-emergency groups was very much a rule-of-thumb process determined by the author, the group identified as emergency had a significantly higher risk of seizure. Fever, organ dysfunction and altered biochemistry might be considered causative factors although these claims are unsubstantiated. The hyperbaric physician might comment that the non-emergency group includes a number of conditions that would usually be treated at 243 kPa or even 203 kPa as opposed to 284 kPa (e.g., non-healing wounds and radiation tissue injury). This is true for current practice; however, clinical practice in the past has seen some of these conditions being treated at 284 kPa. Furthermore, treatment at 284 kPa has sometimes occurred as an operational requirement when time, space or staffing was limited.

In this study, carbon monoxide (CO) poisoning warrants mention with a risk of seizure found to be 0.6% of patients or 0.2% of treatments. These results are at odds with published studies that found the risk of seizure in HBOT treatment of CO poisoning to be about 3% of patients.[2,6] No explanation for this discrepancy can be suggested. Comparison with other published studies is difficult because most have reported oxygen toxicity over a range of treatment pressures between 203 and 304 kPa, with the majority around 243 kPa. The issue is further confounded by use of multi-place versus mono-place chambers, oxygen delivery by mask versus hood, absence of a recognised uniform treatment profile and variable use of air breaks.

Apart from patient-related factors, three other influences on oxygen toxicity in the hyperbaric chamber are oxygen partial pressure, duration of exposure and use of air breaks. Experimental data have repeatedly related the risk of CNS toxicity to the absolute pressure of oxygen although much of this work has used oxygen partial pressures well in excess of those used clinically.[7] The overall incidence of seizure at 284 kPa from this study was 0.3%. Other studies that have utilised oxygen partial pressures of around 243 kPa have reported an incidence of seizure in the range of 0.03–0.06%,[8–10] an approximate tenfold reduction in risk, although most also involve what would be considered non-emergency indications. Hampson provides further clinical support in his report of 900 cases of CO poisoning treated at 248, 283 and 304 kPa.[2] Seizure was reported as significantly more frequent at higher pressures (0.3%, 3% and 2% of patients respectively).

Development of CNS toxicity has been linked to duration of exposure in many animal and human studies which have used a wide range of pressures and sometimes prolonged exposure times.[7] However, when examining clinical hyperbaric treatment with the pressure and duration of exposures typically used, no evidence could be found to support a predictable relationship between duration of exposure and seizure. Although the data in this study are incomplete, seizure does not appear to be related to duration of the treatment and can occur during the first or any subsequent period of oxygen treatment. The CO study by Hampson found no relationship between duration of the treatment and occurrence of seizure.[2]

The inability of clinical studies to clearly demonstrate increasing risk of seizure with increasing duration of exposure may be due to the deliberate use of oxygen pressures with a low risk for seizure, and the use of air breaks in treatment profiles. The use of air breaks is known to extend tolerance for pulmonary oxygen toxicity in humans;[7] however, their role in CNS toxicity is not so clear. Animal studies suggest a benefit from air breaks,[11] but the use of different animal species and different experimental endpoints does not support any predictable relationship between duration of exposure and CNS oxygen toxicity. Evidence for air breaks preventing CNS toxicity in clinical hyperbaric treatment is not available even though it is logical.

A clinical approach to controlling the risk of seizure due to CNS oxygen toxicity has usually invoked the use of a recognised treatment profile with a relatively safe oxygen partial pressure and duration of exposure. Additional factors are use of air breaks and an efficient oxygen delivery system, avoidance of fever, optimisation of biochemistry and minimisation of sympathetic nervous system activity, particularly in the emergency patient. Avoidance strategies and prompt recognition are all we have until the mechanism of CNS oxygen toxicity can be described.

On this front, it has been demonstrated that the cerebral vasoconstriction and reduced cerebral blood flow normally seen with hyperoxia can, at some point, be abolished resulting in cerebral blood flow that is actually increased above baseline.[12] The delivery of a large volume of hyperoxic blood, and subsequent reactive oxygen species, to certain excitatory areas of the brain may then lead to the EEG and clinical manifestations of oxygen toxicity. Nitric oxide appears to play a role in the initial vasoconstriction and in the subsequent cerebral vasodilatation, and may have other actions as well.[13,14] However, monitoring of cerebral blood flow and EEG does not appear to allow reliable prediction or termination of an impending seizure and cannot be recommended for routine clinical monitoring. Although made in reference to divers, the observation by Donald remains relevant to all chamber operators: that the susceptibility to seizure due to oxygen toxicity varies between individuals and within the same person on different days.[15]

Hyperbaric medicine professionals must therefore operate with the constant risk of oxygen toxicity. While symptoms of CNS oxygen toxicity can usually be managed easily by removal of oxygen, seizure is a more dramatic event. It poses a safety risk to the patient, the inside attendant and the other patients in the chamber, not to mention the distress such an event is likely to precipitate in them. Managed well it is known not to result in significant sequelae. Although prompt response to symptoms that may be due to CNS oxygen toxicity is vital, there is no guarantee that such a warning will be given. Clinical studies have clearly reported that a prodrome, or heralding sign of seizure, was not noticed in their experience.[8,10] An accurate understanding of the true incidence of CNS oxygen toxicity is vital to properly inform our patients and to guide us in providing the safest possible environment for treatment.

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The rate of decompression sickness in scientific diving at the Australian Institute of Marine Science (Townsville) 1996 to 2001

Anthony Carter, Reinhold Muller and Angus Thompson

Key words
Decompression sickness, diving tables, science diving, safety, epidemiology

Abstract

(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.)

Objectives: To detail the rate of decompression sickness (DCS) in and describe the pattern of scientific diving according to the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) decompression tables, and project the impact of the AS/NZS Scientific Diving Standard (AS/NZS 2299.2:2002) on dive profiles at the Australian Institute of Marine Science (AIMS), Townsville.

Methods: Data have been collected for all scientific diving conducted at AIMS according to the DCIEM tables from October 1996 to December 2001. Details of location, date, time in and out, bottom time, effective bottom time (bottom time calculated according to residual nitrogen from previous dives), maximum depth, repetitive group and factor, and surface interval were recorded via the dive work sheets.

Results: The data from 14,944 dives were analysed. The total bottom time for all dives was 13,033 hours. No cases of DCS were reported in this period for a DCS rate of zero (exact binomial 95% confidence interval 0 to 30) cases per 100,000 dive hours. More than half (58.0%; n = 8,669) of all dives were conducted more than two hours' travel time from a recompression chamber. Two thirds of dives were conducted at the rate of two (35.8%; n = 5,352) or three (31.4%; n = 4,698) dives per diver per day. The median depth of dives was 10 metres' sea water with a median effective bottom time of 1:00 hr (interquartile range 0:40–1:21 hours). One quarter (25.1%; n = 3,241) of dives would have exceeded the maximum repetitive group limits if they were conducted according to AS/NZS 2299.2:2002.

Conclusions: The results of this analysis demonstrate that the rate of DCS in multi-day scientific diving conducted according to the DCIEM tables is low, regardless of maximum dive depth and travel time from recompression chamber support. The observed DCS rates at AIMS provide evidence that the repetitive group limits of AS/NZS 2299.2:2002 are restrictive for the purposes of scientific diving and require modification.

Introduction

The Australian Institute of Marine Science (AIMS) is located near Townsville and was established by the Commonwealth Government in 1972 to generate knowledge for the sustainable use of the marine environment through scientific research. Accordingly, scientific diving is a core component of the field operations. Diving activity is predominantly focussed in the warm waters of northern Queensland and Western Australia, often in remote locations. Routine tasks performed by scientific divers at AIMS include equipment deployment and recovery, filming transects of reef, and sample collection. Dives are commonly conducted in fixed locations as monitoring changes to the Great Barrier Reef is a core component of the activities of AIMS.

Pressure change is the main occupational health and safety hazard for underwater divers.[1,2] Excess nitrogen absorbed under pressure at depth can form gas bubbles during the decreasing pressures of an ascent and lead to decompression sickness (DCS). The symptoms of Type I DCS are skin rashes, lymphoedema and joint pain, while Type II DCS is characterised by respiratory, neurological, auditory-vestibular, circulatory shock or barotrauma symptoms. The dive-profile parameters of depth, bottom time and ascent rate are the best understood and most readily modifiable risk factors for DCS. While increasing age, obesity, fatigue, dehydration and decreasing maximal oxygen uptake have been identified as risk factors for DCS they are less well understood and modifiable than the dive-profile parameters.[3,4] The incidence of DCS is minimised by the use of decompression schedules that provide time limits for dives according to the maximum depth of the dive. Scientific diving at AIMS is conducted according to the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) decompression tables.

Standards Australia and New Zealand replaced the previous standard governing scientific diving, the Occupational Diving Standard (AS 2299-1992),[5] with a sector-specific Scientific Diving Standard (AS/NZS 2299.2:2002)[6] in 2002 following considerable deliberation. The major difference between these standards is the modification of the DCIEM decompression tables that restrict the dive bottom time and repetitive group according to proximity to a recompression chamber. It is anticipated that the new, more conservative, time limits will increase resource use in scientific diving as most field operations are conducted at least two hours from recompression chamber support.

Very few collections of robust epidemiological data of the rates and patterns of DCS are available in the scientific literature. The rate of DCS in scientific diving is estimated to be 1 per 100,000 dives. This is, however, an arbitrary estimate based on expert opinion only and is unsubstantiated by epidemiological data.[7] The routinely collected, detailed data of AIMS scientific diving operations represent a rich source of information for a historically poorly researched area of occupational health. The aims of this analysis are to detail the rate of scientific diving injury and diving profiles from 1996 to 2001, and to project the likely impact of the AS/NZS Scientific Diving Standard on dive profiles at AIMS. The results of this analysis can be used as a baseline for comparison to subsequent analyses of data of the DCS rate and diving profiles at AIMS following the implementation of the new AS/NZS standard.

Methods

AIMS routinely documents data of all scientific diving as part of its diving safety procedures. The James Cook University Occupational Health Research Group has analysed data of all dives from October 1996 to December 2001.

A dive plan for all proposed dives was submitted to the AIMS Dive Officer in electronic form prior to departure of each dive trip. Divers completed a dive work sheet following every dive. Details of location, date, time in and out, actual and effective bottom time, maximum depth, repetitive group and factor, and surface interval were recorded on the work sheet. The Dive Supervisor appointed for the trip verified that the data entered on the work sheets for each diver were correct. The Dive Officer verified that the work sheets for all participating divers were correct at the completion of each trip. The completed work sheets were stored in hard copy at AIMS by the Dive Officer.

All scientific divers employed by AIMS in the observation period satisfied the qualifications required by AS 2299-1992. Dives conducted under the jurisdiction of AIMS must not exceed an absolute depth of 30 metres' sea water (msw). Visiting divers not employed by AIMS had as a minimum the equivalent of a Confédération Mondiale des Activités Subaquatiques (CMAS) two star diver accreditation.[8] These divers did not exceed a maximum depth of 15 msw unless prior approval was obtained from the AIMS Dive Officer.

All dives during the observation period were conducted according to the AIMS diving procedures.[9,10] The AIMS procedures are based on AS 2299-1992 and allow diving to the no-decompression limits of the DCIEM Air Diving Tables and Procedures. The repetitive group and repetitive factors in this analysis were calculated according to the DCIEM tables. Dives conducted according to these tables and procedures were described as square profiles, where a single ascent and constant depth were assumed. Bottom time was defined as the total elapsed time from the diver commencing the initial descent from the surface to the diver commencing the final ascent. DCS was defined as a confirmed diagnosis of the clinical manifestations by a medical practitioner.

Data from the work sheets were used to calculate the following variables for each dive:

- bottom time
- effective bottom time (bottom time calculated according to residual nitrogen from previous dives)
- repetitive group (classified according to the residual nitrogen in a diver's body immediately on surfacing from a dive)
- surface interval (the time from when a diver surfaces from a dive to the commencement of the descent for a subsequent dive)
- repetitive factor (a factor determined by the repetitive group and the surface interval from a previous dive that modifies the planned bottom time for a subsequent dive)

Travel times by helicopter from recompression chamber support were estimated for each trip in accordance with Clauses 3.4 and 3.13.3 of AS/NZS 2299.2:2002 and are displayed in Figure 1.

The maximum repetitive group limits from the DCIEM tables and according to recompression chamber support in AS/NZS 2299.2:2002 are displayed in Table 1. The criteria for determining the repetitive group limits according to recompression support for dives deeper than 12 msw in Table 3.2 of AS/NZS 2299.2:2002 were applied to dives to depths of less than 12 msw to obtain the modified limits displayed in Figure 3. That is, for dives less than two hours from recompression support, the DCIEM no-decompression

Figure 1
Travel time by helicopter from recompression chamber support

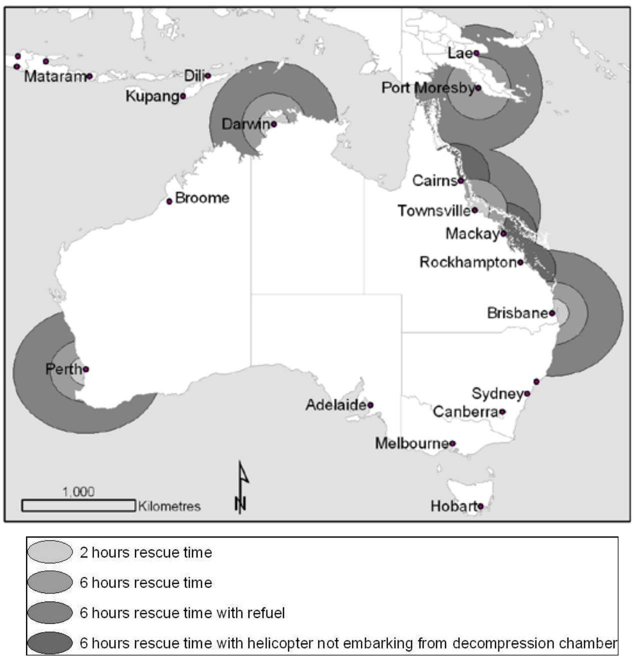


Table 1
Limits for repetitive dives from the DCIEM tables and Table 3.2 in AS/NZS 2299.2:2002 according to depth of dive and level of recompression chamber support

	Maximum repetitive group	AS/NZS 2299.2:2002		
Maximum depth (m)	DCIEM table	Chamber < 2 hrs	Chamber 2 – 6 hrs	Chamber > 6 hrs
3	M	No limit	G (H)	G
6	M	G (J)	G (H)	G
9	M	H	G	F
12	J	H	E	D
12 – 15	G	G	F	E
15 – 18	F	F	E	D
18 – 21	E	E	D	C
21 – 24	E	E	D	C
24 – 27	D	D	C	B
27 – 30	D	D	C	B

limit was used; for dives two to six hours and more than six hours from recompression support, one and two repetitive groups fewer than the DCIEM no-decompression limits were used respectively.

The data were analysed using SPSS for Windows™ statistical software (Version 10, Chicago, USA).

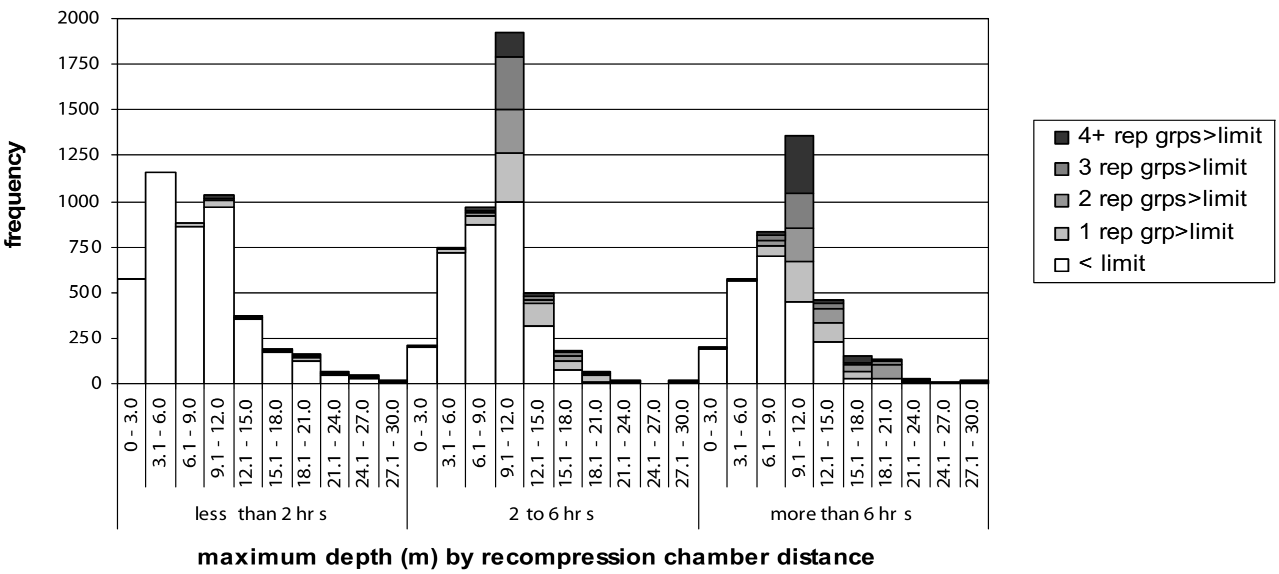
Results

The data from 14,944 dives between October 1996 and December 2001 are detailed in Table 2. The total bottom time for all dives was 13,303 hours. No cases of DCS were reported in this period. The observed DCS rates are zero per 100,000 dives (exact binomial 95% confidence interval 0 to 20) and per 100,000 dive hours (exact binomial 95% confidence interval 0 to 30).

Four hundred dive trips were undertaken by 272 identified divers. The number of dives per diver during the observation period ranged from 1 to 541 dives with a median of 20 (interquartile range 10 to 53). Dives at the rate of one per diver per day accounted for 17.0% (n = 2,546) of all dives. Two thirds of dives were conducted at the rate of two (35.8%; n = 5,352) or three (31.4%; n = 4,698) dives per diver per day. The maximum number of dives per day was eight, all of which were to a maximum depth of 3 msw.

Almost two thirds of all dives were conducted at locations more than two hours (two to six hours, 31.8%, n = 4,751; more than six hours, 26.2%, n = 3,918) in travel time from a recompression chamber. The median maximum depth was 10 msw. The median bottom time was 0:51 hours (interquartile range 0:35 to 1:06 hours). One quarter (25.3%) of dives generated a repetitive group of A to C, while half

Figure 2
Compliance of AIMS scientific dives from 1996 to 2001 with repetitive group limits set by Table 3.2 of AS/NZS 2299.2:2002



(50.4%; n = 7,529) generated a repetitive group of D to F. The surface interval was 18 hours or more for one third (32.7%; n = 4,881) of the dives; for the dives with a surface interval of less than 18 hours, the median interval was 2:37 hours (interquartile range 0:46 to 6:31 hours). Dives were predominantly conducted within no-decompression limits (95.6%; n = 14,282).

Data relating to the proximity of recompression chamber support and effective bottom time are available for 12,915 (86.4%) of the dives conducted. One quarter (25.1%; n = 3,241) of these dives would exceed the maximum permissible repetitive group for dives if the limits according to recompression chamber support introduced in the AS/NZS Scientific Diving Standard in 2002 (AS/NZS 2299.2:2002, Table 3.2) were applied (Figure 2). Dives within two hours of a recompression chamber would be conducted predominantly (95.6%; n = 4,290) within the modified repetitive group limits, while almost one third (31.2%; n = 1,447) of dives between two and six hours and almost half (42.1%; n = 1,595) more than six hours from chamber support would exceed the limits.

Almost half (43.4%; n = 2,933) of all dives to deeper than 9 msw, compared to 5.0% (n = 308) of dives to 9 msw or less, would exceed the repetitive group limits of AS/NZS 2299.2:2002. More than two thirds (68.1%; n = 2,207) of all dives to deeper than 12 msw would exceed the repetitive group limits of AS/NZS 2299.2:2002. Of these, 20.5% (n = 666), 15.5% (n = 502) and 16.5% (n = 535) would be within one, two and three repetitive groups of the limits respectively. More than half (58.6%; n = 1,899) of dives that would exceed the limits would be of the depth category 9 to 12 msw; 28.5% (n = 924) and 28.2% (n = 915) would be two to six hours and more than six hours' travel time respectively from a recompression chamber.

Almost 10% (9.5%, n = 1,225) of dives would exceed the repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 if the criteria for maximum repetitive group for dives of 12 msw or deeper (as described in the Methods section) were applied consistently to dives at all depths (Figure 3). More than 10% (less than two hours, 3.0%, n = 136; two to six hours, 9.4%, n = 435) of dives within six hours of a recompression chamber, and 17.3% (n = 654) of dives at more than six hours, would exceed the limits. Less than one third (31.9%; n = 1,034) of all dives that would exceed the limits are to depths less than 12 msw.

Discussion

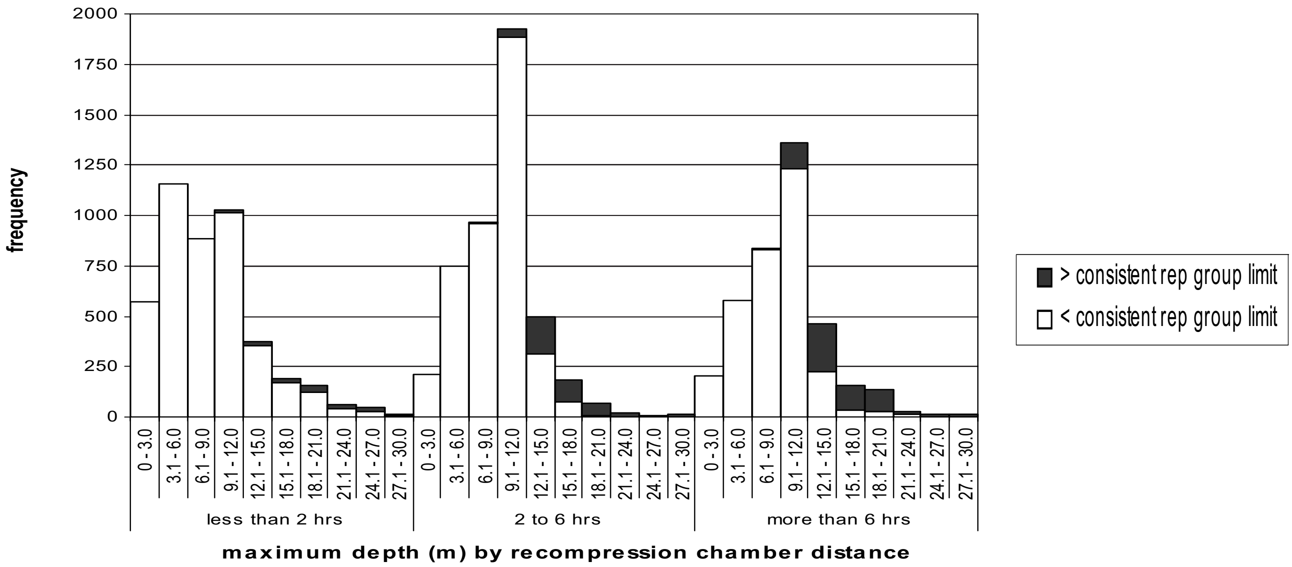
No cases of DCS were reported from the 14,944 dives conducted by AIMS divers during the five-year study period (exact binomial 95%, confidence interval 0 to 20). Scientific diving conducted by AIMS is characterised by multi-day diving (83.0%). Approximately two thirds of all dives were repetitive dives. The dive profiles were typically of depths of approximately 10 msw with effective bottom times of about one hour. More than half (58%) of the dives were in locations more than two hours' travel time from a recompression chamber. The results of this analysis demonstrate that the risk of DCS during multi-day scientific diving conducted according to the DCIEM tables is low.

The low rate of DCS observed in this analysis refers to diagnosed cases where a medical practitioner confirmed the clinical physical manifestations of the condition. However, DCS is a syndrome characterised by a variety of

Table 2
Univariate description (IQR – interquartile range)

Variable	Summary	Result
Year	1996	4.90%
	1997	22.30%
	1998	19.40%
	1999	17.80%
	2000	16.00%
	2001	19.60%
Travel time from chamber support	< 2 hours	30.10%
	2 to 6 hours	31.80%
	> 6 hours	26.20%
	Unspecified	11.90%
Dives per diver per day	1	17.00%
	2	35.80%
	3	31.40%
	4	10.70%
	5 or more	5.00%
Maximum depth	Median	10.0 metres (IQR 6.0 – 12.0)
Bottom time	Total	13,303:08 hours
	Median	0:51 hours (IQR 0:35 – 1:06)
Effective bottom time	Total	15,846:37 hours
	Median	1:00 hours (IQR 0:40 – 1:23)
Repetitive group	A	5.70%
	B	8.60%
	C	11.00%
	D	20.10%
	E	17.00%
	F	13.30%
	G	10.00%
	H	7.20%
	I to P	4.90%
	Unspecified	2.20%
Repetitive factor	Median	1.1 (IQR 1.0 – 1.4)
Surface interval	18 hours or more	32.70%
	< 18 hours	65.20%
	Median	2:37 hours (IQR 0:46 – 6:31)
Decompression stop required	Yes	2.30%
	No	95.60%
	Not known	2.10%

Figure 3
Categorisation of AIMS scientific dives from 1996 to 2001 by consistent application of repetitive group limits for dives of deeper than 12 metres from Table 3.2 of AS/NZS 2299.2:2002 to dives at all depths



symptoms, each with a spectrum of intensities of effect. It is therefore possible that the observed rate may not account for DCS in cases where divers perceived their symptoms to be insufficiently intense to seek any clinical intervention. While tools are available for divers to self-evaluate the presence and the accompanying intensity of the symptoms of DCS,[11,12] they were not used in this study.

The maximum repetitive group limits in Table 3.2 of the AS/NZS Scientific Diving Standard (AS/NZS 2299.2:2002) will impact significantly on diving and resource use at AIMS, as 25% of the dive profiles in this analysis would require a reduced maximum depth or bottom time to comply with the limits (Figure 2). The proportion of dives that would require a reduced maximum depth or bottom time increases with increasing travel time from recompression chamber support. More than one third of dives in this analysis at locations further than two hours (two to six hours, 31%; more than six hours, 42%) from recompression support would exceed the limits, while almost half (43%) of all dives to deeper than 9 msw, compared with 5% of dives to less than 9 msw, would exceed the limits.

Consequently, the time available both to perform routine tasks and to access the biodiversity at depth is likely to be restricted in remote locations. The restrictions to the maximum allowable bottom times and repetitive groups in AS/NZS 2299.2:2002 are intended to minimise the risk of permanent injury resulting from the delay in onset of treatment of DCS. However, the observed DCS rate at AIMS provides evidence that scientific diving conducted according to the DCIEM tables is low risk, and that the repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 are unnecessarily conservative and likely to be restrictive for the purposes of scientific diving.

There are inconsistencies in the repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 that will impact on the dive profiles typically used by AIMS divers. For dives more than two hours' travel from a recompression chamber, the repetitive group limits for scientific dives to less than 12 msw have been set at least three repetitive groups below the DCIEM no-decompression limits. This is in contrast to the limit for dives deeper than 12 msw being set to one (two to six hours' travel time) and two (more than six hours) repetitive groups below the no-decompression limits. In addition, the progression of repetitive group limits with dive depth for dives more than two hours' travel time from a recompression chamber is haphazard. The repetitive group limits for dives between two and six hours' travel from a chamber to depths of 6, 9, 12, 15 and 18 msw are G, G, E, F and E respectively. Similarly, for dives more than six hours from a chamber, the repetitive group limits for the corresponding depths are G, F, D, E and D.

These inconsistencies in the repetitive group limits, rather than the dive profiles used by scientific divers at AIMS, are the major contributing factor to the 25% of all dives that would exceed the maximum repetitive group limits of AS/NZS 2299.2:2002. More than half (53%) of all dives that would exceed the limits were to less than 12 msw and within three repetitive groups of the limits. There is no reference to data in AS/NZS 2299.2:2002 relating the specified maximum repetitive groups to DCS risk equivalence to support the selection of the limits for the depth categories. The limits are the result of modifications, according to expert consensus, to the no-decompression limits of the DCIEM tables that are considered a reliable and valid estimate of DCS risk for dives at all depths. The inconsistencies in maximum repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 compared to the DCIEM dive tables indicate that the risk of DCS is not consistently controlled for dives at depths of less than 12 msw and more than two hours from recompression chamber support.

The distinguishing feature of contemporary risk management processes is the iteration between analysis, deliberation and decision.[13] Addressing the inconsistencies identified in the repetitive group limits of AS/NZS 2299.2:2002 will not only contribute to this process, but also serve to reduce the impact of the limits on the dive profiles typically used by AIMS divers. A plausible modification to Table 3.2 of AS/NZS 2299.2:2002 is to apply the criteria determining the repetitive group limits for dives at deeper than 12 msw (as detailed in the Methods section) to dives at all depths. This modification resolves the identified inconsistencies in determining the limits, while still allowing a conservative safety margin in addition to that already incorporated in the DCIEM tables. The proportion of dives that would require a reduced maximum depth or bottom time would be more than halved to 10% (Figure 3).

Conclusions

The pattern of scientific diving conducted by AIMS is characterised by multi-day diving. The results of this analysis demonstrate that the rate of DCS in multi-day diving conducted at AIMS according to the DCIEM decompression tables is low. While it is anticipated that the repetitive group limits of AS/NZS 2299.2:2002 will restrict the underwater scientific research conducted by AIMS, further research is needed to fully evaluate their impact on dive safety, activity and resource utilisation.

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Erratum

The book review by Glen Hawkins recently published in this journal (*SPUMS J*. 2005; 35: 111-2.) mistakenly indicated that he was based in Adelaide. Dr Hawkins is in fact Hyperbaric Fellow in the Department of Diving and Hyperbaric Medicine at Prince of Wales Hospital, Sydney. The Editor apologises for this error.

Review articles

Venomous jellyfish of the world

Peter J Fenner

Key words
Envenomation, marine animals, jellyfish, review article

Abstract

(Fenner PJ. Venomous jellyfish of the world. *SPUMS J*. 2005; 35: 131-8.)
Jellyfish envenomation is far more common around the world than is realised. Although the vast majority of jellyfish stings are somewhat benign, there are some venomous species that regularly account for both deaths and severe morbidity in humans. Venomous jellyfish occur mainly in tropical and subtropical oceans. This article discusses relevant information on their appearance, distribution, and symptoms of envenomation, and first-aid and medical treatments for their stings.

General classification of jellyfish

There are three main classes of jellyfish that pose a threat to humans: scyphozoans, cubozoans, and hydrozoans.[1]

SCYPHOZOANS (CLASS *SCYPHOZOA*)

These are the 'true' jellyfish. Members of this group are common worldwide. They have tentacles arising at regular intervals all around the bell (and often within the bell), i.e., they are 'radially' arranged.

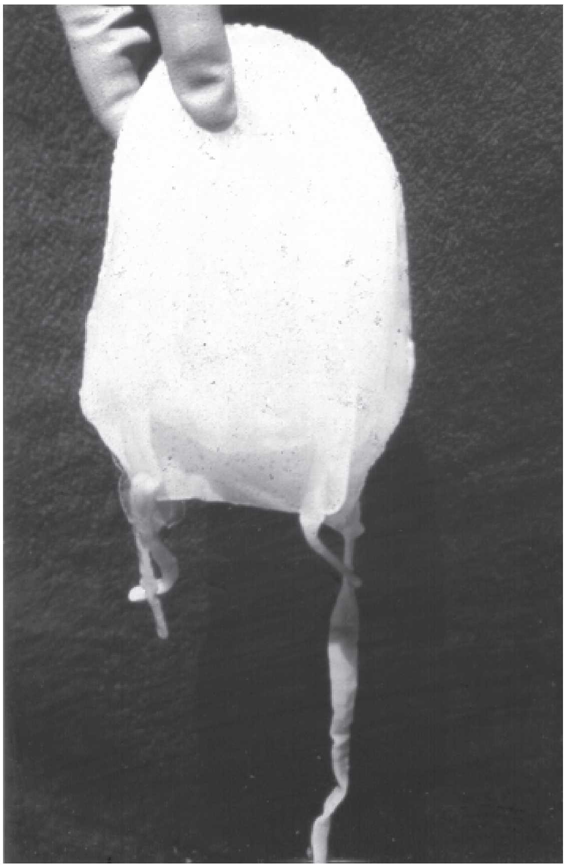
CUBOZOANS (CLASS *CUBOZOA*)

These are the 'box' jellyfish. Cubozoans are the most dangerous jellyfish and have caused hundreds, possibly thousands, of human deaths in tropical and subtropical waters worldwide.[1] They are shaped like a box (or cube) with tentacles arising only from the lower corners. There are two subgroups, or families within the class of cubozoans:

- **Carybdeids** – that have just one tentacle in the corner of each bell (Figure 1). They come in sizes ranging from a few millimetres to 500 mm bell height. Their stings cause symptoms varying from mild skin irritation to severe systemic symptoms; neither the size of the jellyfish, nor the size of the sting has any relation to the severity of the symptoms. There is one small species in Australia (the 'Irukandji') that has caused fatalities; otherwise the sting usually causes moderate to severe skin pain and possibly severe systemic symptoms in some species.

- **Chirodropids** – that have more than one and up to 15 tentacles arising from the corner of each bell (Figure 2). The bell may be up to 300 mm in diameter and the tentacles may reach up to 3 m in length. These jellyfish give severe stings and regularly cause human deaths each year (Table 1.) There are at least ten identified but certainly more species of chirodropid worldwide. Unfortunately the original specimen, described as *Chiropsalmus quadrigatus* and caught by Haeckel in 1880,[2] was immature and its description fits many chirodropids in various parts of the world, although

Figure 1
'Morbakka' from subtropical east coast of Australia, typical of 'large' carybdeid (cubozoan); 14 cm high, 10 cm width; painful welts ("fire jelly"); may cause mild Irukandji reaction in about 10% of cases



comparison of finer structures shows them to be different species. Thus many jellyfish in the western Indo-Pacific oceans that are basically different all bear the name *Chiropsalmus quadrigatus*. Fortunately all appear to cause similar, if not identical symptoms. Thus the first-aid and medical treatments suggested should prove effective for all chirodropid envenomations regardless of geographical location (see below).

'OTHER JELLYFISH' (CLASS *HYDROZOA*)

Members of this group are not actually jellyfish, although they resemble them, and are best dealt with as such. This group includes the siphonophore *Physalia sp*., commonly known as the 'Portuguese man-of-war' and *Gonionemus sp*., a small hydrozoan, which causes sting problems in the Sea of Japan.

The number of all jellyfish envenomations worldwide is measured in the millions; however, fortunately there is usually little need to identify the species of jellyfish. All cause skin pain that varies from a very mild irritation through to the severe, unbearable pain of a multi-tentacled box jellyfish sting. This skin pain can be treated simply, using the first-aid protocols suggested below.

Some jellyfish envenomations may cause systemic symptoms, including generalised muscle pains, painful breathing, breathing difficulty or breathlessness, anxiety, sweating, high blood pressure, heart failure, and even death, albeit rarely.[3–6] Current geographical locations of human deaths from jellyfish are shown in Table 1.

Figure 2
***Chironex fleckeri* – 30 cm diameter specimen caught off beach in north Queensland. Although stinging cells are not present on the bell and it can be held without being stung, wearing shorts (especially in a wind) with some 60 tentacles up to 3 metres in length nearby is not a recommended procedure!**

Jellyfish causing human fatalities

CHIRODROPIDS (MULTI-TENTACLED BOX JELLYFISH)

Envenomation

Envenomation usually occurs in shallow water. Severe stings occur more often in women and young children, who are smaller and relatively hairless. Hair can prevent more intimate tentacle contact, and consequently reduce envenomation.

Chirodropids swim into shallow water when the wind is light and hot, and the water is calm. Unsuspecting victims frequently walk, or run, into tentacles trailing behind the transparent jellyfish bell, both of which are difficult to see in the water, with the tentacles being almost invisible. Most stings occur on the lower legs and body, as the unsuspecting victim enters the water.

Pain is instant and savage; the victim usually screams with the pain. Children, when stung, often stand in the water, picking at the tentacles and getting stung on the hands and arms, consequently increasing the envenomation, whilst adults frequently run out of the water, increasing the heart rate and circulation and thus the speed of venom absorption. If the tentacles are rubbed, the stinging cells are compressed, causing further nematocyst discharge and thus increasing envenomation.

Adherent tentacles look like sticky threads on the skin of the victim; tentacle marks look like the victim has been whipped, or branded with irons.[1] If the victim lives, blistering and skin necrosis occur over the next few hours; scarring often occurs and lasts for life. Victims may rapidly stop breathing, sometimes within a few minutes of the initial envenomation, with death occurring rapidly unless prompt first aid and medical aid is available.[7]

Distribution

The widespread occurrence of chirodropid box jellyfish in tropical waters has been recognised since the turn of the century.[2] However, it was not until 1908 that Old first reported fatalities from jellyfish stings occurring in the Philippines.[8] Deaths from jellyfish stings have since been confirmed in many areas around the world, although most reports remain inadequately authenticated.[1,7,9–11]

Chirodropids occur in tropical waters, usually in the summer months of the northern and southern hemispheres. Their season is longest close to the equator and may last all year.[1]

Indo-Pacific region – The presence of multi-tentacled box jellyfish species (chirodropids) has now been confirmed in the tropical Indo-Pacific oceans: westwards to the Maldive Islands, Southern India, Java, and the Malaysian archipelago (including west coast of Malaysia); eastwards to the Philippines; and northwards to Brunei, Sarawak, Sabah, Papua New Guinea, the Gulf of Thailand, and Okinawa, Japan.[1,9,12–14]

Deaths have previously been reported from Penang, Malaysia; the Philippines; Bougainville Island, Solomon Islands; Sarawak; Brunei; Labuan Island; Sabah; D'Entrecasteaux Islands and Papua New Guinea.[1,7-11] New or unreported deaths are included in this article.

Thailand – Anecdotal reports of a few deaths following jellyfish contact exist in which the species was not known.[15,16] The first death reported in a major medical journal was of a 26-year-old British tourist, swimming off Chaweng Beach on the Thai Island of Koh Samui on 20 October 1999, who received a major box jellyfish sting. Resuscitation was unsuccessful.[17]

Other, unreported deaths in Thailand – A UK male aged 24 was stung late in the afternoon of 9 August 2002 at Hat Rin Nok beach on the western side of Koh Pan Ngan island in the Gulf of Thailand (Gulf of Siam) and died within minutes. A day later a Swedish female sustained stings to her chest, arms, body and legs on the same beach. She had a cardiac arrest on the beach within minutes of the sting and was resuscitated at the scene. Despite being transferred to a major hospital she arrested twice more before succumbing early the following morning, around 12 hours after the sting.

In 2002 a death was also reported to have occurred on Koh Samui island, adjacent to Koh Pan Ngan island in Thailand. No further details are available (personal communication, Professor Henry Wilde, 2002).

Koh Samui and Koh Pan Ngan are popular tourist islands with beaches, huts and good hotels, located off Sura Thani on the east coast of Thailand, 400 air miles south of Bangkok.

Indonesia – A previously unreported death of a seven-year-old boy occurred at Balikpapan, on the mid-east coast of Indonesia. He jumped off a pier, exited the water immediately, collapsed and died within four minutes. He was noted to be covered in whip-like marks over half of his body. The rapid death, the characteristic markings and the almost certain presence of chirodropids throughout this region suggest that this death has to have been caused by a chirodropid.

Philippines – The author visited the Philippines in 1987 to study jellyfish and researched further evidence of previously-reported fatal jellyfish stings. Chirodropid jellyfish proved to be well known in the area with stings occurring annually. Almost every village described a death every two to three years, usually of a child. With some 50 small villages around the Bay of Sual alone, and many hundreds in tropical and subtropical areas of the Philippines, an estimated annual death rate from jellyfish stings in the Philippines of 20–40 was not thought to be excessive,[1] although Heeger, a biologist in the Philippines has estimated 20–30 deaths per year.[18] As a death certificate is not necessary for burial at present, verification of these estimates in the Philippines is not possible.[18] The jellyfish is again described as *Chiropsalmus quadrigatus*, but this cannot be confirmed.[1,9]

Japan – A chirodropid currently identified (again, incorrectly) as *Chiropsalmus quadrigatus* occurs in Okinawa (latitude 27°), Japan.[14] Its distribution extends to the Amani Islands in the north (latitude 28°). Four fatalities have been confirmed,[1] with two further fatalities since (personal communication, Tomihara, 2003). Many stings occur each year despite heightened awareness through an active advertising campaign on the danger of box jellyfish in the summer months, and the use of protective netting swimming enclosures, as in Australia.

India – The chirodropid *Chiropsoides buitendijke* occurs on the southern Indian coastline but no information is known about the west coast, or about how far north they extend.[1,13] Swarms have been reported to cause overheating in power stations due to blockage of the cooling water inlet pipes that drain from the sea, but little envenomation data are available.[1] The author has a copy of a letter dated 1936 that was forwarded to him, which describes a death and serious envenomations in the Bombay area, but no further details have become available.

The Americas – The chirodropid *Chiropsalmus quadrumanus* (Muller 1859) has been described in waters along the eastern coast of the Americas between the tropics, including many Caribbean islands.[1,13] Serious stings from *Chiropsalmus quadrumanus* have also been reported from beaches in Puerto Rico during the summer months (personal communication, Bertha Cutress, 1992). A swarm of *Chiropsalmus* caused many thousands of severe stings on the Atlantic coastline of Florida in the summer of 2003. A fatal chirodropid envenomation was recorded on 20 June 1990 of a four-year-old boy at Galveston Island in the Gulf of Mexico.[10]

Africa – There are neither reported deaths nor serious stings from *Chirodropus gorilla* described from the west coast of Africa, to the author's knowledge, nor from the east coast or Madagascar, although theoretically they should be present.[1]

CARUKIA BARNESI (IRUKANDJI)

Carukia barnesi is distributed throughout tropical Australian waters. In appearance, it is a small, transparent carybdeid, usually 12–15 mm but up to 25 mm bell diameter, with four highly retractile tentacles, each arising in the lower corner of the bell.

Figure 3
Multi-tentacled *Physalia physalis*, 'Pacific man-of-war' – smaller cousin of Atlantic 'Portuguese man-of-war'; causes very painful skin sting, often with nausea and sweating

A mild skin sting is followed after a short delay by severe muscular cramping pains, nausea, vomiting, sweating, anxiety and restlessness – known as the Irukandji syndrome.[3] Hypertension, which may be severe, occurs in all severe cases, with some developing pulmonary oedema and toxic heart failure.[4,5] Severe hypertension up to 300/150 mm Hg has been reported. This may be followed by an intra-vascular bleed – the cause of two deaths in north Queensland.[6] This jellyfish was discussed in detail in the last issue.[19]

STOMOLOPHUS NOMURAI

Distribution

Stomolophus nomurai is reported in the Yellow Sea between China, South Korea and Japan.[20]

Appearance

It has a large, translucent or milky-white dome with numerous non-stinging, sand-like dots on the outer surface of the large bell, which may be 1–2 metres in width and can weigh over 100 kg. Many long brown tentacles hang underneath.

Envenomation

There is initial severe skin pain. Systemic symptoms are usually delayed, characteristically developing about 40 minutes after the sting, although this time may extend from a few minutes to about 50 minutes. This syndrome is similar to the 'Irukandji syndrome' with sweating, nausea, vomiting, anxiety and restlessness, although pulmonary oedema and toxic heart failure develop rapidly and may result in death.[20]

Fatalities

Reports of eight deaths have now been published.[21] Victims died from pulmonary oedema some 2–24 hours after the initial envenomation. No deaths have been reported since 1995, although this may be due to communication problems rather than a downturn in numbers of envenomations.

PORTUGUESE MAN-OF-WAR (*PHYSALIA PHYSALIS*)

Distribution

These hydrozoans are found throughout the world in temperate and tropical oceans. Stings appear to be more severe in warmer waters.[1]

Appearance

The Portuguese man-of-war has a clearly visible blue float that may grow up to 25 cm in length in the Atlantic Ocean; in other oceans the maximum size appears to be 15–20 cm. Long, blue, highly retractile tentacles hang underneath and may extend up to 30 m in length in the largest specimens. The smaller specimens that occur in the Pacific are often referred to as the 'Pacific man-of-war' (Figure 3) to differentiate, as their sting, although very painful, has not proven life threatening. A similar 'cousin', *Physalia utriculus*, has just one tentacle and is common in the Pacific, especially around Australia, where it is usually known as the 'bluebottle'.

Envenomation

Both the Pacific and Portuguese man-of-war cause very painful skin stings (although not as severe as those of *Chironex* box jellyfish) and can cause painful breathing (with reduced effort even leading to hypoxia), nausea, muscle cramps and anxiety.[1]

Physalia sp. was thought to be responsible for a severe envenomation resulting in brachial artery spasm after a second sting, two weeks after the initial sting, at Mangalore in the Indian Ocean in the summer of 1983.[22] The cause was attributed to hypersensitivity. Another serious envenomation off Goa in the Indian Ocean produced

Table 1
Locations of deaths from marine envenomation around the world

Jellyfish	Geographical location	Countries with fatalities
Chirodropids (Box jellyfish)	Tropical waters of: Pacific – West Coast; Indian – East Coast and mid ocean; Atlantic – East(?) and West Coasts	Australia; Brunei; Indonesia (Kalimatan), Labuan; Malaysia (Penang & Langkawi Is.); Japan (Okinawa); Papua New Guinea; Philippines, Sabah, Sarawak; Solomon Islands (Bougainvillea); Thailand, USA
Carukia barnesi (Irukandji)	North and east tropical waters of Australia	Australia (North Queensland)
Stomolophus nomurai	China Sea	China (around Qindao – 8 deaths)
Physalia physalis	Worldwide	USA (South-east – 3 deaths)

localised vasospasm in upper limbs, finger necrosis, and gangrene. Based on serological titres from the patient, *Physalia sp.* was implicated, although the identity of the jellyfish was not confirmed.[23]

Fatalities

There have been three deaths recorded from the Portuguese man-of-war in the south-eastern United States (Table 1).[1]

Jellyfish causing severe envenomation syndromes

SANDERIA MALAYENSIS

Distribution

This jellyfish is present in the Indian Ocean, Singapore, East Africa, the Gulf of Aden, the Suez Canal, the Red Sea, and waters off Oman (and the Arabian Gulf), India, Malaysia, Japan and the Philippines.[13]

Appearance

Sanderia malayensis has a colourless to yellow, flat-topped bell 30–130 mm in diameter, with red spots extending over the bell surface and mouth arms. The bell edge drops vertically into a short 'skirt' with approximately sixteen tentacles hanging from the skirt edge, and four frilled mouth-arms hanging from the centre of the jellyfish.

Envenomation

The sting causes moderate to severe skin pain and local skin necrosis often occurs. The sting venom may be responsible for the peripheral vasospasm and tissue necrosis reported in the cases above. The severe skin pain and appearance of the injury resemble those of a chirodropid and it may be difficult to distinguish between the two, especially in areas where both occur.[1]

GONIONEMUS VERTENS VERTENS

Distribution

The small hydrozoan *Gonionemus vertens* is present worldwide; however, it causes severe envenomation effects only in the Sea of Japan around Vladivostok, and the north-west shores of Honshu Island, Japan, where it is referred to as *Gonionemus vertens vertens*, seemingly to differentiate it from the non-toxic variety.

Appearance

A small hydrozoan, 5–15 mm in diameter, the *Gonionemus* has many tentacles around the edge of the bell, within which a symmetrical, right-angled cross is visible.

Envenomation

Serious stings from *Gonionemus* tend to occur in the hot summer month of August in the Sea of Japan. Three types of envenomation syndrome have been described, making these jellyfish stings very unpleasant.[1]

Painful syndrome (approximately 37%) – generalised painful muscle fasciculation with severe muscle, joint, chest and loin muscle pains that persist for 2–3 days.

Respiratory syndrome (approximately 44%), – allergic rhinitis, lacrymation, hoarseness, cough and dyspnoea, persisting from a few hours to two days.

Mixed syndrome (approximately 19%) – severe joint and muscular pains, with cough, bronchospasm, throat irritation, rhinitis and lacrymation. Some patients develop a tachycardia and mild hypertension. Psychic dysfunction with neuropsychiatric symptoms, depression and hallucinations has also been reported.

These symptoms occur mainly in northern Japan, usually in women gathering edible seaweeds. One sting even occurred after the victim ate this seaweed raw. It is presumed the syndrome resulted from ingestion of *Gonionemus*.[1]

LARGE CARYBDEIDS (*TAMOYA* AND *CARYBDEA SP*.)

Distribution

Large carybdeids (box jellyfish) appear to be present in all temperate subtropical and tropical oceans, although they are much more common in the latter. Severe envenomations have been described from tropical areas with fringing reefs, including northern Australia, the Red Sea and Indian Ocean, and the Pacific coast of the far south-eastern United States, Mexico, Central and northern South America.[1,22]

Envenomation

Skin pain occurs in all large carybdeid jellyfish stings and they frequently cause systemic symptoms similar to a mild-to-severe Irukandji syndrome. However, no deaths have been reported from these species to date.

'OTHER' SEVERE STINGS

Bali – On 17 October 2003, a nine-year-old boy and his father were snorkelling 15 metres from the beach when they felt a 'burning' pain, as if they were being electrocuted. When they exited the water they were covered in tentacles (blue and dark purple/black). The father was severely stung on both arms and shoulders, right neck and a third of his back; the son suffered less severe injuries.

At the diving centre some 25 m down the beach a local diver knew of the problem – "*It is a bad jellyfish – a hunting jellyfish and fire jellyfish*". Divers started to remove the tentacles with their bare fingers and poured vinegar on the area. The son's symptoms settled quickly but the father had severe respiratory difficulties and muscle spasms in the back about 1–1.5 minutes after being stung. His hands, feet and lower legs became cold and blue, his arms and face, white. Seven minutes after the sting a local doctor arrived and gave him two injections, one an antihistamine, the other unknown. The victim then lay on the floor for some two hours before being able to get up and back to his hotel, still with severe burning pain all through the sting area. After a bad night with the pain and burning, he eventually settled with analgesia. This was probably a chirodropid sting, or possibly a severe sting from a multi-tentacled *Physalia physalis.*

Oman – A 60–70 cm carybdeid that he saw stung a diver on his right forearm in Omani waters in October 2002. He had severe burning over the stung area. He treated the area with vinegar but then went back into the water. About an hour later he felt dizzy and returned to the boat. The stung area on the right arm had raised, painful welts and the arm was slightly swollen. This swelling increased over the next five hours until he could not bend his arm at the elbow. During this time he developed stomach cramps, became nauseated and was vomiting for some five hours.

At 48 hours he still had severe pain and swelling of his right arm but flew home to the UK, feeling nauseated the whole flight. Despite resting the arm, over the next three days it began to blister and his nausea increased, he started vomiting and the stomach cramps returned and continued over the next three days. The severe blisters formed scabs, took weeks to heal and then scarred. The skin continues to feel very sensitive to touch. Could this have been a sting from *Carybdea alata* with Irukandji-like syndrome?

Puerto Morales – On Puerto Morales Beach, Mexico, a 29-year-old female was stung in April 2000 in open water near a coral reef. She described the jellyfish as the "invisible sea wasp" (no further details available). Initially she had a stinging pain in both her legs and a rash all over her body, like hives; she had severe muscle spasms, along with numbness in the arms and hands, palpitations, an "asthma attack" and she was itchy all over. Two years later she still had skin rashes, and had developed "food allergies" (which may or may not have been related). This could have been a sting from a carybdeid with Irukandji-like syndrome, or possibly a severe 'sea bather's reaction' from *Linuche sp*.

Punta Cana, Dominican Republic – On 18 September 2002 a female swimmer was stung and developed large whip-like sting marks between the thighs, on the right shoulder and upper arm, and the left side of her abdomen. She started getting palpitations. The abdominal sting marks blistered and ulcerated and caused abdominal swelling; she also developed some facial swelling. The affected areas healed with little scarring. This could have been a carybdeid or mild chirodropid sting.

Red Sea – On 25 October 2002, a 54-year-old male, who had been diving for 34 years without problem or accident, was in Egypt diving in the Red Sea. He saw a carybdeid 'box' jellyfish just as he was stung on the leg. He had severe pain in his leg, and within five minutes could barely breathe: he thought he was "going to die". Five to ten minutes after the sting he complained that he couldn't speak, although he could hear clearly. He developed severe vomiting and was taken to the hyperbaric centre at Sharm-el-Sheik within 20 minutes of the initial sting.

He was taken from there by boat and bus to another clinic; here they found his heartbeat was irregular but "it was corrected by medication". The leg pain lasted about 24 hours with the stung area covered with thick blue welts. He then developed dysuria, urgency and incontinence. After 1–2 days the dysuria and frequency passed but he remained incontinent for a further two weeks. He also had abdominal pain and constipation, but laxatives caused faecal incontinence.

A week later he suddenly "felt awful". Medical examination showed him to be hypertensive (205/120 mm Hg), in atrial fibrillation, with left ventricular dilatation and pulmonary oedema, which settled with medical treatment (exact details unknown). He then developed severe muscle weakness, causing difficulty walking and using his arms; he was unable to work. A neurologist was unable to define the cause and the muscle weakness slowly settled over the following year.

Mononeuritis multiplex

Two cases of mononeuritis multiplex following coelenterate stingings have been reported.

Norfolk, Virginia, USA – A 25-year-old male was stung by a jellyfish off the coast of Norfolk, Virginia, USA. Although the animal responsible was not identified, both *Physalia* and *Cyanea* species were present in the water at the time of injury. The patient noticed typical erythematous wheals at the site of tentacle contact and had slight constitutional symptoms that disappeared within a day. During the subsequent week he noticed gradual weakness in his right hand and seven days later had diffuse weakness of the contralateral hand and arm. This delayed neuropathy of the radial and ulnar nerves improved spontaneously within 10 weeks.[24]

Penang, Malaysia – A similar case occurred following a sting from an unidentified jellyfish in Penang, Malaysia.[25] A 26-year-old female was swimming off the beach when she felt immediate, severe pain on her right arm and hand. She became nauseated and faint, developed severe trunk pain, felt agitated and became breathless. Her right arm became swollen and she had pain up to her elbow, with numbness, paraesthesiae and muscular weakness. Over the next 24 hours she had more pain and swelling, and vesicular bullae appeared over the sting area, which then desquamated and later became hyper-pigmented.

Five weeks after the sting she had marked weakness of right hand dorsiflexion with mild thenar and hypothenar atrophy and decreased sensation in the distribution of the right median and radial nerves. This improved very slowly over the next year, still leaving her with some hand weakness and inability to perform her work as a typist.

Local lifeguards deny any knowledge of other severe stings in this area, but when the author visited in 1987 and asked local fishermen questions and showed them photos of chirodropids, they immediately recognised them. They stated that they were present much of the year and one reported a death from a jellyfish sting within the previous couple of years. This was unsubstantiated by anyone else, including the local policeman. Cleland and Southcott had also described a fatal sting in that area in 1946.[9]

Treatment

Cold packs or ice stop the majority of skin pain in jellyfish stings tested to date when applied to the stung area for 5–15 minutes and can be repeated when necessary.[26] Heat has been shown to be useful in some areas after some delay (Hawaii; the large carybdeid *Carybdea alata*),[27] but in view of the high temperatures needed (over 42 °C) is difficult to maintain and entails the risk of scalding. Also, the time taken for the heat packs to ease the pain was similar to the natural regression of pain after most jellyfish stings.

CHIRODROPID ENVENOMATION: FIRST-AID TREATMENT

To prevent further envenomation, household vinegar (4–6% acetic acid) is poured over the stung area for at least 30 seconds to inactivate stinging cells on remaining adherent tentacles. Others should be sent for help whilst the victim's airway, breathing and circulation (ABC) are checked and expired air resuscitation (EAR), or cardiopulmonary resuscitation (CPR) commenced, if necessary.[1] Cold packs (15 minutes and repeated when necessary) will help ease skin pain but takes longer to work than in the smaller non-life-threatening stings, due to the severity of pain and tissue destruction.

Treatment of other envenomation symptoms, such as the Irukandji syndrome, is not possible in the first-aid situation, although glyceryl trinitrate spray or tablets, 1–2 as required (and if available), will reduce life-threatening hypertension.[28]

Medical treatment

Clinical management is specific for the symptoms of serious envenomation: to provide analgesia, reduce hypertension, and provide specific drug therapy to manage severe symptoms. It may include advanced life support, antivenom administration, and management of both systemic and regional vascular problems. Antivenom is available for *Chironex fleckeri* stings and has been used with success in other chirodropid envenomations (author database).

Conclusions

Deaths from marine envenomation are not common, although four jellyfish species have been shown to cause many human fatalities, mostly in the Indo-Pacific region. Jellyfish envenomation has emerged as a major medical problem for local populations, indigenous or not, and tourists in both modern and third-world countries. Despite heightened awareness and research of ecology, preventive measures and first-aid and medical treatment remain vestigial, with both undergraduate and postgraduate medical teaching remaining conspicuous by their absence.

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Reverse dive profiles: the making of a myth

Carl Edmonds, Stephanie McInnes and Michael Bennett

Key words
Reverse dive profiles, decompression sickness, review article

Abstract

(Edmonds C, McInnes S, Bennett M. Reverse dive profiles: the making of a myth. *SPUMS J*. 2005; 35: 139-43.)
A consensus workshop in 1999 indicated that some previously established diving procedures used to reduce the incidence of decompression sickness (DCS) were not necessary under certain conditions. Specifically, the Workshop implied that it was not relevant whether one conducts the deepest dive or deeper part of the dive first (forward dive profile – FDP), or the deepest dive or deeper part of a dive last (reverse dive profile – RDP). The final recommendation of the Workshop was: "*We find no reason for the diving communities to prohibit RDPs within the no-decompression limits for dives less than 40 metres and with depth differentials less than 12 metres.*" The approval thus bestowed on RDPs has serious implications for diving safety, and deserves critical assessment before it is generally accepted. If applied, the recommendation may also result in adverse modifications to some decompression meter algorithms. We have reviewed the evidence concerning the relative safety of FDPs and RDPs, including some recent animal experiments. It is our opinion that recommendations were made by the Workshop in the absence of adequate data or critical evaluation. There is now sufficient evidence to demonstrate that FDPs and RDPs with analogous exposures within the recommendation of the Workshop have different decompression obligations, with the RDPs being more hazardous, at least in some situations. We conclude that the current practice of advocating forward dive profiles should be retained at this time.

Introduction

To challenge established diving procedures is both laudable and inevitable, but unless this is based on reliable data, experience and adequate testing, then changing recommendations is ill informed and constitutes a gamble with diver safety. A consensus conference is a fashionable way to achieve change, and is a legitimate procedure. This is especially so if the consensus is based on reliable data and does not disintegrate into a simple debate of beliefs during which a powerful chairman or the more eloquent delegates impose a predetermined position.

In 1999 a workshop considered the possibility of altering certain long-established and recommended safe diving procedures.[1] Specifically, this workshop proposed there would be no increase in the risk of decompression sickness (DCS) through the adoption of what is termed 'reverse dive profiles' (RDPs) to supplement the established 'forward dive profiles' (FDPs), without increasing decompression obligations.

An FDP involves performing the deeper part of the dive first (in multi-level diving), or performing the deepest dive first (in repetitive dives). Subsequently the dive or dives become shallower. An RDP involves diving from shallow to deep, either in multi-level diving or repetitive dives.

The RDP Workshop

The Reverse Dive Profile Workshop was arranged by the scientific divers of the Smithsonian Institute, in collaboration with the Divers Alert Network (DAN), the American Academy of Underwater Scientists (AAUS), the Diving Equipment and Manufacturing Association (DEMA) and *Dive Training* magazine. The issues it addressed were:

- the increasing use of RDPs
- RDPs being permitted by dive computers, and therefore becoming acceptable to divers
- the physiological basis for limiting RDPs
- the evidence for limiting RDPs
- a critical examination of the established limitations of RDPs as a logical extension of dive-computer technology.

The Workshop dealt almost entirely with beliefs, attitudes, theoretical concepts, decompression models and dive-computer analyses. Practical anecdotes and experiences were given little credence. Debate was spirited, but there was considerable agreement at least on one point – the absence of hard data on which to make valid recommendations. The Workshop seems to have ignored the maxim that an absence of evidence is not the same as evidence of absence.

The belief that FDPs and RDPs are equivalent and, therefore, require comparable decompression, is based mainly on the assumption that, given the diver is exposed to the same depths and durations underwater, both produce the same load of inert gas dissolved in the tissues. This concept is inherent in many decompression meter algorithms, especially those that deal only with dissolved inert gas loads, although not those employing 'bubble-based' models.

As the Convener properly stated: "*Does it really matter in which order dives are conducted as long as one keeps track* *of nitrogen loads and performs adequate decompression?*" The follow-up question that remained unanswered was: do RDPs and FDPs actually have the same decompression obligations, and can we therefore apply the same decompression requirements to them?

At the conclusion of the Workshop, a compromise was reached in which the Workshop approved RDPs with very specific limitations including a maximum dive depth of 40 metres of sea water (msw), a maximum differential depth between dives of 12 msw, and that all dives must be within no-decompression limits. While these limitations were based on as few relevant data as the justification for RDPs overall, they at least had the virtue of restricting such dives to less stressful decompression exposures than if there were none at all.

Based on the Workshop's recommendations, divers' advisors are withdrawing their preference towards FDPs and embracing the concept of RDPs as an equivalent and safe procedure.[2]

Views and reviews of the RDP Workshop

A reading of the full proceedings suggests that support for the recommendations was not as unqualified as the summary implied. In a later review of the Workshop, Hamilton and Baker did not refute the recommendations, but did point out that decompression modellers who took into account only gas loading (mainly the older algorithm models) drew different conclusions from those who considered the effect of bubble development (and thus slower out-gassing).[3] The former were more tolerant of the RDPs and tended to equate them with FDPs.

They also noted that the lack of diving data available to demonstrate any danger from RDPs might be due to the prohibition against such profiles being used, i.e., insufficient experience. This view has been mirrored in the popular diving press.[4] To quote Hamilton and Baker "*the discussion got a little bit heated…folk who work with bubble models had serious reservations about a complete retraction of warnings against reverse profiles…you might really get into trouble on an improperly planned or executed RDP.*"

Indeed, a reading of the general discussion section of the proceedings confirms that a broad range of opinions were expressed by the various identified delegates, often repeatedly, and these are now summarised.[5] Neuman pointed out that, while delegates were concerned about the paucity of evidence for the safety of RDPs, we do have a lot of data on FDPs, literally millions of dives with an acceptable incidence of DCS. Lewis noted that we have ample evidence that uptake and washout of inert gas are asymmetrical, a concept that is inconsistent with FDPs and RDPs being equivalent.

On a more experimental level, Gerth provided some evidence that the US Navy air diving tables may not be as safe with RDPs as with FDPs, and extended this to the dive-computer algorithms, while Huggins produced a retrospective analysis of the admittedly restricted numbers of DCS cases at Catalina Island. The difference did not reach statistical significance, but showed a tendency for RDPs to have more severe DCS and more delayed resolution. Yount, too, took issue with the claim that no evidence existed against RDPs, and illustrated this in his decompression model. The varying permeability model indicated that a shallow dive followed by a deeper one results in greater bubble formation. He stated "*We must not go away from here and gradually allow the myth to build up that RDPs are safe or even safer than FDPs...it depends on the precise profile.*"

Wienke, on the basis of his reduced gradient bubble model, also questioned the symmetry of RDPs and FDPs in the decompression obligations of two repetitive dives. He claimed that the differences between FDPs and RDPs were fewer with short, shallow dives, and increased as the dives became deeper and longer. For two consecutive dives, he suggested a limit of about 40 msw depth and a differential between depths of 12 msw. He specifically did not extend this concept to three or more dives or to multi-level dives, and Gerth supported these limitations.

Moon and Neuman summarised other RDP hazards with repetitive dives. They noted, for example, that a deep dive is one that is more likely to be associated with a variety of problems, and it may be preferable to encounter these with a low gas load. Moon reiterated the axiom that if adequate decompression procedures were initiated, RDPs would be safe. However, he then noted "*studies designed specifically to address the question have not been performed.*"

On the other hand, there were many proposals to remove the 40 msw limit and the no-decompression provision from the final recommendations. Both were retained on the bases of conservatism and current recreational limits, more than on practical evidence. The same could be said for the 12 msw differential.

Gernhardt cautioned "*I don't think it's wise to put a bunch of qualifications that we know nothing about...don't think we can draw qualifications that are stronger than the data we have*", while Beyerstein made a prescient comment, "*A consensus in a body like this gets written down and tends to become engraved in stone and has a life of its own*".

Finally, Brubakk argued that because the incidence of DCS symptoms is so low, any useful comparison between FDPs and RDPs would be best done using experimental animals.

Rationale for removing prohibition on RDPs

The case for RDPs as put by the conveners was based on four observations:

- RDPs are being performed in recreational, scientific, commercial and military diving

- prohibition of RDPs by recreational diver training organisations cannot be traced to any definite diving experience that indicates an increased risk of DCS
- no convincing evidence was presented that implied RDPs within the no-decompression limits lead to a measurable increase in the risk of DCS
- dive-computer algorithms do not differentiate between FDPs and RDPs.

It was also stated that FDPs had originally been employed to obtain more bottom time, that the US Navy did not prohibit RDPs, and that RDPs may be required for logistic reasons relating to the environment or military tactics.

One cannot contest the last of these reasons, as military operational parameters are infinite, and risk is relative. The same considerations partly explain the persistence of RDPs in a number of settings. Prohibitions limit the flexibility of an operational diving team to cover unexpected exigencies, not an option that any operational unit relinquishes readily. In the context of the Workshop, this operational consideration is used to infer that RDPs are routinely used by these organisations. While some experimental trials, by no means always successful, were quoted by Lewis, this does not mean that RDPs were routinely employed. On the contrary, Navy and commercial dive instructors would all be aware of the universal industry recommendation against such RDPs. To imply there is a vast amount of data somewhere out there demonstrating routine and safe RDPs is not tenable. As Wethersby and Gerth stated "*Over 1200 repetitive and multi-level exposures are present in the [Navy] database...only a few dozen are reverse.*"

The belief that FDPs were introduced only to obtain more bottom time is a myth that seems to have developed at the Workshop. Lewis did observe that, using old decompression concepts, FDPs allowed a longer bottom time than RDPs in repetitive diving. This does not mean it was the reason for the embargo on RDPs. Flynn, who was a dive instructor in the 1960s, stated in reference to repetitive dives that the 'deep dive first' recommendation specifically was a safety issue, and not promoted to prolong bottom times. Edmonds had made a similar statement in 1988 regarding multi-level diving.[6] "*If a multi-level dive is carried out [using a dive computer] then the deepest part of the dive should be performed first, and the diver should ascend throughout the dive, until he reaches a depth of 30 feet. We would be pleased to modify these restrictions, once we have information on which to base such a modification.*"

Both Flynn and Edmonds, who were active during the period when the RDP prohibition was promulgated, are supported by references in the popular texts of the time, including the *PADI open water diving manual*, the *British Sub-Aqua Club diving manual* and *Australian scuba diver*.[7–9] There is no reference to prolonging bottom times in any of these publications. The advice was based on experience and promoted for reasons of perceived safety. The rationale was the theoretical belief in bubble development and its slowing effects on out-gassing, and the repeated and frequent observation that divers who did deeper excursions at the end of a dive profile or dive sequence, such as to retrieve dropped equipment or release fouled anchor chains, seemed to be more frequently afflicted with DCS. Whilst neither reason is adequate to prove the FDP recommendation, neither can be summarily dismissed as irrelevant.

Finally, the assertion that dive-computer algorithms do not differentiate between FDPs and RDPs, is more contentious. It might be so for those that rely only on gas loading. Others do make some allowance for slower off-gassing with bubble production during decompression (usually the non-Haldanian, 'bubble-based' types). The degree to which decompression is made more conservative in the latter equipment varies and seems somewhat arbitrary. There is considerable variation in the decompression obligations imposed by different manufacturers, as shown by Lippmann and Wellard, for both multi-level and repetitive dives.[10] In any case, it seems a little perverse to hypothesise that because a machine-based algorithm permits a dive profile, then it should be safe and applicable to humans. It would be more reasonable to reverse the hypothesis and assert that only dives safe for humans should be incorporated in the machines we employ. The belief that dive computers indicate safe and innovative dive profiles has been shown to be misleading and dangerous in the past.[11–13]

RDP conditions imposed by the Workshop

"We find no reason for the diving communities to prohibit RDPs within the no-decompression limits for dives less than 40 metres and with depth differentials less than 12 metres."

RESTRICTIONS

The Workshop imposed restrictions on RDPs, as noted above. We are led to ask: if RDPs are safe and have the same decompression requirements as FDPs, why are extra restrictions necessary? As Tikiisis stated in the proceedings: "*You say there is nothing to suggest that there is a difference in safety [between RDPs and FDPs], then [with your restrictions] you imply there is a difference.*" Others had similar views. From a sceptic's point of view, these restrictions at least have the advantage of imposing some conservative factors on RDPs, thereby reducing the intrinsic extra risk. We might then question whether the restrictions are adequate to limit this extra risk to acceptable levels.

THE NUMBER OF REPETITIVE AND MULTI-LEVEL DIVES PERMITTED

The initial definition supplied by Lang limited the repetitive dives to two in a 12-hour period, or a single multi-level dive, presumably in a similar time frame. This limitation disappeared without explanation or discussion and is not evident in the final recommendations.

THE MAXIMUM DEPTH AND DEPTH DIFFERENTIAL PERMITTED

Wienke, whose work was the basis for the 40 msw/12 msw limitations, had stipulated that his calculations were based on only two consecutive dives employed using his reduced gradient bubble model. Under these conditions, the deeper the dives and the greater the difference between dives, the more hazardous the RDPs became. He did not describe any multi-level dives. Nevertheless, his work was extrapolated to more than two dives and to multi-level dives.

A depth differential (12 msw) without a stipulated minimum duration is illogical. Also, a diver who ascends or descends 24 metres at 6 $m.min^{-1}$ has the same gas load as a similar diver who ascends or descends at 12 $m.min^{-1}$ and stops half way for two minutes. Yet one has complied, the other not.

INADEQUACY OF THE RESTRICTIONS

If a diver does an RDP tri-level dive to 12 msw, 36 msw then 24 msw, he has not complied with the Workshop's recommendation of a 12-metre differential between levels. One descent involved a 24-metre differential. So did the final ascent to the surface. Although not stated, we have assumed that the differential depth changes should apply only to the ascents, not the descents, the omission by the Workshop presumably being a typographical error.

Application of the limitation to the final ascent is less clear. Indeed, it is obscure. If the final depth is greater than 12 msw, say 14 msw after a shallow multi-level dive, is the final ascent considered to conflict with the 12-metre rule? Possibly it does. But if not, why not?

MULTIPLE DIVES WITHIN NO-DECOMPRESSION LIMITS

If one considers multiple dives, say three or more, and reviews the information supplied at the Workshop, it is difficult to find any data on which to base any recommendation. Multiple dives, or multi-level dives, that do not approach the no-decompression limits, cannot and should not be used to compare FDPs and RDPs as neither are likely to produce DCS.

EXTRAPOLATION OF LIMITATIONS

Lumping an infinite combination of repetitive dives and multi-level diving all together, as if there is no substantial difference between them, and then applying a one-rule-fits-all solution for the final recommendations, was the most presumptuous of the Workshop's actions. It was neither questioned nor explained in the proceedings.

The above does not presume that the restrictions are incorrect. We simply make the point that they are unclear and unsubstantiated.

Clinical information

As suggested earlier, it is a frequent observation that divers who are compelled, by virtue of retrieving lost equipment or untangling anchors, to undertake a last deep but short dive seem at increased risk of DCS. Even if this were the only clinical information at our disposal, however, it should not be dismissed in the absence of contradictory evidence. In fact, we do have more information to consider, and there are several data sets that suggest the dangers of RDPs are all too real.

Huggins' analysis of DCS treatments at Catalina "*hints at the potential for more severe DCS with RDPs*". More recently, St Leger Dowse et al analysed female divers' log books, and indicated that symptom rates were higher in those using RDPs, although this difference did not reach statistical significance.[14] They indicated a greater risk with both RDPs and greater depth differentials between dives.

Unfortunately, in both of these surveys there were insufficient numbers of both dives and DCS cases to draw definite conclusions. More importantly, we have only limited information from these surveys on how close these divers were to their no-decompression limits. It is those divers who approach the FDP no-decompression limits who are likely to be at increased risk. Some no-decompression triple, repetitive dives, which did not follow the FDP concept, were described by Leitch and Barnard but were found to be too hazardous to recommend.[15] There certainly have been triple, repetitive RDP dives undertaken in the past, and many no-decompression dives that were close to the no-stop limit, but very few have been documented that combine both parameters.

Animal experimental evidence

It was clear at the Workshop that there was no experimental evidence to support or refute the relative safety of FDPs and RDPs. For this reason, we have recently performed and reported two controlled animal experiments.[16] Using matched-weight guinea pigs, we have examined multi-level single dives and a sequence of three repetitive dives in both forward and reverse profiles.

First, a multi-level, no-decompression dive (for guinea pigs) was made to 36 msw, then 24 msw, then 12 msw using an FDP, without incident in 11 pigs. The identical exposure, but with the sequence of depths reversed, caused death from DCS in 6 of 11 similar guinea pigs. The difference between the FDP and RDP was statistically significant ($P = 0.01$) and we concluded that it is likely to be of great practical significance. In essence, multi-level dives that did not require decompression when performed in the established forward-profile manner were hazardous if carried out in the reverse-profile mode.

Second, we performed a sequence of three no-decompression dives for another group of 11 guinea pigs using an FDP to

30 msw, then 20 msw and then 10 msw, with short surface intervals, again without incident. The identical exposures, but with the sequence of depths reversed, caused death from DCS in 1 of 11 weight-matched guinea pigs. Extending the exposures to 36 msw, 24 msw and 12 msw produced no DCS in the FDP group and 6 cases in the RDP group, including a further three deaths in the RDP group. The difference in the incidence of serious DCS between these FDPs and RDPs for repetitive dives was statistically significant (P = 0.01), and again of likely practical significance. Thus, at least with the profiles chosen, it was less dangerous to perform the deeper dives first than it was to perform them last.

An incidental observation of the Buhlmann bubble-based decompression meter used in these experiments supported the observation made by some Workshop participants that these meters apply some safety corrections for delays in out-gassing. They do differentiate FDPs from RDPs in practice and in their theoretical tissue levels. How close these modifications come to physiological reality is unknown, and will vary with each computer type.

We concluded, therefore, that reverse profiles, as they apply to both multi-level and repetitive diving, are not merely the mirror image of forward profiles, with similar decompression obligations. Extrapolating the decompression obligation from FDP to RDP in the profiles selected resulted in a statistically significant difference in the risk of DCS, despite complying with the current restrictions recommended by the Workshop. The application of FDP decompression calculations to RDP multi-level diving and repetitive diving is sometimes unsafe.

Conclusions

The wide divergence of opinion expressed at the 1999 Workshop on RDPs highlighted the paucity and limitations of the data available. Nevertheless, it is on these inadequate and conflicting data that established procedures advocating FDPs are now being revoked, and RDPs promoted as safe and equivalent alternatives. We believe there is adequate evidence from the dive experiences reported at the Workshop, clinical experience, and now animal experiments, that some RDPs are likely to require more decompression obligations than FDPs. The development of bubble-based decompression algorithms and the demonstrated temporal difference between uptake and elimination of nitrogen supports this conclusion.

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Articles reprinted from other journals

The relative safety of forward and reverse diving profiles [Abstract]

Stephanie McInnes, Carl Edmonds and Michael Bennett

Introduction: A recent workshop recommended that within certain restrictions, and from a decompression perspective, it is not substantially important whether one conducts dives from deep to shallow or shallow to deep. Thus, in multi-level dives the deeper part of a dive may be performed later in the dive, while repetitive dives may progress from shallow to deep. These are referred to as reverse dive profiles (RDP). The consensus recommendations were made in the absence of experimental data.

Methods: We performed two experiments [approved according to the Declaration of Helsinki] to test these recommendations. We first exposed two matched groups of 11 guinea pigs to a single *multi-level* diving profile (36 msw for 30 min, 24 msw for 30 min, 12 msw for 30 min), one group in a forward progression (FDP), the other in reverse, and compared the incidence of severe DCS using the method of Albano.[1] Second, we compressed two groups each of 11 guinea pigs to three *repetitive* dives (30 msw for 30 min, 20 msw for 30 min, 10 msw for 30 min, surface intervals 15 minutes). Similarly, one group performed FDP and the other RDP. Again, we compared the incidence of severe DCS. A second series of repetitive dives with increased depth and time was required to produce substantial risk of DCS (36 msw for 40 min, 24 msw for 40 min, 12 msw for 40 min).

Results: Multi-level exposure: there was no evidence of DCS in any of the animals exposed to the FDP, while six (55%) of the RDP group exhibited symptoms of severe DCS and ultimately died ($P = 0.01$). Repetitive exposures: there was no evidence of DCS in the FDP group versus seven (33%) in the RDP ($P = 0.01$).

Conclusions: Our findings suggest that multi-level and repetitive dives performed in the established forward profile manner are less hazardous than those performed in the reverse profile mode. We believe the recommendations of the workshop should be re-examined.

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Reprinted with kind permission from: McInnes S, Edmonds C, Bennett M. The relative safety of forward and reverse diving profiles. *Proceedings of the Undersea and Hyperbaric Medical Society Annual Scientific Meeting*, Los Vegas, 2005: No. 176

Key words

Decompression illness, reverse dive profiles, research, land animals, reprinted from, abstracts

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Trends in scientific diving: an analysis of scientific diving operation records, 1970–2004 [Abstract]

Sayer MDJ, Barrington J

A detailed trend analysis was made of 8,611 scientific diving operation records undertaken at the Dunstaffnage Marine Laboratory between 1970 and 2004. The analysis represented 15,711 separate person dives and a total of 285,512 minutes of diving time. Specific trends were highly influenced by predominant project areas during specific periods of the analysis. However, most diving was relatively shallow with only 0–12% of annual dive duration at depths of 30 metres or greater, and the majority (32–87%) being in the 10–29 metre depth range. Diving was undertaken throughout the year and average dive depth and duration were not influenced by month. One incident of decompression illness occurred within the dives analysed yielding DCI incidence rate of 0.12 per 1000 dives or 0.06 per 1000 person dives. The level of 0.12 DCI incidents per 1000 dives is within the range for previous studies on scuba diving (0.07–0.14) but below reported incident rates for wreck and/or multi-day recreational diving (0.25–0.49). However, it is suggested that true inter-sector comparisons of estimated risk to the individual diver can only be made when expressing DCI rates in relation to person dives. Average numbers of divers per dive in ‘at work’ operations will usually be below two; some recreational dives may have many more than two divers per dive.

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Key words

Decompression illness, science diving, safety, epidemiology, reprinted from

SPUMS Annual Scientific Meeting 2005

Smithsonian underwater research

Michael A Lang

Key words
Scientific diving, biology, research, review article, general interest

Abstract

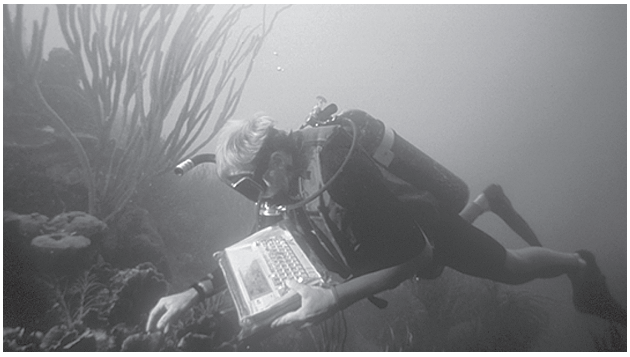
(Lang MA. Smithsonian underwater research. *SPUMS J*. 2005; 35: 145-53.)
More than a century and a half ago, the Smithsonian Institution was established to promote the "*increase and diffusion of knowledge*". It is one of the oldest and most distinguished scientific institutions in the United States and scientific diving has been a research tool integral to its marine research efforts for over 30 years. The Smithsonian operates a unique Marine Science Network of coastal laboratories and long-term research sites along the latitudinal gradient of the western Atlantic Ocean, and bridging the Panamanian isthmus from the Caribbean Sea to the Pacific Ocean. Many of the most pressing environmental issues in marine ecosystems are studied using scientific diving techniques. To illustrate this, specific examples of the Institution's underwater research are used.

Introduction

The Smithsonian Institution was established more than a century and a half ago to promote the "*increase and diffusion of knowledge*" by a gift to the United States from an English chemist and mineralogist, James Smithson, and an act of Congress. The Smithsonian is one of the oldest and most distinguished scientific institutions in the United States and, indeed, science was the only mission of the Smithsonian for nearly a century. Outside the Smithsonian Castle in Washington DC is a statue of the first Secretary, Joseph Henry – the most eminent physicist in the United States.

The Institution was almost exclusively dedicated to basic science until the latter half of the twentieth century, when it became increasingly the home of America's public art treasures and memorabilia, housed today in 16 museums and research institutes. The science enterprise of the Smithsonian was often invisible in the glare of the brilliance of the expanding set of museums of art, history, and culture on the Mall. Many people register surprise on learning that the Smithsonian has any science mission at all, above or under water.

Figure 1
Smithsonian scientist with 'dive computer' on a reef census dive



Scientific diving is a research tool integral to the Smithsonian's marine research efforts for over 30 years (Figure 1). The Smithsonian operates a unique Marine Science Network of coastal laboratories and long-term research sites along the latitudinal gradient of the western Atlantic Ocean, and that bridges the Panamanian isthmus from the Caribbean Sea to the Pacific Ocean (Figure 2). Many of the most pressing environmental issues in marine ecosystems are studied using scientific diving techniques, including investigation of the following questions:

Figure 2
Map of Smithsonian Marine Science Network
1 – SERC; 2 – SMSFP; 3 – CCRE; 4 – Bocas del Toro; 5 – Galeta; 6 – Coibita; 7 – Naos
(see text for explanation)

- What is this species? (taxonomy)
- How are species related? (phylogenetics)
- Where are they found? (biogeography)
- How do species interact? (ecology)
- How did they come to be? (evolution)
- How are they used? (ethnobiology)
- How do they respond to change? (paleobiology and conservation biology)

In the face of the global biodiversity crisis, the need could not be more urgent to discover, describe, and classify the species of our planet in order to allow us to conserve, manage, understand, and enjoy the natural world. Our generation is the first to fully comprehend the threat of this crisis and the last with the opportunity to explore and document the species diversity of our planet.[1]

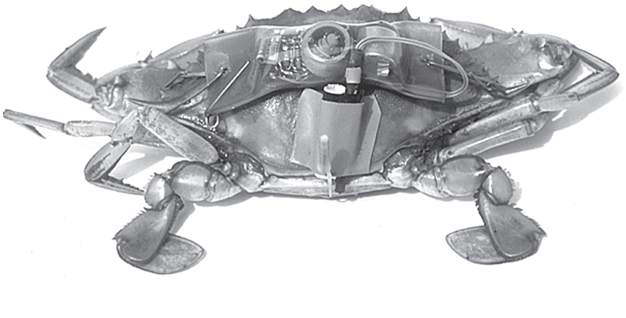
Smithsonian Marine Science Network

ENVIRONMENTAL RESEARCH CENTER (CHESAPEAKE BAY)

The Smithsonian Environmental Research Center (SERC) advances stewardship of the biosphere through interdisciplinary research and education. SERC laboratories, education facilities and field sites are located 25 miles east of Washington DC, on the western shore of Chesapeake Bay. SERC's long-term studies have focused on the interactions among ecosystems in complex landscapes, tidal marshes and estuaries. With the Rhode River, 3,200 acres of land and 16 miles of undeveloped shoreline as its hub, SERC's comparative marine research radiates to sites around the world.

SERC has explored connections in Chesapeake Bay's food web leading from plankton production up to commercially important species of fish and crustaceans, like the blue crab (Figure 3). Fisheries in Chesapeake Bay have collapsed as a result of over-fishing and environmental degradation, and the blue crab is now the only species with a sustained commercial catch.[2,3] Marine biological invasions by non-native species, introduced through human activities, have disrupted ecosystems around the world, causing major ecological change and enormous economic impact. SERC is the national centre for the study of alien invasive species in coastal ecosystems. Ballast water in commercial ships is the major vector for the introduction of alien marine species.

Figure 3
Blue crab (*Callinectes sapidus*) wired for ultrasonic biotelemetry study



MARINE STATION AT FORT PIERCE (INDIAN RIVER LAGOON, FLORIDA)

The Smithsonian Marine Station at Fort Pierce (SMSFP) is a marine science research centre located on the Indian River Lagoon alongside 156 miles of Florida's central-Atlantic coast. The Indian River Lagoon is a long, narrow and shallow estuary adjacent to the Atlantic Ocean, separated from it by a strip of barrier islands just 20 miles from the Florida current. This stream of warm water from the Caribbean moves northward past Florida's coastline as part of the larger, complex system of currents known as the Gulf Stream.

SMSFP's location in this biogeographic transition zone allows researchers to work at the interface of the hemisphere's tropical and temperate regions. The facility provides access to an extraordinary diversity of marine and estuarine species and to a variety of habitats. These include: mangroves, salt marshes and sandy beaches, rocky intertidal substrates, seagrass beds, mud and sand flats, coral reefs, deep coral rubble zones, shallow- to deep-water sandy plains, and the blue waters of the Gulf Stream. SMSFP has developed the Indian River Lagoon Species Inventory as a relational database that documents more than 3,000 species of plants and animals found in the estuary, which is likely to have the highest biodiversity in the nation.

CARIBBEAN CORAL REEF ECOSYSTEMS PROGRAM (BELIZE)

Coral reefs are unique biogeological structures that thrive in clear, nutrient-poor (oligotrophic) tropical oceans and support a rich and diverse biological community. Reef ecosystems are driven by the symbiosis between scleractinian corals and microscopic dinoflagellate algae (zooxanthellae) as their chief energy source. The largest, best-developed, least-polluted and commercially exploited coral reef in the Atlantic region is the Mesoamerican Barrier Reef.[4,5] It is a complex of reefs, atolls, islands, oceanic mangroves, and seagrass meadows that extends over 160 km. For its unique characteristics and relatively unperturbed condition, the Belize barrier reef has been declared a World Heritage Site.

Carrie Bow Cay (Figure 4), only three hours by plane and boat from Miami, was chosen as the Smithsonian site in former British Honduras for an interdisciplinary, long-term study of systematics, ecology, behaviour, evolution of reef organisms and the dynamics and historical development of reef communities: the Caribbean Coral Reef Ecosystems Program (CCRE). Carrie Bow Cay is located on top of the barrier reef, only metres away from a variety of habitat types: reef flats, deep spur and groove, patch reefs, seagrass meadows and mangroves.

Figure 4
Carrie Bow Cay, Belize: a one-hectare island atop the Mesoamerican Barrier Reef

TROPICAL RESEARCH INSTITUTE (REPUBLIC OF PANAMA)

The Smithsonian Tropical Research Institute (STRI) operates marine stations at Bocas del Toro (Figure 5) and Galeta Point in the Caribbean, the Naos marine laboratory complex and Coibita Island in the Pacific, and a 96-foot, near-shore, coastal oceanographic vessel, *R/V Urraca*.

At the Panama Canal, the Isthmus of Panama narrows to less than 100 km, separating oceans that are very different tropical marine ecosystems. The Caribbean is a relatively stable ocean, with small fluctuations in temperature and relatively low tidal variation. Its transparent, nutrient-poor waters are ideal for the growth of reefs, and it ranks just behind the Indian Ocean and the west Indo-Pacific in terms of numbers of marine species. The tropical eastern Pacific, in contrast, exhibits much greater fluctuations in tides and temperature, with local seasonal upwelling and longer-term variation due to the El Niño southern oscillation cycle. Its more nutrient-rich waters support commercial fisheries of major importance. The creation of these two distinct marine realms by the rise of the Isthmus of Panama during the last 10 million years also contributed to the formation of the modern biological and geological world. During this interval, the Gulf Stream was established, the mammals of North America conquered a newly connected South America, the Ice Ages began, and modern man arose. The rise of the Isthmus set in motion a fascinating natural experiment, as the animals and plants of the two oceans went their separate evolutionary ways.

In celebration of STRI's role in coral reef research, the Smithsonian's 150th anniversary and the International Year of the Reef in 1996, the Smithsonian hosted the Eighth International Coral Reef Symposium in Panama.[6]

Smithsonian research projects – a sampler

ALGAL SEXUAL REPRODUCTION ON CORAL REEFS

A remarkable spectacle while studying damselfish reproduction at the Smithsonian's San Blas field station in Panama was observed by Ken Clifton. Documenting over 850 natural spawning events involving 24 different species,

Figure 5
The Bocas del Toro Marine Research Laboratory at the border of Panama and Costa Rica; dedicated in October 2003

Clifton's observations provided the first intimate details of a seaweed's love life (Figure 6).[7]

Common tropical seaweeds such as *Caulerpa* are a familiar sight to divers on coral reefs. With their relatively large size and abundant distributions, these calcified green algae have long been recognised as an important source of food, shelter, competition, and sediment within reef and seagrass communities (Figure 7). Green seaweeds, like some invertebrates (including corals), regularly undergo bouts of 'mass spawning'. Resulting clouds of sperm and eggs often shroud the reef in a pall of green, though few scientists have observed this phenomenon. Synchronous gamete release among neighbours boosts the concentration of eggs and sperm, increasing the likelihood that gametes from different individuals will meet. Each species has a highly specific time of gamete release and more closely related species spawn at different times (reducing the likelihood that similar, but potentially incompatible, gametes will encounter one another).

As primary producers, these algae contribute significantly to nutrient flux on reefs and help sustain many reef-

Figure 6
Green algal spawn on a Caribbean reef

Figure 7

(a) The green algae *Caulerpa racemosa*

(b) *Caulerpa racemosa* magnified

associated herbivores. As relatively large, structurally complex members of the benthic community, green algae compete directly with corals and other sessile marine organisms for space on reefs while simultaneously providing shelter for myriad others. Correlation between increasing green algal abundance and declining coral cover and reef biodiversity emphasise their importance as a trophic node within the reef community. These algae also produce complex defensive compounds that alter the foraging of herbivorous fishes and invertebrates and have potentially useful biomedical properties. Even in death, the heavily calcified thalli of the *Udoteacae* contribute to sand production, reef building, and other important geological processes.

CORAL SPAWNING

Corals are the building blocks of coral reefs and are renowned for the diversity of organisms they shelter. Nancy Knowlton's studies have revealed that marine tropical environments contain four to five times more species on average than has been generally realised. The most abundant and best-studied coral 'species' (*Montastraea spp.*) of the Caribbean is in fact a complex of at least three species: *M. annularis*, *M. franksi* and *M. faveolata*. All three spawn in approximate synchrony, typically seven to eight days after the full moon in August (Figure 8).[8] Even more surprisingly, these species each host a diverse array of symbiotic algal partners, so that the combined diversity of Caribbean reefs is an order of magnitude greater than previously assumed.

The ecological importance of this diversity was sharply highlighted during an episode of coral bleaching caused by a Caribbean-wide temperature increase in the summer of 1995. Which corals and parts of corals would be bleached, and the pattern of bleaching, could only be predicted by knowing which algae occurred where.[9] Thus, basic research on patterns of biodiversity has led to important insights into the likely consequences of global warming.

In the recent past, *Montastraea* and several other corals have declined in abundance. This poses a threat to reefs both now and for future generations of corals, because in order for this or any species to persist it must reproduce. *Montastraea* does not fragment prolifically, and thus sexual reproduction is critical for its long-term survival. What critical densities are needed to ensure fertilisation success during mass spawning is not known. This phenomenon of reduced population growth at low population size can place endangered species in a downward spiral from which recovery may be impossible. Corals are long-lived organisms, making it difficult to assess how present reproduction will affect future abundance.

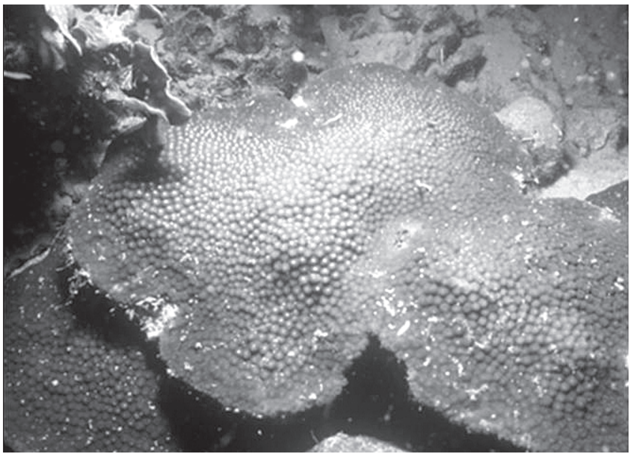
BLACK SEA URCHINS IN THE CARIBBEAN

Tropical marine environments are highly dynamic on many temporal scales. Perhaps the most dramatic revelation of long-term major change was the demise of the long-spined sea urchin (*Diadema antillarum*, Figure 9) throughout the western Atlantic.[10] Apparently due to a disease originating near the mouth of the Panama Canal in 1983, 95% of this once abundant organism disappeared over the course of two years. Notwithstanding the high reproductive output of this urchin, recovery has largely failed to occur and many over-fished reefs throughout the Caribbean have been smothered under algae freed from the urchin's grazing.

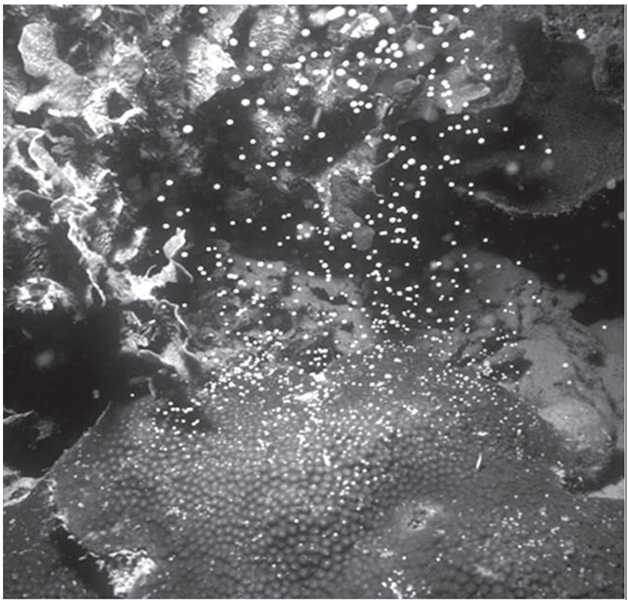
Haris Lessios' diving research showed how over-fished reefs persisted for years with high coral cover prior to the urchin die-off, but then rapidly succumbed to the decimation of this single keystone species, showing that synergy between multiple stresses on marine environments can have unpredictably severe consequences. The sea urchin saga (the most severe, widespread epidemic ever documented for a species of marine animal) also demonstrates how even extraordinarily abundant organisms (> 70 animals.m^{-2}) are potentially vulnerable to rapid elimination by diseases that combine the lethality of *Ebola* with the contagion of the common cold.

Figure 8

(a) 'Setting' colony of *Montastraea annularis* showing gamete bundles protruding through coral pharynx

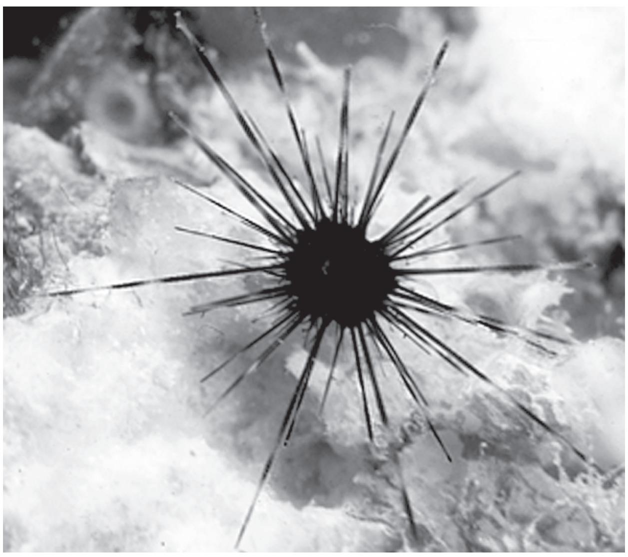


(b) Simultaneous release of gamete bundles of the same colony as in (a)



Diadema is the first marine species affected by mass mortality to have been monitored continuously for over 10 years.[11] The data, from both Panama and Jamaica, indicate that a one-time historical event can not only reduce the density of a previously abundant species throughout a whole region but also maintain it at constant low levels for a long time. This occurs even though the affected species is known for high fecundity and planktonic larvae. These characteristics are thought to reduce the chance of catastrophic mortality and extinction. It is possible that the high pre-mortality *Diadema* densities on some reefs were a recent phenomenon, perhaps a side-effect from man's over-fishing of its predators and competitors. However, historical information on the composition of most communities is lacking. Therefore, we cannot be sure that currently rare species may not always have been rare. Rarity of a species may not be due to any continuing process (such as competition or predation), but rather because of some catastrophe similar to that of *Diadema* in their past. The only way to evaluate the potential importance of historical events is through long-term studies of their consequences, so that their persistence can be assessed.

Figure 9
Juvenile Carribean black sea urchin,
Diadema antillarum



BIOGEOGRAPHY OF REEF FISHES

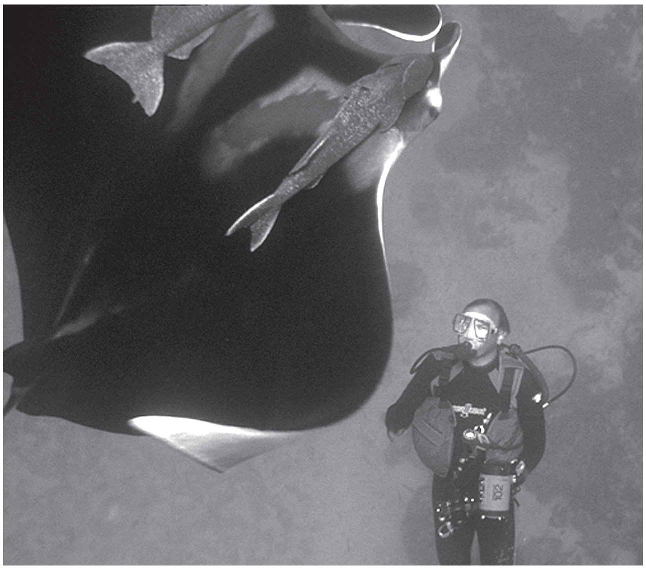
Populations of individual species of most reef fishes are generally thought to 'operate' on large spatial and temporal scales, due to a fundamental characteristic of their life cycles – the production of pelagic larvae. The larval life lasts weeks to months and begins as a relatively passive particle (an egg or a 1–2 mm swimming larva that has every chance of being carried well away from its natal reef). Consequently, larvae from one reef seem likely to seed populations on other reefs, and populations of reef fishes tens to thousands of kilometres apart may have strong demographic and genetic connections.

While most species of coral reef fishes have broad distributions (hundreds of thousands of square km), a very few occur only on single, small, isolated tropical islands.[12] Such small-island endemics may provide important information about the long-term maintenance of reef fish biodiversity precisely because they exist on mere specks of habitat for very long time periods (100,000–1,000,000s of years). If such species (or their island environments) do not have special life-history attributes that facilitate long-term persistence then reef fishes whose populations operate on large spatial scales also may be quite capable of surviving severe, widespread population decline and habitat stress.

Ross Robertson's underwater research projects to investigate the biological characteristics of small-island endemics in the tropical eastern Pacific have dived the Revillagigedos Islands, Clipperton Island, Cocos Island, the Galapagos Islands and Malpelo Island.[13] Clipperton Island, the only atoll and the largest coral reef in the eastern Pacific, is the most isolated reef in the tropical Indo-Pacific (950 km from the nearest shoals, Figure 10). It has a depauperate fish fauna (98 shorefish species), including a relatively large number of endemics: eight species from seven families (squirrelfishes, groupers, angelfishes, damselfishes, wrasses, blennies and gobies) that have a range of adult and larval ecologies. Population sizes of adult Clipperton endemics were estimated to range between 100,000 and 3,000,000. These are remarkably small populations for short-lived marine organisms that produce pelagic larvae. Mainland congeners of the endemics probably have populations about a thousand times as large. Recruitment of pelagic larvae of reef fishes often fluctuates considerably over time. Populations of short-lived species are more susceptible to local extinction from short-term recruitment failures. Interestingly, most Clipperton endemics are relatively small and thus appear to be short lived. Otoliths (ear bones) have growth rings that form on different time scales (daily, lunar cyclic, seasonal) and can be used to determine the age and growth rate of individuals, and population age structure and longevity.

The loss of endemics' larvae from Clipperton represents an extinction risk. Successful endemics have adaptations that aid the retention of their larvae near the island. Unique oceanographic characteristics may also aid larval retention. For species with planktonic eggs this factor is most acute in that released eggs are completely passive for the first 24 hours of their pelagic life. Species that have benthic eggs, on the other hand, release swimming larvae that should have some ability to resist offshore loss.

Figure 10
Smithsonian scientific diving officer (the author) 'sampling' manta rays at Clipperton Atoll



GEOLOGICAL HISTORY OF CORAL REEFS

Ian Macintyre of the National Museum of Natural History studies the recent history of coral reefs, particularly in the Caribbean region, by collecting cores from these reefs with a diver-operated drill. This sample of recent history (the past 18,000 years) represents the interval since the earth's last major glaciation. In this recent period, sea level has risen about 100 m, because of the runoff from melting ice sheets.

In the 1960s, modern coral reefs were considered immature, thin growths having inherited topographic relief. Since then, many coral reef core-drilling projects have brought new information to light about reef history.[14] Many reefs of the western Atlantic have an impressive record of Holocene accumulation, in terms of both the amount and duration of deposition.

A series of holes can be drilled along transects across modern coral reefs by a three-man dive team operating a submersible hydraulic drill (Figure 11). The resulting coral reef cores produce valuable data on reef community succession, rate of framework construction, and post-depositional processes for interpretation by coral reef geologists.

Core drills have a 0.6-metre core barrel attached to the wrench. The drilling unit weighs about 68 kg and can be handled easily by two science divers for shallow penetration such as the coring of an individual coral head. A tripod-winch assembly must be used, however, when working with the larger 1.5-metre core barrel and additional drill pipes. After every 1.5 m of penetration, the core barrel is retrieved and the core removed from the inner barrel. Under ideal conditions a 12 m core can be taken in about two days. A typical Caribbean fringing reef is dominated by *Acropora palmata*, with a mixed coral-head community on its outer slope. As the reef kept pace with the rising sea level, it formed a thick structure that masked the relief of the erosional surface on which it was established and began to construct its own topographic relief. When the rise in sea level started to subside, about 3,000 to 4,000 years ago,

Figure 11
Hydraulic core drilling of large coral head in Panama

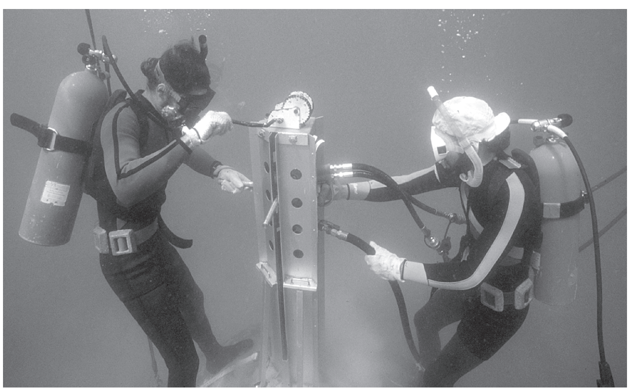


Figure 12
Profile of typical Caribbean reef face from coring data

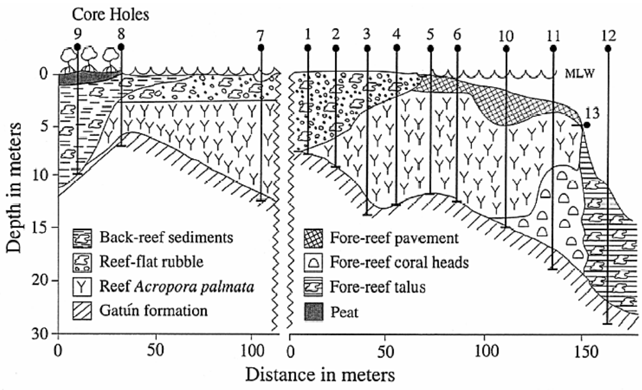
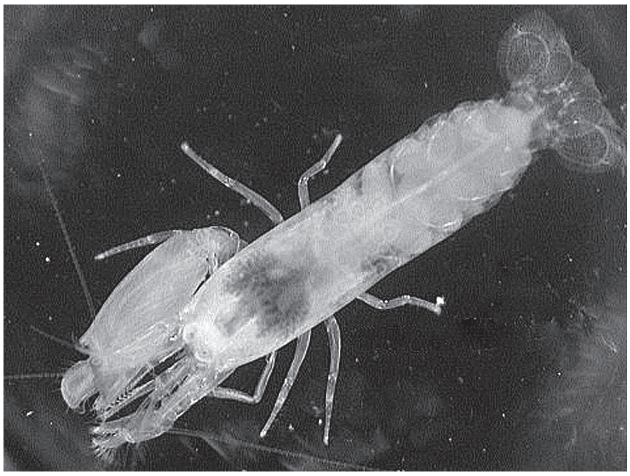


Figure 13
Belizean sponge-inhabiting snapping shrimp, ***Synalpheus regalis***



vertical development of the reef became restricted. At the same time, a loose sediment apron formed in the fore reef, and restricted lateral reef growth. The encroachment of mangroves over the back-reef sediments, absence of present-day active framework construction, and thick talus deposits on the fore-reef slope all indicate that a fringing reef has passed the climax of its development (Figure 12).

SPONGE-INHABITING SHRIMP (Figure 13)

Emmett Duffy's underwater study of a sponge-inhabiting shrimp (*Synalpheus regalis*) confirmed eusociality, an advanced social structure, for the first time in a marine animal.[15] This marine model provides competition for land-bound ants and airborne bees as a suitable subject for the study of cooperative animal societies in which queens rule.

CORAL DECLINE

A monitoring programme was established to quantify the long-term effects of temperature change on the distribution and progress of black-band disease in reef corals. A bleaching event in 1998 killed almost all the corals in the Pelican Cays, and those in the surrounding lagoon area.[16] A two-year scientific diving project at Cayos Cochinos, Honduras, documented the vigorous recovery process of coral reefs after Hurricane Fifi and the enforcement of a ban on all types of indigenous fishing pressures.[17]

The effects of oil spills on reefs

Marine environments are subject to man-made disasters. The escape of 100,000 barrels of oil into the mangroves and reefs of Bahia Las Minas (Caribbean) has had unexpectedly prolonged effects.[18] Oil seeps into the sediments around mangroves and returns to coat the coral reefs year after year as heavy rainfalls (exacerbated by the effects of deforestation) slowly wash it out (Figure 14). The skeletons of corals record the history of acute disasters as well as chronic stresses. X-ray analyses of corals undertaken in response to the oil spill document a worrying decline in coral growth over the past century.

Diving education and outreach

For former divers or non-divers, the closest one might come to reminiscing about the underwater world or contemplating dive training certification is to visit the Smithsonian's 3-D IMAX film *Galapagos*, a virtual ticket to the underwater world. June and July of 1998 was spent aboard the Harbor Branch Oceanographic Institution's *R/V Seward Johnson*, complete with underwater film crew, scientific staff and the *Johnson Sea-Link* submersible (Figures 15 and 16). Several of the Galapagos Islands were visited, but most spectacular were Wolf and Darwin, the northernmost islands. The El Niño conditions of 1998, a tragic ultralight flying accident, and the technological difficulties of filming with a 1,700-pound underwater 3-D IMAX camera and housing made it necessary to reshoot certain sequences in February and March, 1999.

Other Smithsonian educational products available to the general public and marine scientists alike are in the form of field guides, electronic interactive identification keys, and natural history lessons disguised as cookbooks.[19–21]

Conclusions

The Smithsonian Marine Science Network and the Scientific Diving Program provide the facilities and support for the efficient conduct of underwater research. The primary objective of the scientific diving effort is the advancement of science. The deliverables are peer-reviewed publications and public outreach/education programmes. The Smithsonian supports an extensive array of underwater research projects involving scientific diving that address many of the most pressing environmental and biodiversity issues in marine ecosystems. More complete information can be found on the Smithsonian web site: Smithsonian Scientific Diving Program (<www.si.edu/dive>) and the Smithsonian Marine Science Network (<www.si.edu/marinescience>).

Figure 14
Galeta reef oil spill

Figure 15
Scientist and cinematographer with underwater 3-D IMAX camera in the making of *Galapagos*

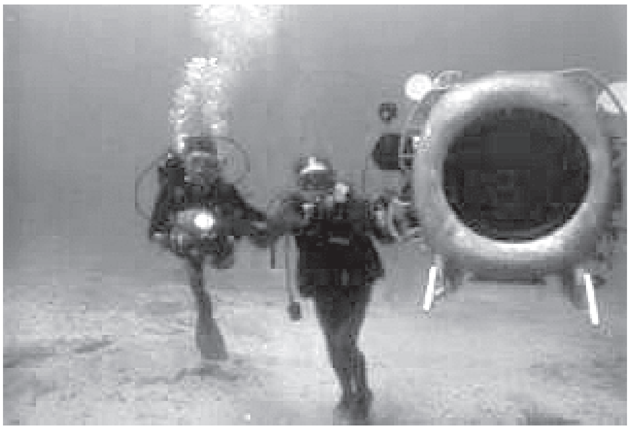
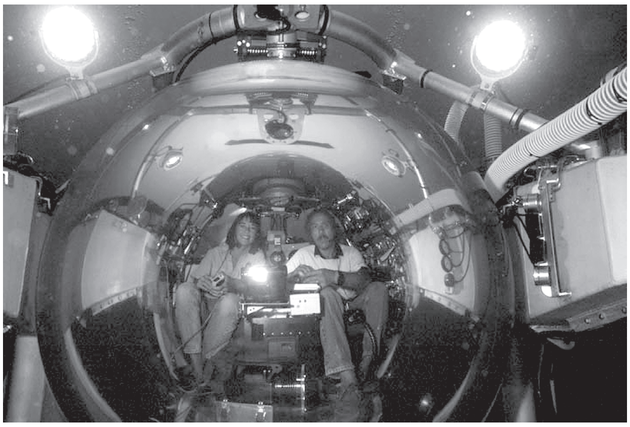


Figure 16
***Johnson Sea-Link* submersible used in the Galapagos Islands to maximum depths of 1,000 msw, resulting during 15 dives in the discovery of 15 marine species new to science**



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Credit card facilities are not available for this.

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The USA scientific diving medical and safety experience

Michael A Lang

Key words
Scientific diving, research, operations – diving, medicals – diving, standards, safety

Abstract

(Lang MA. The USA scientific diving medical and safety experience. *SPUMS J*. 2005; 35: 154-61.)
The scientific diving community has very effectively used scuba as a research tool for over 50 years, since the first programme was established at the Scripps Institution of Oceanography. Lang and Vann published decompression sickness incidence rates that were by a factor of 10 lower than those for recreational diving and commercial diving. This is, in part, due to thorough medical, training and operational standards and programmatic supervision of relatively conservative diving activities. Safety considerations are of primary concern for the diving programmes and regulations are promulgated by the underwater scientists who live by them. This community has also been proactive over the last 15 years in addressing physiological and operational questions related to diving that directly impact the safety and health of the scientific diver. The results of the scientific diving safety projects have benefited the recreational diving community in many ways as evidenced by the incorporation of consensus guidelines and operational practices into recreational diver training curricula and operations. Scientific research objectives, whether through mensurative or manipulative experiments, in many instances could not have been accomplished without scientific diving techniques, as evidenced in materials and methods sections of peer-reviewed published literature. At some point in the future, decompression, dive training, and medical issues may no longer be of major concern to scientists, as emerging technologies develop. In the meantime, the investigation of many topics of current scientific interest, including marine biodiversity, coral-reef health, sea-level change and global warming, largely depends on placing the trained scientific eye under water to sample, record and interpret the underwater environment.

Introduction

The purpose of a research diving project is the advancement of science. Scientific divers, by the very nature of their activities, use scientific expertise in studying the underwater environment and, therefore, are scientists or scientists-in-training. The tasks of a scientific diver are those of an observer and data gatherer who uses scuba diving as a research tool. Information and data resulting from a scientific project usually are disseminated in a technical document or peer-reviewed research publication. 'Scientific diving' is defined by the Department of Labor's Occupational Safety and Health Administration (OSHA) as "*diving performed solely as a necessary part of a scientific, research, or educational activity by employees whose sole purpose for diving is to perform scientific research tasks*."[1] Scientific diving does not include performing any tasks usually associated with commercial diving such as: placing or removing heavy objects under water; inspection of pipelines and similar objects; construction; demolition; cutting or welding; or the use of explosives.

The scientific diving programmes in the United States can be broadly categorised into three groups: those of research institutions (predominantly research); public and private universities, museums and aquaria (predominantly education and teaching, and research); and consulting companies (predominantly contractual environmental, geological and archaeological investigations). The current scientific diver population in the United States is estimated at 4,000 individuals. A minority of these are long-term, career scientific divers (e.g., federal employees, university professors) who may be considered in the average age category of 40+ years. At the university level, the turnover of scientific divers can be rather high as evidenced by undergraduate students enrolled in diving courses, research technicians on grant funds, or students in master's or doctoral programmes. This population tends to be in the age category of 18–34 years. An upper age limit for scientific diver certification does not exist; the lower limit is generally 18 years of age. Of the total scientific diver population, approximately one quarter is estimated to be female.

The American Academy of Underwater Sciences (AAUS) publishes *Standards for scientific diving certification and operation of scientific diving programs*.[2] The purposes of this document are to ensure that all scientific diving is conducted in a manner that will maximise protection of scientific divers from accidental injury and/or illness and to set forth standards for training and certification that will allow a working reciprocity between organisational member institutions that adhere to them. This document sets minimum standards for AAUS-recognised scientific diving programmes, the organisation and conduct of these programmes, and the basic regulations and procedures for safety in scientific diving operations. The AAUS standards are generally considered the standard of practice for scientific diving in the US.

Diving medical surveillance

The employer determines that scientific divers who are exposed to hyperbaric conditions have passed a current diving medical evaluation and have been declared by the examining physician to be medically fit to engage in diving activities as may be limited or restricted in the scientific diver medical certification. All medical evaluations are performed by, or under the direction of, a licensed physician of the applicant-diver's choice, preferably one trained in diving/undersea medicine. The diver must be free of any acute or chronic disabling disease or condition contained in the list of conditions by Bove for which restriction from diving may be recommended.[3] There currently are no fitness standards *per se* for scientific divers other than those imposed during the initial scientific diver training course, which include in-water time/distance parameters for swimming, or a stress tolerance test prescribed by a physician based on coronary artery disease risk-factor screening.

Medical evaluations are completed before a diver may begin diving; thereafter, at five-year intervals up to the age of 40, every three years after age 40, and every two years after age 60 (Table 1). Any major injury or illness, or any condition requiring hospital care requires diving medical clearance. If the injury or illness is pressure related, the clearance to return to diving must be performed by a physician trained in diving medicine. Diving medical evaluations conducted initially and at the interval frequency specified above consist of the following: a diving medical history, a diving medical examination, and completion of a scientific diver medical certification by the examining physician.

Diver training

SCIENTIFIC DIVING AUTHORISATIONS

There are three types of scientific diving authorisations.

Diver-in-Training

This authorisation signifies that the diver has completed entry-level training requirements through a nationally or internationally recognised scuba certification agency (e.g., PADI, NAUI, SSI, BSAC) or scientific diving programme.

Scientific Diver

This certification is a permit to dive with compressed air within no-decompression limits of current US Navy dive tables or, if using an approved dive computer, within no-decompression limits specified by the dive-computer manufacturer. This permit is valid only while it is current and for the depth and specialty intended (see below).

Temporary Diver

This authorisation is issued only following a demonstration of the required proficiency in diving and if the person in question can contribute measurably to a planned dive. Temporary diver authorisation is restricted to the planned diving operation under the host institution's auspices and complies with all other scientific diving policies, regulations and standards, including medical requirements.

DEPTH CERTIFICATIONS

The scientific diving community has long adhered to a proven experience-accumulation schedule. Depth certifications provide a mechanism by which diving experience may be gathered incrementally. The Scientific Diver certification authorises the holder to dive to a specific depth as indicated on the approved dive plan. A diver shall not exceed his/her depth certification, unless accompanied by a diver certified to a greater depth. Under these

Table 1
Laboratory requirements for diving medical evaluations and intervals (ECG – electrocardiogram)

	Initial examination Age in years		**Re-examination intervals Age in years (interval)**		
	< 40	**> 40**	**< 40 (5 yrs)**	**> 40 (3 yrs)**	**> 60 (2 yrs)**
Medical history	X	X	X	X	X
Physical exam (emphasis on CNS and otological components)	X	X	X	X	X
Chest X-ray	X	X			
Resting EKG	n/a	X			
Spirometry	X	X			
Haematocrit or haemoglobin	X	X	X	X	X
Urinalysis	X	X	X	X	X
Any further tests deemed necessary	X	X	X	X	X
Coronary artery disease risk-factor assessment including lipid profile and diabetic screening	n/a	X	n/a	X	X
Exercise stress testing (if indicated by risk-factor analysis)	n/a	X	n/a	X	X
Resting ECG	n/a	n/a	n/a	X	X

circumstances the diver may not exceed his/her depth limit by more than one step. Diving with compressed air is not permitted beyond a depth of 58 metres' sea water (msw).

- Certification to depth of 9 msw – This is the initial certification, approved upon the successful completion of the Scientific Diver training.
- Certification to depth of 18 msw – A diver holding a 9 msw certification card may be certified to a depth of 18 msw after successfully completing, under the supervision of a scientific diver certified to that depth or greater, 12 logged training dives to depths between 10 and 18 msw, for a minimum total time of four hours.
- Certification to depths of 30 msw and 40 msw – A diver holding a 18 msw certification may be certified to depths of 30 and 40 msw respectively, by logging four dives near the maximum depth, and successfully completing an approved check-out dive.
- Certification to depths over 40 msw – A diver may be certified to depths of 45 and 58 msw by logging four dives near each depth, and successfully completing an approved check-out dive.

Dives are planned and executed under the close supervision of a scientific diver certified to these depths. The diver also needs to demonstrate knowledge of the special problems of deep diving, and of special safety requirements.

DIVING SPECIALTIES

Diving specialties require additional training and approval. Scientific Diver certification is a prerequisite for engaging in the following specialties: decompression diving, surface-supplied diving, mixed-gas or oxygen-enriched air (nitrox) diving, semi- or closed-circuit rebreather diving, lock-out and saturation diving, blue-water diving, drysuit diving, overhead environment (ice, cave or wreck) diving, altitude diving, and diving with dive computers as the sole source for monitoring decompression status.

SWIMMING EVALUATION

The applicant for training performs the following tests, or their equivalent, without swim aids:

- underwater swim for a distance of 25 m without surfacing
- 400-metre swim in less than 12 minutes
- 10-minute water tread (or two minutes without the use of hands
- transport of another person of equal size for a distance of 25 m in the water.

SCIENTIFIC DIVER TRAINING

The 100-hour Scientific Diver training course consists of theoretical training, practical skills training in confined water, and completion of 12 supervised open-water dives in a variety of dive sites for a minimum cumulative bottom time of six hours.

CONTINUATION OF CERTIFICATION

During any 12-month period, each certified scientific diver must log a minimum of 12 dives, including two dives within the certified depth range. Divers certified to 48 msw or deeper may satisfy these requirements with dives over 40 msw. If no dive is made for a six-month period, a check-out dive must be made. Once the initial Scientific Diver certification requirements are met, divers whose depth certification has lapsed due to lack of activity may be requalified. If a scientific diver's certification expires, is suspended or revoked, he/she may be recertified after complying with such conditions as the scientific diving programme may impose.

Operational procedures

DIVING SUPERVISION

Diving Officer (DO)

The DO has full responsibility and accountability to the Diving Control Board (DCB) in all operational, diving and safety matters. The DO is appointed by the appropriate administrator on the recommendation of the DCB; is a certified scientific diver; is certified by a nationally recognised scuba certification agency to teach basic and advanced scuba diving courses; and, is responsible for the conduct of the diving programme. The DO also oversees scientific diving activities, and ensures compliance with all diving policies, requirements and procedures established in the diving safety manual. The DO is responsible for maintaining diver and medical certification records and dive logs, and has the unilateral authority to suspend diving operations or scientific divers whose diving activities he/she considers unsafe and refer such actions to the DCB.

Lead Diver

For each dive, one scientist is designated as the Lead Diver, who is present at the dive location during the entire diving operation. The Lead Diver is responsible for coordination, briefing, dive planning, and emergency equipment and procedures.

Individual scientific diver's responsibilities

The scientist initially submits a Scientific Diver application to the DO and obtains a Scientific Diver medical certification. The scientist must maintain him/herself in good physical condition and at a high level of diving proficiency commensurate with the frequency, scope, and type of diving activity being undertaken. The individual has the right to refuse to dive if in his/her judgment the conditions are unsafe or unfavourable for the type of diving operations planned; for any reason he/she believes his/her diving participation might jeopardise human life; he/she is not in proper physical or mental condition; and/or, he/she believes the scuba equipment to be used is faulty.

Each scientific diver receives current emergency-care training, has maintenance performed on their scuba equipment annually and conducts a pre-dive functional check of diving equipment. The diver is responsible for terminating the dive while there is sufficient cylinder pressure to permit a safe ascent to the surface, including a safety stop. The diver submits a dive plan for DO approval prior to engaging in any diving activity. Dive log sheets or dive files from down-loading dive computers are periodically submitted to the DO to monitor diving activities. The ultimate responsibility for personal safety and compliance with the diving safety manual regarding a planned diving operation is borne by the diver.

DIVING EQUIPMENT

Each scientific diver wears the following equipment: mask and fins (snorkel is optional), regulator and alternate breathing source, scuba cylinder, underwater timing device, depth indicator and pressure gauge. An approved dive computer is authorised after the diver receives training in its use and is preferable to monitoring decompression status with dive tables. A buoyancy compensator that provides the diver with the capability of attaining and maintaining positive buoyancy is equipped with a low-pressure power inflator. A dive knife, sharp enough to cut through monofilament line, and appropriate thermal insulation must also be worn.

DIVING PROCEDURES

All scientific diving is planned and executed in such a manner as to ensure that every diver maintains constant, effective communication with at least one other comparably equipped, certified scientific diver in the water. This buddy system is based upon mutual assistance, especially in the case of an emergency. If loss of effective communication occurs within a buddy team, all divers surface and re-establish contact. A dive flag is displayed prominently whenever diving is conducted.

Scientific diving is not conducted unless procedures have been established for emergency evacuation of the diver(s) to a hyperbaric chamber or appropriate medical facility, and these procedures have been approved by the DO. Emergency-care training (CPR, oxygen administration, first aid, field neurological evaluation and dive rescue) is requisite for Scientific Diver certification. First-aid and emergency oxygen kits are present at the dive location. Hyperbaric chambers, as a rule, are not required to be in close proximity to the diving operation. Where an enclosed or confined space is not large enough for two divers, a diver is stationed at the underwater point of entry and an orientation line is used.

In the case of an asymptomatic diver diving within the US Navy tables or dive computer no-decompression limits during the previous 48 hours, there should be a minimum 12-hour delay prior to flying. The longer the diver delays an ascent to altitude, the lower the probability of onset of symptoms of decompression sickness (DCS).

Scientific dives are planned around the competency of the least experienced diver. Before conducting diving operations, the Lead Diver for a proposed project submits to the DO a dive plan for approval that lists all divers' qualifications, emergency contact information, an emergency plan, the nearest hyperbaric chamber location and method of transport to be used, the Divers Alert Network (DAN) emergency phone number, the location and approximate number of proposed dives (including estimated depths and bottom times), the proposed work, equipment and boats to be employed, and any hazardous conditions anticipated.

Scientists log dives made under the auspices of their employer and the logs are periodically submitted to the DO for review. If pressure-related injuries are suspected, or if symptoms are evident, the following additional information is recorded and retained by the DO with the record of the dive for a period of five years: complete accident report, description of symptoms (including depth and time of onset) and description and results of treatment. The DO maintains permanent records for each scientific diver certified and retains the following: scientific diver medical certifications (five years), records of dives (one year, except five years where there has been an incident of pressure-related injury), pressure-related injury assessment (five years) and equipment maintenance records (current entry).

All diving accidents requiring recompression or resulting in moderate or serious injury are reported to the DO. The DCB records and reports occupational injuries and illnesses as established by OSHA: the occurrence of any diving-related injury or illness that requires any dive team member to be hospitalised for 24 hours or more, or after an episode of unconsciousness related to diving activity, or after treatment in a recompression chamber following a diving accident.

COMPRESSOR SYSTEMS AND BREATHING-AIR QUALITY

Gas analyses and air tests are performed on each breathing-air compressor at regular intervals of no more than six months. The results of these tests are entered into a log by the DO who also records hours of operation, repair, overhaul, filter maintenance and temperature adjustment for each compressor. Breathing air for scuba meets the Grade E specifications as set forth by the Compressed Gas Association (CGA Pamphlet G-7.1) and referenced in OSHA 29 CFR 1910.134 (Table 2).

Low-pressure compressors used to supply air to the diver are equipped with a volume tank with a check valve on the inlet side, a pressure gauge, a relief valve and a drain valve.

Table 2
Compressed Gas Association Grade E specifications for scuba breathing-air quality (THC – total hydrocarbon content; ppm – parts per 10^6)

Component	Specification
Maximum O_2	20–22%
Maximum CO_2	500 ppm
Maximum CO	10 ppm
THC	25 ppm
Water vapour	67 ppm
Dew point	-50 °Fahrenheit
Condensed hydrocarbons	5 $mg.m^{-3}$
Odours	None

Compressed-air systems over 500 psig (34 bar gauge) have slow-opening shut-off valves and all air-compressor intakes must be located away from areas containing exhaust fumes or other contaminants. These compressors are operated and maintained according to the manufacturer's specifications.

Equipment used with oxygen or mixtures containing over forty per cent (40%) by volume oxygen are designed, dedicated and maintained for oxygen service. Components exposed to oxygen or mixtures containing over forty per cent (40%) by volume oxygen are cleaned of flammable materials before being placed into service. Oxygen systems over 125 psig (8.5 bar gauge) must be equipped with slow-opening shut-off valves.

Scientific diving safety

The scientific diving community has a traditionally proactive record of furthering diving safety. The first scientific diving safety programme was established at the Scripps Institution of Oceanography in 1954 in preparation for the Capricorn Expedition to the South Pacific. This programme pre-dated the national recreational scuba training agencies by five years. Most scientific diving programmes today trace their ancestry to common elements of the original Scripps diving programme.

Diving safety programmes can be generalised as fulfilling two purposes. The first being a research-support function, which assists the diving scientist with specialised underwater equipment, advice, and diver support to assist in fulfilling the scientific objectives of the diving project. The second is a risk-management function that protects the safety and health of the individual scientist, and the employing organisation from excessive liability exposure, by providing state-of-the-art diving equipment, breathing air, training and medical surveillance programmes.

More recently, ongoing scientific diving safety research has been conducted to consider a more effective means of monitoring decompression status using dive computers.[4] DCBs approve specific makes and models of dive computers that may be used as a means of determining decompression status. Each diver relying on a dive computer to plan dives and indicate or determine decompression status must have his/her own unit and pass a practical and written training session. On any given dive, both divers in the buddy pair follow the most conservative dive computer. If the dive computer fails at any time during the dive, the dive is terminated and appropriate surfacing procedures are immediately initiated. After such a failure, a scientific diver is not allowed to dive for 18 hours before activating a dive computer to control his/her diving and, once in use, it is not switched off until complete out-gassing has occurred. Multiple deep dives and/or decompression dives with dive computers require careful consideration.

Lang and Egstrom investigated the slowing of ascent rates and the performance of safety stops to provide scientific divers with a greater margin of decompression safety.[5] It has long been the position of the American Academy of Underwater Sciences that the ultimate responsibility for safety rests with the individual diver. Scientific divers are trained to slow and control their ascents, of which buoyancy compensation can be a significant problem. This is fundamental to safe diving practice. Before certification, the diver demonstrates proper buoyancy, weighting and a controlled ascent, including a 'hovering' stop. Ascent rates are controlled at a maximum of 9 $msw.min^{-1}$ from 18 msw and are not to exceed 18 $msw.min^{-1}$ from depth, at the rate specified for the make and model of dive computer or table being used. Scientific diving programmes require a stop in the 3–9 msw zone for three to five minutes on every dive.

Scientific divers using drysuits receive additional practical training in their use. Drysuits must have a hands-free exhaust valve and buoyancy compensators a reliable rapid exhaust valve that can be operated in a horizontal swimming position. A buoyancy compensator is required with drysuit use for ascent control and emergency flotation. In the case of a runaway ascent, breathing 100% oxygen above water is preferred to in-water air procedures for omitted decompression.

The next phase of this scientific diving safety project was the consideration of the physiological aspects of multi-day, repetitive diving.[6] Although diving is a relatively safe activity, all persons who dive must be aware that there is an inherent risk to this activity. In 1992, the risk of decompression illness in the United States was estimated at one to two incidents per 1,000–2,000 dives for the commercial diving sector, two incidents per 10,000 dives for recreational diving activities and 1 incident in 100,000 dives for the scientific diving community. Scientific diving programmes provide continuous training, recertification and dive-site supervision, which help to maintain established safe diving protocols (Table 3). Recreational divers, who may lack such direct supervision, need to be aware of their need to stay within established protocols, especially when making repetitive dives over multiple days, during which the risk of DCS may be higher.

Table 3
2003 summary of scientific diving of the American Academy of Underwater Medicine

	Total scientific dives			
Organisations	**Dives**	**Minutes**	**Divers**	**Incidents**
76	104,921	4,133,207	4,478	2

	Dives by depth range			
Depth (msw)	**Dives**		**Divers**	**Incidents**
0–9	65,355		2,508	1
9–18	28,650		1,881	0
18–30	8,650		985	1
30–39	1,524		451	0
39–45	459		103	0
45–57	147		54	0
57+	136		28	0

	Dives	**Minutes**	**Divers**	**Incidents**
Dives by classification				
Scientific	90,014	3,695,919	3,032	2
Training/ proficiency	14,907	437,288	1,809	0
Dives by mode				
Open circuit	95,492	3,737,229	3,742	2
Hookah	5,949	313,190	415	0
SSBA	3,035	70,192	194	0
Rebreather	445	12,596	31	0
Dives by breathing gas				
Air	95,295	3,701,615	3,708	1
Nitrox	9,470	420,276	770	1
Mixed gas	156	11,316	27	0
Dives by planning method				
Dive tables	47,993	1,803,510	1,852	1
Dive computer	48,345	2,131,931	2,160	1
PC-based software	107	7,357	20	0
Dives by specialty				
Decompression	435	40,520	75	0
Overhead	600	28,790	78	1
Blue water	366	12,027	80	0
Ice/polar	708	22,730	80	0
Dives during saturation	179	28,318	11	0
Aquarium	44,389	1,043,435	868	0

Increasing knowledge regarding the incidence of DCS indicates that our ability to predict the onset of DCS on multi-level, multi-day diving is even less sensitive than our ability to predict DCS on single square-wave dives. There appears to be good evidence that there are many variables that can affect the probability of the occurrence of DCS symptoms. The ability to mitigate these variables through education, good supervision and training appears to be possible for variables such as dehydration, lack of fitness, rapid ascents, undue fatigue, etc., and preventive measures to minimise these factors are continuously promoted. Scientific divers are subject to a host of specific conditions that may increase risk if precautions are not taken. There is adequate technical support for the use of oxygen-enriched air (nitrox) and surface-oxygen breathing in scientific diving where higher gas loadings are anticipated in multi-level, multi-day dives. We must continue to remember that DCS is generally recognised as a probabilistic event, which tends to lean the scientific diving community towards a more conservative diving position.

Table 4
Data set submitted to OSHA covering years 1965–1981, leading to exemption of scientific diving from commercial diving regulations

Scientific diving		
Certified scientific divers		5,441
Dives to depth	10 m	172,546
	20 m	154,751
	30 m	40,199
	40 m	7,002
	50 m	3,202
	60 m	917
	60 m+	40
Total no. dives		380,295
No. decompression dives		1,638
No. pressure accidents		18
No. deaths		4
Scuba diving training		
No. classes		835
No. trainees		18,421
No. training hours		242,979
No. training dives		57,886
Max. training depth (m)		60
No. certified scuba divers		13,786
Programmes with decompression chamber		4

The scientific diving safety record is remarkably clean. The national scientific diving statistics snapshot of 2003 (Table 3) is representative of the period from 1981–2003. The data set submitted to OSHA that resulted in the scientific diving exemption from commercial diving regulations covered the years 1965–1981 (Table 4). Eighty-eight diving programmes submitted information to the national scuba safety survey conducted at that time through UCLA.

A comparative analysis of pre-and post-1980s diving incidents becomes increasingly difficult due to the lack of descriptive data and the changing ‘incident’ collection parameters. ‘Pressure accidents’ from before the 1980s do not solely represent the number of DCS presentations, but also include incidents of other reported barotrauma. That period possibly also represents a significant amount of under-reporting of mild DCS, a period when mild aches and pains associated with diving were accepted as minor miseries of life. Since the early 1980s, scuba divers have been oversensitized to recognition of DCS signs and symptoms, resulting in a significant emphasis on diving safety training in CPR, field neurological examinations, first aid, and oxygen administration. The early reporting of potential DCS and activation of emergency plans coupled with oxygen administration unquestionably results in high percentages of resolution. However, once a diver enters the decision-making tree, it is difficult to extract the number of cases of non-DCS, because invariably they end up at the chamber where precautionary treatment is more often than not provided. This results in over-reporting of DCS cases. Scientific diving DCS data collection criteria need to be refined for a better approximation of rates. No detailed information is available on the four deaths from 1965–1981. Since 1981, there have been at least three scientific diving deaths under the following circumstances: blue-water diving, under-ice diving, and missed decompression.

After 50 years, the DCS rate of 1:100,000 continues to appear acceptable within the scientific diving community. Compared with other sectors of the diving community, the recreational diving profiles most closely resemble those of scientific diving. However, the scientific diving incident rates are an order of magnitude lower, and we attribute this to thorough entry-level and continued training and supervision, and controlled medical and operational procedures. Incident rates in military and commercial diving communities are much higher, but, taking into account the commensurately riskier profiles, are efficiently handled with on-site chambers and diving medical personnel.

The order of dive profiles was investigated by Lang and Lehner, in part because of the difficulty for scientific divers to adhere to the 'dive progressively shallower' rule while on projects investigating coral reefs at varying transect depths.[7] More importantly, the genesis and physiological validity of the 'dive deep first' rule was in need of examination. Historically, neither the US Navy nor the commercial sector has prohibited reverse dive profiles. Reverse dive profiles are acknowledged as being performed in recreational, scientific, commercial and military diving. The prohibition of reverse dive profiles by recreational training organisations cannot be traced to any definite diving experience that indicates an increased risk of DCS. There is no convincing evidence that reverse dive profiles within the no-decompression limits lead to a measurable increase in the risk of DCS. Lang and Lehner found no reason for the diving communities to prohibit reverse dive profiles for no-decompression dives less than 40 msw and depth differentials less than 12 msw.

Oxygen-enriched air (nitrox) has been used in the scientific diving community since the early 1970s. Lang reports for entry-level, open-circuit nitrox diving, that there is no evidence that shows an increased risk of DCS with the use of oxygen-enriched air (nitrox) versus compressed air.[8] A maximum PO_2 of 162 kPa (1.6 ATA) is generally accepted based on the history of nitrox use and scientific studies. Routine carbon dioxide retention screening is not necessary for open-circuit, recreational nitrox divers. Oxygen analysers should use a controlled flow-sampling device for accurate mix analysis, which should be performed by the blender and/or dispenser and verified by the end user. Training agencies recognise the effectiveness of nitrox dive computers. For recreational diving with oxygen-enriched air, there is no need to track whole-body exposure to oxygen (e.g., oxygen toxicity units or unit pulmonary toxic dose); the 'CNS oxygen clock' concept is taught instead, based on NOAA oxygen exposure limits.[9] However, it should be noted that CNS oxygen toxicity could occur suddenly and unexpectedly. Based on history of use, no evidence is available to show an unreasonable risk of fire or ignition when using up to 40% nitrox with standard scuba equipment. The level of risk is related to specific equipment configurations and the user should rely on manufacturer's recommendations.

Operational guidelines for remote scientific diving operations were promulgated on a consensual basis by the senior practising scientific divers for blue-water diving by Heine, and polar diving operations by Lang and Stewart.[10,11]

Acknowledgements

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Inner ear decompression illness [Abstract]

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(Klingmann C. Inner ear decompression illness. *SPUMS J*. 2005; 35: 161. **Abstract only**)

Inner ear decompression illness (IEDCI) was first described in the 1970s in professional divers during and after deep mixed-gas dives. Until the 1990s inner ear symptoms in sport divers after diving were attributed to inner ear barotrauma, as IEDCI was thought to occur only in dive excursions deeper than 100 msw. During the 1990s several case reports were published attributing the development of isolated inner ear symptoms such as hearing loss, vertigo and tinnitus to decompression illness.

In 2001, Nachum et al presented 29 cases of IEDCI representing 26% of cases of severe decompression illness that had been treated during a 12-year period.[1] In 2002 our group presented the first case report in which an association between decompression illness and a right-to-left shunt could be shown.[2] In 2003, Cantais et al presented 34 divers with IEDCI out of 101 divers treated for DCI (mild and severe symptoms).[3] Further, they were able to demonstrate that the divers with IEDCI had a significantly greater prevalence of a right-to-left shunt than a control group of healthy divers. In 2003, we presented 11 further cases of sport divers with IEDCI, who were all positive for right-to-left shunting.[4]

IEDCI seems not to be a rare manifestation of decompression illness as previously thought but rather to occur regularly in sport divers. The symptoms and pattern of onset of IEDCI, and the differential diagnosis and treatment of IEDCI are explained. Furthermore, the different pathological mechanisms for IEDCI will be discussed; bubble arterialisation through a right-to-left shunt, local bubble growth because of local tissue inert-gas overload with respect to counter diffusion and central air embolism resulting from pulmonary barotrauma.

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Key words
Inner ear decompression sickness, patent foramen ovale (PFO), abstracts, meetings

Is oxygen toxicity in recompression treatments increasing and if so what are the possible relationships with changing diving and treatment practices? [Abstract]

Martin DJ Sayer and Colin M Wilson

(Sayer MDJ, Wilson CM. Is oxygen toxicity in recompression treatments increasing and if so what are the possible relationships with changing diving and treatment practices? *SPUMS J*. 2005; 35: 162. **Abstract only**)

Acute oxygen toxicity in divers being treated for decompression sickness using hyperbaric oxygen tables is rare (< 0.4% of all treatments undertaken at Dunstaffnage Hyperbaric Unit). When acute episodes do occur, they are distressing both to the patient and the attendant, may result in injury to either party and usually precipitate the cessation of treatment or transfer onto deep air-only treatment tables. A recent incident in a Scottish chamber will be used to illustrate the problems associated with an incident of acute oxygen toxicity. Analyses of presentation detail and treatment procedures demonstrate quite marked increases in the use of mixed gases in recreational diving:

- significant pre-presentation exposures to either oxygen-rich air or pure oxygen during either staged decompression or transfer to a recompression chamber
- increased use of modified (extended) treatment tables
- increased number of treatments per diver
- use of saturation treatments.

Although not recorded quantitatively, there is a subjective impression that the incidence of chronic oxygen toxicity is increasing in treated divers. A number of incident profiles are presented that collate the total oxygen doses to which divers are being subjected. There are significant changes occurring globally in diving practices. This account raises the possibility of altering the recompression treatment protocols for divers with significant pre-presentation exposures to oxygen.

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Key words
Oxygen, toxicity, decompression sickness, treatment, abstracts, meetings

Technical advances in UK scientific diving operations [Abstract]

Martin DJ Sayer

(Sayer MDJ. Technical advances in UK scientific diving operations. *SPUMS J*. 2005; 35: 162. **Abstract only**)

The introduction of new regulations in the UK governing all diving-at-work operations has had a significant influence on scientific diving practices.[1] The framework of the regulations is based on risk-assessment and minimum competency standards without being overly prescriptive. As a consequence, since their introduction, the new regulations have permitted much more flexibility to employ differing diving techniques and practices. However, there is now increased legal accountability placed on the structure and supervision of diving operations that, in turn, is affecting changes in how they are undertaken. Analyses of diving trends in the scientific sector demonstrate significant changes in practices over the past 35 years. These changes were driven predominantly by shifting patterns of scientific focus rather than being of any direct consequence of top-down regulation in response to any particular diving practices. In fact, the UK scientific sector possesses one of the best published diving safety records but there is now a requirement on any scientific institution undertaking diving to maintain best practice through a risk-management policy of continual review and evaluation of diving procedures. This account reviews the historical basis for changing practices in UK scientific diving in association with comparative analyses of other sectors. Advances in diving technology in the recreational, military and offshore sectors have increased the options by which scientific diving can be undertaken within the framework of the new regulations. These advances are reviewed and details of some of the evaluation programmes are given.

Reference

1 Sayer M. Assessing and managing risk in United Kingdom scientific diving at work operations. *SPUMS J*. 2004; 34: 81-7.

Martin Sayer is Head of UK National Facility for Scientific Diving, Dunstaffnage Marine Laboratory, Oban, Scotland.

Key words
Scientific diving, abstracts, meetings

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

Additional information

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

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

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

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

Key words
Qualifications, underwater medicine, hyperbaric oxygen, research

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Minutes of the SPUMS Committee telephone conference held on Sunday 10 April 2005

Opened: 0730 hr

Present: Drs R Walker (President), C Meehan (Secretary), M Davis (Editor), A Patterson (Treasurer), C Lee (Committee Member), D Smart (ANZHMG Representative), C Acott (Education Officer)

Apologies: Dr G Williams (Immediate Past-President)

1 Minutes of the previous meeting (October 2004)
The minutes of the previous meeting as circulated will be kept as a transcript of the meeting, documenting the original discussions. The minutes will be edited and formalised for printing in the Journal by Dr R Walker. Proposed Dr R Walker, seconded Dr A Patterson, carried.

2 Matters arising from the minutes
2.1 Update on the new website given by Dr R Walker. It is hoped that it will be up and running and able to be shown to members at the Annual Scientific Meeting. Dr Walker will also provide something for the June issue of the Journal regarding the website.

2.2 Update from the Editor, Dr M Davis
A full report will be given at the ASM. The Journal has moved its premises. There is no capital cost associated with this. Sarah is returning to the UK and so will only be able to assist with proof reading and editing by e-mail. There is no progress to report regarding the Editorial Board. The CD of journal articles which will be included with a new membership package will not be ready for distribution until 2007. The deadline for the June issue is 18 April and for the September issue 18 July. Dr R Walker has sent the speakers from the last ASM a letter regarding their outstanding papers.

2.3 Update from Education Officer, Dr C Acott
One further diploma awarded. Dr Acott suggests that in order to receive the diploma the candidate should have been an active member of SPUMS for a minimum of two years, and should publish their paper in the SPUMS Journal. Dr Acott will write to the SIG proposing this. Dr M Davis also proposed that there should be a fee for registering to do the diploma. Drs Acott and Davis will discuss this further.

2.4 Once the new SPUMS website becomes functional, we will need to review how SPUMS runs its administration. There will need to be a review of the contractual agreement with Mr S Goble.

2.5 The correct meaning of the three-year term for committee members was discussed. The actual wording in the constitution needs to be looked at carefully. The concept of three-year terms was that each member would remain on the Committee for a term of three years and not that an election of committee members be held every three years. There were different views regarding the interpretation of this.

3 Annual Scientific Meetings

3.1 2004 ASM Noumea final figures
The P&L needs to be adjusted to include the refunds sent to the registrants who left before the Gala Dinner.

3.2 2005 ASM, Coco Palm Resort and Spa, Maldives
There was discussion regarding the low numbers of registrants. This is assumed to be a result of the tragic Boxing Day Tsunami. There was discussion regarding the exchange-rate fluctuations. There will possibly be an adjustment regarding this as the exchange rate is now more favourable. The agenda for the AGM and the minutes of the last AGM will be printed in the conference booklet for convenience. Although the laptop and the projector are getting on in years, it was decided not to upgrade at this time. It was decided that the Treasurer will invoice Allways staff for their attendance at the social events. Mr Skinner has been informed regarding this.

3.3 Venues for future Annual Scientific Meetings to be discussed
To date neither a convener nor venue has been decided upon. In view of the rising expense of the offshore conferences, and the reduced numbers attending, the future format of the meeting needs to be discussed further. Dr R Walker has suggested that it may be time to consider changing the format to a shorter on-shore meeting for the educational component, followed by an optional diving component. Dr M Davis has suggested New Zealand as a possible venue for this concept.

4 Treasurer's report

Membership fee and joining fee to cover the journal CD discussed. The CD will probably not be available for this purpose till 2007 membership period. Dr A Patterson has recommended that the subscription fee remain the same for 2006.

5 Correspondence

5.1 Letter from Dr R Williams regarding reduced registration fee for retired doctors. This will be discussed further at the face-to-face meeting later this year. A suggestion is that a long-term member of SPUMS who retires could continue their membership as an associate. At the conferences the full registrant fee covers the cost of the guest speaker, and so any member who wishes to attend the lectures needs to contribute to this cost.

5.2 Letter received by Dr R Walker regarding the alleged inappropriate behaviour of a diving doctor. Medicolegal advice will be sought re this matter.

6 Other business

6.1 To date there are no nominations for the positions of President or Secretary. Dr C Acott has expressed a willingness to stand for President. Dr R Walker has suggested Dr S Sharkey for the position of Secretary. Nominations will also be taken from the floor at the ASM for these positions and for one position as committee member.

6.2 A date needs to be set for the face-to-face meeting held at the end of the year.

Closed: 0930 hr

Minutes of the informal SPUMS Committee telephone conference held on Sunday 22 May 2005

Opened: 0910 hr

Present: Drs C Acott (Chair/President), R Walker (Immediate Past-President), S Sharkey (Secretary), A Patterson (Treasurer), M Davis (Editor), G Williams (Public Officer), C Lee, D Vote (committee members)

Apologies: Dr D Smart (ANZHMG Representative)

1 The Chair thanked Dr Walker for her previous work as President of SPUMS.

2006 SPUMS Conference

2 Fiji was agreed by all as an appropriate venue for the next conference.
3 Dr Patterson agreed to act as Convenor for the conference and would welcome assistance and guidance from other members.
4 Suggestions for a theme were requested. Dr Walker passed on suggestion from this year's conference that a 'back to basics' theme would be welcomed. There was general endorsement of this including suggestion for workshop on basic airway skills, John Lippman demonstration of DAN equipment, sponsorship from Laerdal. Dr Richard Moon was suggested as a guest speaker who offered 'good value'.
5 Other matters discussed included current work in progress regarding formalising agreements with travel agents (Dr Walker to pass on documentation to Dr Patterson); intention to seek tenders for provision of travel services from several agents; business-class travel for guest speakers is not essential.

Face-to-face committee meeting

6 It was generally agreed that Sunday 31 July in Melbourne would be appropriate. A venue close to the airport would facilitate a day trip for those who travel interstate. Venue to be confirmed.
7 Minutes of the previous meeting and request for agenda items will be circulated in due course.

Other business

8 The review of amendments to the constitution requires completion prior to the next meeting. Committee members are encouraged to forward their input directly to Dr Davis by e-mail.
9 There was some confusion regarding advice provided by Dr Williams that amendments were required to be submitted to the Victorian authorities within 30 days, a deadline which has now passed. Dr Williams will clarify the implications with the authority and advise the Committee.

Closed: approximately 1000 hr

Undersea and Hyperbaric Medical Society

(Extracts from the award citations)

2005 Charles W Shilling Award presented to Associate Professor Mike Davis

This award is presented at the annual meeting for contributions of an outstanding nature to teaching, education and communication in diving medicine and related fields. Professor Davis has a long and distinguished career in diving and hyperbaric medicine, with a string of insightful and penetrating scientific works to his name. He has been the Medical Director of the Hyperbaric Medicine Unit in Christchurch, New Zealand, for many years, and in this isolated role has almost single-handedly battled to deliver high-quality medical education and resources to the community. Over the last three years he has taken on two further important roles. As Editor of the *SPUMS Journal*, Mike has raised the quality of local medical research, insisting on a raised level of scientific rigour so that the Journal is now eagerly awaited across the globe. Second, he is overseeing the first academic, university-based course in diving and hyperbaric medicine in the English-speaking world at Auckland University. This award is given in recognition of his long-standing commitment to teaching, research and practice in diving and hyperbaric medicine.

2005 Craig Hoffman Memorial Award presented to Dr David Smart

This award is presented at the annual meeting for David's contributions over the last 17 years to diving safety in the State of Tasmania, Australia, through the education of recreational and professional divers. In the late 1980s Dr Smart was instrumental in identifying a high rate of diver morbidity in Tasmania's salmonid aquaculture industry. He has been proactive in working with the industry to develop safer diving systems including improving training for professional divers, as well as safer tables for shallow bounce diving. His work has assisted the industry to achieve a 98% improvement in the incidence of decompression illness (DCI), preventing 150 divers per annum from the industry contracting DCI. He is currently validating the bounce diving decompression schedules set for the industry using Doppler assessment of decompression stress. He also remains active in teaching risk management to divers, working with government agencies, such as Standards Australia, in identifying and remedying areas of risk for divers.

SPUMS Annual Scientific Meeting Fiji, June 2006

3 - 10 June

The Pearl South Pacific

Pacific Harbour, Fiji

Theme: "Something old, something new..."

Guest Speaker: To be announced

Please make this ASM a resounding success with your attendance.
Those wishing to present a paper are invited to contact the Convenor.

Conference Convenor:
Dr Andrew Patterson

28A Roland Avenue, Wahroonga,
NSW 2076, Australia
Phone: +61-2-9489-1267; **Fax:** +61-2-9489-1237
E-mail: <a.j.patterson@exemail.com.au>

Conference attendees will receive CME points from relevant speciality bodies,
e.g., Royal Australian College of General Practitioners
Australian and New Zealand College of Anaesthetists
Other Colleges will usually recognise prior application

Geoff Long

Dr Geoff Long joined SPUMS in 1985 just in time to attend the ASM on Bandos in The Maldives. He enjoyed the diving, camaraderie and scientific programme so much that he went to Tahiti the following year. He became addicted, and has now attended 21 consecutive ASMs up to and including the meeting in The Maldives in 2005 – a clear record amongst Society members. On behalf of SPUMS and Allways Dive Expeditions the Convenor, Cathy Meehan, presented Geoff with a woodcarving of dolphins. Geoff lives on the far south coast of New South Wales where he is a general practitioner in Bega. Despite arthritic hips, he continues to dive year round, thanks to his understanding buddies who know he needs help putting on and taking off his fins. He is a keen underwater cine photographer and enjoys producing DVDs of his (most recent) SPUMS trips.

The SPUMS Hall of Fame

Previous SPUMS recipients of Undersea and Hyperbaric Medical Society Awards over the past decade have included (information taken from the UHMS web site):

2003	Oceaneering International Award	David Doolette
	Albert R Behnke Award	James Francis
2001	Albert R Behnke Award	Mike Bennett
1999	Charles W Shilling Award	Carl Edmonds
1997	Oceaneering International Award	Bob Wong
	Craig Hoffman Memorial Award	Bob Wong
1996	Charles W Shilling Award	David Elliott

The world as it is

Diving's 'black box' – the coronial system. A plea to rethink research into diving safety factors

Douglas Walker

Key words
Diving, accidents, deaths, investigations

The aviation industry has two important and effective methods of updating understanding of factors that reduce safety and may become critical to survival. It has a process for soliciting information on events that had a potential to result in an adverse outcome, and an active investigation of incidents where there has been a serious or fatal incident. The former scheme depends on a guarantee that there will never be action or charges as a consequence of such self-incrimination except where the problem revealed was caused by gross negligence. The similarities in the critical factors affecting safety in the aviation and diving environments have long been recognised. For this reason the development by the former discipline of a proactive attitude to improving safety has valuable lessons for the diving community. The principle of maintaining an active search for information relating to operational and systemic events with adverse potential has undoubtedly improved the safety of aviation.

It is common knowledge that the diving industry is efficient at keeping in-house most of the details of investigations into serious commercial diving incidents, using as the reason its valid fear of opening itself up to legal actions utilising the information in such reports. For similar reasons, instructor organisations refuse access to their data or to make available reports from their members of occasions where later legal actions could potentially result if the details were known, however remote the possibility. This attitude has expanded to a resistance to seeking information on incidents their members may have observed but which did not involve them. It is noteworthy that the legal profession continues to successfully claim the right to withhold documents from access by others but steadfastly refuses to permit a similar privilege to others.

There has arisen a further impediment to obtaining access to information: a rigid belief in the total confidentiality of personal data except through a restricted gateway guarded by an ethics committee. The decisions of such committees show a wide range of opinions in their interpretation of the concept of 'the public good' expected to result from permitting the requested access. In the real world of commerce and government business it is naive to believe that the conditions of access they impose are honoured.

Of primary interest to investigators of aviation fatalities are the 'black boxes' carried by all commercial planes. This approach to the problem has brought attention to systemic problems before they climax in the inevitable concordance of circumstances called 'an accident'. It allows analysis of the fatal final cascade of events. Mechanical as well as human factors are analysed in an unbiased manner. These data are fleshed out by seeking information from all other possible sources, including examination of the wreckage. The air-accident investigators' reports detail their findings and their conclusions concerning any changes needed to reduce the likelihood of future similar incidents. Any organisation or person ignoring such findings would find it difficult to justify failure to implement the advised action in a Court of Law if subsequently a similar accident occurred. Human nature is imperfect and experience shows that critical problems in aviation disasters were often a consequence of known but ignored non-fatal incidents, of tolerated unsafe practices.

In the diving context, the police investigation of diving-related deaths on behalf of the local coroner mirrors in many ways the aviation approach. Unfortunately the findings of the coroner are frequently unreported, and even more commonly have no apparent impact on the diving community. In the diving situation the findings might require amendment of current medical or instruction protocols. This does not prejudge the correctness of the current procedures but may draw attention to a failure to accommodate information and understanding of critical factors in diver safety that have accumulated since most of these protocols were formulated. Wherever possible all the evidence collected by the police investigation should be available before accepting even a coroner's opinion, as the task of a coroner is not specifically to determine the factors of primary interest to the diving community. There should be an acceptance that knowledge, and hopefully also understanding, is not static. One of the inputs into such re-evaluations must be data from reports of non-fatal events.

The reporting of non-critical events, such as equipment problems, is an important element in Australian diving safety management, its limitation being the natural reluctance of divers and diving organisations to make public any possible shortcomings in themselves, other divers, or their training programmes.

In the diving community, an understanding of the value of such approaches appears to be bedevilled by fears of lawsuits following the revelation of imperfections in present training protocols. These may be due to an imperfect understanding of the critical factors that are now recognisable as the underlying critical elements in many fatal incidents. It is increasingly accepted that to preferentially blame aviation accidents on 'pilot errors' leaves unanswered the question of why these occurred. Similarly in diving incidents there should be a focus on why inexperienced divers mistakenly believe they are as experienced as the words on their certificates imply, and so place themselves in danger. Also, while medical factors can be critical in a minority of recreational and commercial scuba diving fatalities, it is the fact of divers being faced with problems beyond their capacity to manage that may be more critical than any medical condition they may have. There is an obvious need to review available data to improve understanding of the importance of such factors in diving-related problems. We need to recognise that most 'incidents' are multi-factorial in causation, and their avoidance requires a rethink beyond the apparently rigid instruction protocols and the belief of medical professionals that they are always able to efficiently diagnose medical fitness to dive.

In Australia we are particularly fortunate that the coronial system inherited from the UK ensures that the police, on behalf of the coroner, investigate all 'unnatural' deaths. Fortunately the police investigation follows routine protocols that ensure that in most cases all details relevant to understanding the factors contributing to a diver's death are recorded. Even more fortunately there is an appreciation by the state coroners of the importance of utilising the information obtained to improve diver safety. This value is present even when the local coroner has dispensed with holding an inquest as the police investigation results are often available. There appears to be no similar facility afforded researchers in other countries. One factor averse to the investigation of diving-related incidents is the uncritical application of confidentiality laws in some other countries, as these appear to outweigh consideration to the public good of ethical reviews of such data.

While there is an aphorism "those who do not learn from history are condemned to repeat it" there appear to be few who apply this insight in this context. It is a condition that information from coronial sources be managed in the same strictly confidential manner required for medical journal reports and public discussion of cases, and that all identifying details are removed. Fortunately this apparent limitation in no way reduces the value of the information from coronial sources. Only those who have good alternative sources of information will be able to identify specific cases, and these only because they have prior knowledge. Indeed this author has on occasion found it difficult to identify old cases from his own published reports.

It must be remembered that critical analysis of the information in a plane's 'black box' is only a part of any investigation, there being an equally important search for all and any other pieces of evidence. In researching all factors that may influence diver safety, there should be inclusion of information from both divers and doctors concerning non-fatal events. Such reports may appear of minor importance but their examination may lead to the identification of problems that in a dive scenario would be serious.

This is a plea to divers, diving associations, and those involved in diving medicine in any manner, to realise the positive benefits from the sharing of information in a confidential, anonymous manner. The demonstration of having an active involvement in seeking to improve diver safety, through analysing incidents and then applying the results, should become a very valuable marketing tool. At the present time diving medical advice and training protocols are often based on presumptions and unproven clinical experience. There is always a problem with uncritically accepting as 'facts' even the most obvious 'truths' and this has been shown repeatedly in the medical profession. There is no shortage of matters requiring evidence: the need for a buddy-breathing ascent test in basic courses, the belief in the reliability and effectiveness of a 'diving medical' and what effect the reported equipment problems have had on diver safety.

It is suggested that SPUMS take a lead in developing an ongoing investigation involving all parties interested in diver safety. This is on the principle that someone has to take the lead in applying the precept that a fence at the top of a cliff is more useful than an ambulance at its base.

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Diving-related fatalities document resource

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

These documents have been the basis for the series of reports previously printed in this Journal as Project Stickybeak. These documents will be available free of charge to bona fide researchers attending the library in person, subject to the stipulation that the researcher signs an agreement that no identifying details are to be made public.

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

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

Critical appraisal

Significant improvement in hearing for people with idiopathic sudden sensorineural hearing loss with the addition of hyperbaric oxygen

Clinical bottom line

1 Significant improvement in hearing in 4 of 5 frequencies
2 Some evidence that HBOT is more effective with mild initial loss and [in] people under 50 years.

Citation

Topuz E, Yigit 0, Cinar U, Seven H. Should hyperbaric oxygen be added to treatment in idiopathic sudden sensorineural hearing loss? *Eur Arch Otorhinolaryngol*. 2004; 261: 393-6.

Lead author's name and fax number: 0 Yigit; +90-212-234-1121

Three-part clinical question

Does the addition of a hyperbaric oxygen regimen to a standard medical treatment improve hearing in people with idiopathic sudden sensorineural hearing loss (ISSHL)?

Search terms

Hyperbaric oxygenation, idiopathic sudden sensorineural hearing loss, ISSHL, hearing loss

The study

Non-blinded randomised controlled trial with intention to treat.

The study patients

Sudden hearing loss of > 30 dB in at least 3 continuous pure tone frequencies. Less than 2 weeks since onset of symptoms. All were admitted to hospital.

Control group

(N = 21; 21 analysed) Prednisone 1 $mg.kg^{-1}.day^{-1}$ for two weeks, rheomacrodex 500 $mL.day^{-1}$ for five days, diazepam 5 mg twice a day (seven day duration), pentoxiphyllin 200 mg iv twice a day (seven day duration).

Experimental group

(N = 30; 30 analysed) As above plus hyperbaric oxygen 253 kPa (2.5 ATA) for 90 minutes twice a day over five days then 2.5 ATA daily for 15 days.

The evidence

See Table 1.

Comments

- No 'functional' improvement assessment was performed.
- Intervals given in Table 1 are not defined (probably standard deviations).
- Results given for "34 ISSHL out of 30 patients" in the HBOT group; meaning not clear.
- Only age and sex were considered as possible confounders, no other patient data.
- No indication of loss to recruitment or attempt to recruit consecutive patients.

Conclusions

Difficult to assess numbers in this study because there was a problem in the interpretation of numbers of treatments per person, or per hearing loss event in the same person.

Appraised by:
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Appraised Thursday 10 March 2005

Key words

Hyperbaric oxygen, hearing, ENT, research, reprinted from

Table 1
Major outcomes in randomised study of hyperbaric oxygen for idiopathic sudden sensurineural hearing loss (means +/- ?standard deviations shown)

Non-event outcomes (time to outcome 4 weeks)	Control group	HBOT group	P value
Mean hearing gain all patients (dB)	17.4dB	33.3dB	?
Mean hearing gain by initial hearing levels (dB)			
≤ 60	22.33 ± -9.311	22.53 ± -12.68	0.758
61–80	6.18 ± -9.00	35.45 ± -22.09	0.014
≥ 80	13.00 ± -6.58	50.70 ± -21.54	0.005

Conference report

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

Part 2: Diving and drowning

Jürg Wendling

A short introduction to the structure of the World Congress on Drowning in Amsterdam 2002 and the concensus statements with regard to teaching children to dive were given in the first of these reports.[1] This article summarises the aspects of other sessions and the consensus recommendations (edited) of the final session with regard to diving. The author was rapporteur for the diving task force, 'Breath-hold, scuba and hose diving'. Other members of the panel were Alfred Bove, Glen Egström, David Elliott, Des Gorman, Rob van Hulst and Maida Taylor. The proceedings of the Congress with the recommendations of the various taskforces for drowning are now available.[2]

Hazards

Hazards while diving, due to the unique physiological and physical situations, are barotraumas (compression or decompression), related to partial pressure (oxygen toxicity, hypoxia, nitrogen narcosis, etc.), or related to solubility or uptake (decompression sickness). All may directly or indirectly cause drowning.

Diving techniques and their specific hazards (apnoea, compressed air and oxygen-enriched air (nitrox), scuba and surface-supplied diving, deep mixed-gas diving, rebreathers) were discussed. The given hazards seem to produce almost negligible risk for professional divers with appropriate control systems (safety management, regulations and routine), while the same techniques, particularly the more advanced ones, are a considerable risk when used by recreational divers (often diving solo and diving beyond their competence, no regulations forcing them to apply any safety planning, etc.).

Epidemiology of drowning while diving

Professionals (complying with regulations): almost no drowning and if it happens is usually the result of human error rather than inadequate procedures.
Professionals (uncontrolled): incidence unknown (unreported) but high anecdotal incidence of decompression illness (DCI).
Recreational: about 50% of fatalities are reported as being caused by drowning, but incidence is unknown because there is no knowledge of the size of the active diving population.

CONSENSUS STATEMENT

- Collection of morbidity and mortality data of accidents as well as find[ing] the denominator (total active diving population) is necessary to calculate the risk of certain diving procedures.

Fitness (physical, medical, mental)

Drowning may be the consequence of loss of consciousness in the water, extreme breathlessness, panic or other inappropriate behaviour, disorientation or vertigo, or cardiac disease. Therefore, divers should be screened for fitness to dive. While the commercial and military sectors, and, in some countries, recreational diving instructors are well monitored under national regulations, in some groups of divers like student scientists, emergency rescue divers, self-employed professional divers, etc., medical review in many countries never happens.

CONSENSUS STATEMENTS

- Recreational divers must consider their responsibility to their buddies and to the public when unfit for diving.
- Greater stringency is needed in the assessment of the physical, mental and medical fitness of all who choose to dive. A single assessment of fitness for diving at the beginning of the diver training should not be considered valid throughout the rest of the diver's life. Reassessments in an appropriate interval and after illness or injury are recommended.
- Examining doctors must be competent for their assessment knowing the unique hazards faced by the diver. Standardised training and competence certifications, including periodical revision, are recommended (like EDTC standards, see <www.edtc.org>).
- Standards of fitness in each diving category should be harmonised internationally.

Impact of training on drowning while diving

The most important factor in the causes of drowning is diving beyond the diver's level of competency. This is particularly so in recreational diving, where dive planning and preparation are often missing and/or neglected. Loss of control underwater is the key hazard that leads to a chain of mishaps culminating in panic. Strategies to regain control need to be trained, practised and overlearned.

CONSENSUS STATEMENTS

- All levels of diving training should include causation and prevention of in-water fatalities.
- Reassessment of diving competency should be established after 3–5 years without regular diving for all divers.

Self-rescue and assisted rescue

CONSENSUS STATEMENTS

- Emergency procedures like buddy breathing, octopus air-sharing or using pony bottles must be retrained while using a new configuration of equipment (equipment systems are not standardised).
- Rescue training should include recovery into boats and helicopters.
- Hand signals should be standardised worldwide.

Treatment of the freshly drowned victim

CONSENSUS STATEMENTS

- Rescue must consider various possible accompanying complications like pulmonary barotraumas, hypothermia, CO poisoning, DCI (omitted decompression) or envenomation.
- There is a need for national and international standards of medical care for medical diving emergencies.

Fatal accidents: investigation and autopsy

CONSENSUS STATEMENTS

- As drowning is mostly a diagnosis of exclusion (based on circumstantial evidence) investigations must include complete autopsy, evaluation of equipment and review of the circumstances.
- All investigations, particularly the autopsy should be performed by a pathologist who is knowledgeable about diving (or at least advised by a doctor who is knowledgeable).

An extra contribution from Jim Caruso provided detailed recommendations for the conduct of the autopsy and its interpretation.

Investigation of non-fatal diving accidents

Professor Gorman in his contribution pointed to the central role of critical-incident monitoring to enable modern human factor analysis. Accident data should be available for evaluation and a forum including diving physicians, pathologists, diving instructor agencies and divers should consider corrective strategies, modification of educational programmes and development of appropriate procedures.

Summary

There is no difference in physiology and physics between recreational and working divers. However, there are sufficient important differences in motivation and procedures for them to be considered in separate categories. Diving in navies and commercial companies is well regulated and supervised, thus drowning is extremely rare, while all other professional and recreational diving still produces too many fatalities. Safety management, including risk assessment for each dive, would certainly be a better way to increase safety than the traditional application of prescriptive rule books!

CONSENSUS STATEMENTS

- Most national regulations have been effective where enforced. Improvements in health and safety for all divers would arise only from a more inclusive definition of working divers (e.g., recreational diving instructors, self-employed fishermen-divers and industry divers, rescue divers).
- Self-regulation of the recreational diving world is still a practical route for further improvement but conflicts between commercial interests and safety are to be considered and avoided. Independent monitoring of incidents/accidents could assure effective use of ‘safe’ procedures.
- Subsistence fishermen, predominantly in poor countries, use inappropriate equipment and lack any medical support, training and safety monitoring (no regulations). To reduce drowning and enhance safety, data collection of representative samples should be installed, to be followed up with NGOs, charities and UN development initiatives. Scientific bodies and training organisations could then deliver suitable advice and training compatible with the limited local resources.

References

1 Wendling J. Report on the World Congress on Drowning, 7 June 2002, Amsterdam. Part 1: Expert meeting: Introducing children to diving. *SPUMS J*. 2005; 35: 49-51.
2 Bierens JJ, Branche CM, Brewster BC, Brons R, Daanen H, Elliott D, et al (editors). Handbook on drowning: prevention, rescue and treatment. Heidelberg, Germany: Springer Verlag; 2005. ISBN: 3-540-43973-0; price: 160.45 Euro; available from Springer Verlag, <www.springer.de>

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Key words
Drowning, diving, meetings

Letter to the Editor

The SPUMS Diploma: "No" to prescriptive publishing of theses

Dear Editor,

I read with interest the letter from Chris Acott in the last issue concerning the SPUMS Committee's recent change to the SPUMS Diploma requirements, along with the proposed further change.[1] It seems that the inclusion of the Diploma as a requirement prior to certification by the Australia and New Zealand College of Anaesthetists (ANZCA) has caused some inconvenience and concern within SPUMS.

As a member involved with both groups I would like to say a few words about the situation. My aim is to help maintain the highly desirable close association between the two organisations.

The Special Interest Group (SIG) of the ANZCA discussed at some length the format our certification process might take. I was one who felt strongly that the SPUMS Diploma should be made a prerequisite for certification for several reasons. First, the SIG did not want to take a position in direct academic conflict with SPUMS, but rather to complement the very important and successful efforts made by SPUMS to raise the academic standard in the field. Second, there seemed little purpose in setting a second mechanism in place – run by largely the same people (Chris and the Editor are members of the SIG and the Academic Board of SPUMS for example) – to formally assess written 'projects' in our small field. Third, we wanted to encourage publication in this journal, and that seemed more likely through the existing system than through one based entirely at the College. Finally, we wanted to strongly encourage members of the SIG to join SPUMS. It seems this latter aim has been almost immediately realised.

During the period when the SIG was being formed, this move was discussed several times in the SPUMS Committee. There were no dissenting voices at that time. We certainly did not envisage creating problems for SPUMS. Speaking solely for myself, I believe there were errors in the way in which the requirements for the ANZCA Certificate were formulated. In particular, the requirement to have been actually awarded the Diploma before sitting the Certificate examination was (in my view) unnecessarily restrictive and likely to lead to demands on the Education Officer.

I sympathise with Chris's position. No-one should take for granted the work done by the Education Officer and the rest of the Academic Board in this regard. It should be said, however, that there have been only two diplomas completed specifically for the College certificate so far, and there are not likely to be more than one or two per year for the foreseeable future. The SIG has recently asked SPUMS for a presence on its Academic Board in order to tighten the academic ties between the two.

The requirement for a two-year period of membership before being awarded the Diploma seems a petty change in response to a temporary situation, but one to which I have little objection. I do not see there is a great deal of difference in the new position except one year's subscription for SPUMS, and that cannot be bad. Now that the initial rush to satisfy the College interim requirements is over, we will have no more candidates who could be inconvenienced by this.

The proposed change to require submission for publication in the SPUMS Journal is more disturbing to me. We made the decision only a few years ago to reverse that requirement, and I believe the reasons advanced at that time are still persuasive. Since then the standard of the Journal has risen considerably rather than fallen. In any case, not all projects would be suitable for publication, there is an element of restriction of academic freedom in this move, and it might dissuade individuals from taking on the Diploma in the first place.

Chris points out that to date no candidate for the ANZCA Certificate has published their work in the Journal. This is true, and I will be encouraging those who follow to do so. It is not as if there have been many opportunities, however – only one candidate has submitted elsewhere as far as I am aware.

It is my concern that an insistence on publication in the SPUMS Journal will not be acceptable to the ANZCA. There are already some raised eyebrows there about using an 'outside' qualification (the SPUMS Diploma) as a prerequisite for a College qualification. It was accepted only because of the clearly demonstrated close ties between SPUMS and all the SIG members. I would be saddened if we lost this special relationship.

Dr Michael Bennett
Department of Diving and Hyperbaric Medicine, The Prince of Wales Hospital, Randwick, NSW, Australia.

Reference

1 Acott C. New requirement for the SPUMS Diploma of Diving and Hyperbaric Medicine. *SPUMS J*. 2005; 35: 110.

Key words
Qualifications, medical society, policy, letters (to the Editor)

Book review

The biology of human survival: life and death in extreme environments

Claude A Piantadosi

263 pages, hardback
New York: Oxford University Press; 2003.
ISBN 0-19-516501-2
Price GBP 24.00

From ocean depths to outer space, Antarctica to the Sahara, and starvation to a post-nuclear-holocaust world, this small book's exploration of man's ability to adapt and the limits to survival is far-ranging. The purpose of *The biology of human survival* is to identify the main determinants of life or death in extreme environments from a physiological perspective, integrating modern concepts of stress, tolerance and adaptation in Nature's most austere conditions.

Dr Piantadosi is Professor of Medicine at Duke University, well known for his work on oxygen at the sub-cellular level and Editor-in-Chief of *Undersea and Hyperbaric Medicine*. He is thus well equipped to lead us on this exploration of the limits of human endurance, and makes this a fascinating and fulfilling journey in an excellently written book.

For each environment described, three key questions are posed to the reader. How does the body respond to environmental challenges and what happens when adaptive physiological mechanisms fail? At what point does biology end and technology need to take over? How does evaluation of the biology of extreme environments help to provide life-support solutions to ensure survival? The physical world imposes strict limits on human survival, and learning where these limits are and how to deal with them is known as 'limit physiology'. These principles are applied to each environment discussed. The role of human behaviour in adaptation is a central theme, as indeed it should be.

Many readers will be familiar with the rectangular hyperbola that describes the limits of oxygen tolerance (for lung or CNS toxicity, for instance) in terms of the length of exposure and the partial pressure to which the organism or biological system is exposed, and which appears in all the diving physiology textbooks. This relationship, though not universal, is characteristic of many of the survival functions in response to physiological stresses described in this book. The author is not afraid to theorise on the implications for human survival of our propensity to restructure our environment and, as he points out, even our biology. He states in the preface "*no matter how pleasing the vision of mind over nature, it underestimates natural selection and the effect of the unpredictable on human evolution*." I am reminded of Professor Steven Jones' stern warning in *Almost like a whale* that the biotechnology of genetic engineering denies the central facts of evolution and "*takes no account of the notion of species as interacting groups of genes, the properties of one depending upon the others with which it is placed*."[1] We manipulate our world at our peril as well as to our advantage; that environment shapes humanity is never at issue in the book.

The book contains 20 short, easy-to-read chapters. The first three are devoted to basic concepts, such as survival analysis, the principles of physiological regulation (the *milieu-intérieur*) and adaptation, and the definitions of terms used. Chapter three draws attention to the concept that acclimation to a single stressor triggers a general pattern of responses that might augment or interfere with acclimation to another independent stress, resulting in both positive and negative acclimatisation to a new environment.

All the remaining chapters are devoted to a wide range of specific environments and physiological stressors. These include a fascinating and, with the recent accident off the Kamchatka Peninsula, topical discussion of survival in a sunken submarine, using the *Kursk* tragedy as the model. Those SPUMS members who attended the Madang ASM a few years ago heard an enthralling talk from James Francis on US Navy simulation studies of this problem.

Talking about weapons of mass destruction, Piantadosi states "*It will become clear that the greatest threat to the survival of humankind remains thermonuclear weapons…If not already apparent, it will also become clear that the idea of a 'preparedness plan' for a full-scale thermonuclear exchange is irrational*." Finally, he muses on the challenges of space colonisation, such as cosmic radiation, microgravity, provisioning and evolutionary pressures.

Some physiology is already slightly out of date as these are rapidly changing fields. For instance, thermal physiologists have moved on from Benzinger's 'set point' concept of temperature regulation.

This is a highly readable book that anyone interested in human biology will thoroughly enjoy. The typeface is clear, errors rare and illustrations and figures used sparingly but sensibly and clearly, with good explanatory captions. The majority of the terms used are defined, but the text does assume the reader has a basic working knowledge of biology. There is an extensive, carefully selected bibliography and a good index. I look forward eagerly to the second edition.

Reference

1 Jones S. *Almost like a whale. The origin of species updated*. London: Anchor; 2000. p. 247.

Mike Davis, Editor SPUMS Journal

Key words
Biology, environment, general interest, book reviews

The poetry doctor

From grave to grotto

Farewell a mighty warrior
Who's served her country well,
Cruising troubled waters
With guns that pound to hell,
Protecting troops and friendly ships
Patrolling through the waves,
Now timely decommissioned
And retired beneath the waves.

Welcome friend to your new home
Scuttled near our shore.
Settle softly on your bed
In peace and no more war.
You'll be adorned in corals fine
And fish will be your crew.
The quiet of this inner world
Will rest and transform you.

'Tis just that you are so preserved
And not be cut for scrap,
To be a monument conserved
Beneath a roof whitecap.
Where we can dive and explore
Bathed in your history
And celebrate your newfound peace,
A joyful place to be.

Living in the Sunshine hinterland I am excited by the scuttling of the *HMAS Brisbane* just 5 km offshore in 30 metres of water. This 133-metre destroyer has a rich history of service in the Vietnam and Gulf wars. It has been prepared especially for divers, with easy access to living quarters and engine room, and will be a world-class dive.

John Parker
<www.thepoetrydoctor.com>

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

All enquiries to:
Diving Historical Society Australia, SE Asia,
PO Box 2064,
Normansville, SA 5204,
Australia
Phone: +61-(0)8-8558-2970
Fax: +61-(0)8-8558-3490
E-mail: <bob@hyperbarichealth.com>

Australia and New Zealand Hyperbaric Medicine Group of SPUMS

Introductory Course in Diving and Hyperbaric Medicine

Dates: 27 February to 10 March 2006
Venue: Prince of Wales Hospital, Sydney, Australia

Course content includes:

- History of hyperbaric oxygen
- Physics and physiology of compression
- Accepted indications of hyperbaric oxygen (including necrotising infections, acute CO poisoning, osteoradionecrosis and problem wound healing)
- Wound assessment including transcutaneous oximetry
- Visit to HMAS Penguin
- Marine envenomation
- Practical sessions including assessment of fitness to dive

Contact for information: Ms Gabrielle Janik, Course Administrator
Phone: +61-(0)2-9382-3880
Fax: +61-(0)2-9382-3882
E-mail: <janikg@sesahs.nsw.gov.au>

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>

THE UNIVERSITY OF AUCKLAND
FACULTY OF MEDICAL AND HEALTH SCIENCES

Master of Medical Science
Postgraduate Diploma in Medical Science
Diving and Hyperbaric Medicine

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- Hyperbaric medicine
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- Research project in diving or hyperbaric medicine

For further information, including fees, please contact the Course Coordinator: Jessica Rorich
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Fax: +64-(0)9-308-2379
E-mail: <j.rorich@auckland.ac.nz>

Full information on courses and admission regulations is available in the University of Auckland Calendar or online <http://www.auckland.ac.nz>

UNDERSEA and HYPERBARIC MEDICAL SOCIETY
Annual Scientific Meeting 2006

Dates: 22 to 24 June 2006
Venue: Hilton in the Walt Disney World Resort
Orlando, Florida

For additional information:
Lisa Wasdin
c/o Undersea and Hyperbaric Medical Society
PO Box 1020, Dunkirk, Maryland 20754, USA
Phone: +1-410-257-6606 extn 104
Fax: +1-410-257-6617
E-mail: <lisa@uhms.org>

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Fax: +61-(0)8-8232-4207

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Middle Head Rd, Mosman, 2088 NSW, Australia
Phone: +61-(0)2-9960-0572
Fax: +61-(0)2-9960-4435
E-mail: <Sarah.Sharkey@defence.gov.au>

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Venue: Columbia, Ohio

For additional information:
Dick Clarke, President
National Baromedical Services,
5 Richland Medical Park, Columbia, SC 29203, USA
Phone: +1-803-434-7101
Fax: +1-803-434-4354
E-mail: <HBO2006@baromedical.com>

Instructions to authors

(**revised June 2005**)

The *SPUMS Journal* welcomes contributions (including letters to the Editor) on all aspects of diving and hyperbaric medicine. Manuscripts must be offered exclusively to the *SPUMS Journal*, unless clearly authenticated copyright exemption accompanies the manuscript. All manuscripts, including SPUMS Diploma theses, will be subject to peer review. Accepted contributions will be subject to editing.

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

Requirements for manuscripts

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

The text should be double-spaced, using both upper and lower case. Headings should conform to the current format in the *SPUMS Journal*. All pages should be numbered. Underlining should not be used. Measurements are to be in SI units (mmHg are acceptable for blood pressure measurements) and normal ranges should be included.

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

Illustrations, figures and tables should not be embedded in the wordprocessor document, only their position indicated. No captions or symbol definitions should appear in the body of the table or image.

Tables are to be in Word for Windows, tab-separated text rather than using the columns/tables option or other software and each saved as a separate file. They should be double-spaced and each in a separate file. No vertical or horizontal borders are to be used.

Illustrations and figures should be in separate files in TIFF or BMP format. Our firewall has a maximum size of 5 Mb for incoming files or messages with attachments.

Photographs should be glossy, black-and-white or colour. Posting high-quality hard copies of all illustrations is a sensible back-up for electronic files. Colour is available only when it is essential and may be at the authors' expense. Indicate magnification for photomicrographs.

Abbreviations may be used once they have been shown in brackets after the complete expression, e.g., decompression illness (DCI) can thereafter be referred to as DCI.

References

The Journal reference style is the 'Vancouver' style *(Uniform requirements for manuscripts submitted to biomedical journals*, updated July 2003. Web site for details: <http://www.icmje.org/index.html>). In this system references appear in the text as superscript numbers at the end of the sentence and after the full stop.[1,2] The references are numbered in order of quoting. Index Medicus abbreviations for journal names are to be used (<http://www.nlm.nih.gov/tsd/serials/lji.html>). Examples are given below:

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

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

Any manuscript not complying with these requirements will be returned to the author before it will be considered for publication in the *SPUMS Journal*.

Consent

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. 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.

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DIVER EMERGENCY SERVICES PHONE NUMBERS

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The toll-free number 1-800-088-200 can only be used in Australia

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0800-4-DES111 or 09-445-8454 (in New Zealand)
+64-9-445-8454 (International)
The toll-free number 0800-4-DES111 can only be used in New Zealand

The DES numbers are generously supported by DAN-SEAP

PROJECT STICKYBEAK

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

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

DIVING INCIDENT MONITORING STUDY (DIMS)

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

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

PROJECT PROTEUS

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

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

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

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