

# Diving and Hyperbaric Medicine

*The Journal of the South Pacific Underwater Medicine Society  
and the European Underwater and Baromedical Society*

**SPUMS**

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**EUBS**



## Diving-related fatalities in Australia 2011

Divers with pre-existing medical conditions

Estimating the risks for diving fatalities

Enhancing rebreather diving safety

Pressure testing endodontic post materials

Facial palsy from middle ear barotrauma

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

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## DIVING AND HYPERBARIC MEDICINE

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# The Editor's offering

## Understanding diving-related fatalities

Whilst there are earlier reports of diving-related fatalities, the sport diving community and diving physicians owe a particular debt to two men who almost single-handedly embarked on documenting fatalities so that we could better understand the underlying causes and, hopefully, develop strategies to reduce their numbers. John McAniff of the National Underwater Accident Data Center, University of Rhode Island, recorded annual USA diving fatalities from 1970 to 1994.<sup>1</sup> In Australia, Dr Douglas Walker, a general practitioner in Sydney, commenced *Project Stickybeak* in the early 1970s and his first report appeared in the SPUMS Newsletter in 1972.<sup>2</sup> In both countries, the Divers Alert Network (DAN) took over responsibility for preparing the annual reports, though Douglas continued to contribute to the Australian ones until very recently.

Without doubt, it is the Australian database that is by far the most comprehensive internationally, detailing as it does each individual case. In the earlier reports, the police and coroners' investigations were of a very variable standard, and much supposition and commentary were interspersed with the facts, making interpretation sometimes difficult. However, we have now established a structured format that presents the facts of the case, the autopsy findings and a commentary in separate sections, prepared by a panel of experts in their fields. The latest report, for 2011, is presented in this issue, some 30 deaths.<sup>3</sup> As Editor, I make no apology for taking up half of this issue with these reports as I consider that their continued detailed documentation is important.

Several years ago, I called for more analysis, rather than simply documenting an ever-growing database. To some extent, this call has been responded to by Lippmann and his colleagues in a recent article,<sup>4</sup> but more such research is needed. It is disappointing that DAN Europe has not made contributions to this journal from their extensive databases, like its counterparts in America and the Asia-Pacific region.

The 2011 Australian report highlights several recurring themes. One in particular is the fact that the vast majority of dead scuba divers still have their weight belt on when recovered. In many emergency situations, establishing positive buoyancy could make the difference between death and survival. Since this is so common, it is clear that training in weight-belt ditching is inadequate. Even where one might think this action would be totally inappropriate, it is worth re-reading Trytko and Mitchell's case report on the technical diver who, when he lost consciousness on ascent at 24 metres' depth after an 80 m dive, was sent to the surface by his buddy in a rapid buoyant ascent and survived in a situation where he would almost certainly have died had this action not been taken.<sup>5</sup>

Another striking feature of the reports is the often long delay

to CT scanning and the autopsy, making any likelihood of assessing intravascular gas virtually impossible. It appears that most police departments, coroner's offices and forensic pathologists still do not understand the scientific urgency to conduct these investigations as soon as possible, preferably within hours, even if it is a Sunday night!

Haynes pushes another simple safety message for the sport technical diving community, based on military and commercial rebreather diving.<sup>6</sup> If a rebreather diver loses consciousness underwater, his mouthpiece falls out and he is likely to drown, whereas using a mouthpiece retention strap can increase the time that water aspiration is avoided and thus enhance the chances of retrieval and survival – not difficult logic to follow. So why has the recreational industry ignored this simple safety device?

I have recently tendered my resignation as Editor-in-Chief, effective at the end of 2017, and expressions of interest are now being called. Not only will I be in my mid-70s, but it allows a new Editor to launch DHM as an electronic journal in 2018. Whether a print version will also be available (certainly at a premium rate) is a decision yet to be made by the executive committees. The costs of production of the journal continue to rise as the number of submissions and our consequent workload and its complexity increases. This has been a stimulating 14 years for me, but more on that later. Best wishes for a safe and successful 2017 in every way!

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Michael Davis

### Key words

Deaths; Scuba; Technical diving; DAN – Divers Alert Network; Editorials

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**The front page cartoon originally appeared on the front page of the SPUMS Journal in the December 1979 issue (volume 9; number 4).**

# The Presidents' pages

David Smart, President SPUMS

## Australia's model Work Health and Safety Regulations for Diving Work

In my role as President, I continue to provide input into Safe Work Australia's (SWA) development and review of occupational diving legislation. In 2011, the Australian Federal Government via SWA, released a national set of model Work Health and Safety Regulations (WHSR), with the aim of harmonising the multiple pieces of workplace legislation that existed across the Australian States and Territories. Contained within the harmonised regulations was a section on diving work (section 4.8, p. 177–90).<sup>1</sup> Whilst the intent was admirable, it does appear that there was some rush to publish the regulations. For the diving-at-work section, very few stakeholders were consulted; SPUMS definitely was not, prior to the legislation release. The Australian Diver Accreditation Scheme (ADAS) was referenced in only a limited way; a surprising decision given its international status and parallels for diving training.

There appeared to be major input from Queensland, because much of the Federal Legislation had similar wording to the 2008 Queensland Legislation.<sup>2</sup> This affected the emphasis of the legislation because of Queensland's significant recreational industry and the large number of scientific divers and divers involved in seafood harvesting in that state. Categories of "incidental divers" and "limited scientific divers" were introduced. Unfortunately, the legislation did not clearly specify this requirement, so it was technically possible to have incidental or limited divers with some defined experience working as occupational divers without formal qualifications. In addition, there were some sections of the Queensland legislation that were included in the Federal WHSR, but without their sunset clauses.

SPUMS identified fundamental problems with the legislation:

- A broad classification into "general divers" or "high risk divers", without taking into account what the diver was actually doing during the dive led to a significant unfilled gap in the regulations when classifying "general diving" and "high-risk diving". High risk diving was the only type of diving subject to AS/NZS 2299.1.
- There was a lack of incorporation of task-related risk into diver operational classification.
- De-emphasising the world class and internationally recognised qualification system which is overseen by ADAS (AS/NZS 2815.1-6), has led to an inconsistent approach to diver training/qualifications.
- Recreational standards such as 4005.2 were recognised, whilst other occupational standards were ignored.
- There was a serious deficiency in legislative requirement for competent dive supervision and risk management.

- Compressed air and hyperbaric facility workers were completely missed from the regulations.
- There was a lack of recognition of the diving medical assessment as a high-level risk control.

The medical requirements for occupational diving were not significantly changed. I have described these previously.<sup>3</sup> A long period of lobbying by stakeholders followed, during which another iteration of the legislation was released in 2014.<sup>4</sup> This new version failed to correct the fundamental deficiencies. Finally, SWA released a consultation regulation impact statement in August 2016, recognising the following problems and seeking input from stakeholders:<sup>5</sup>

### 1. Regulatory confusion

- confusion over categories of diving work, for example, in defining high risk diving, incidental diving and limited scientific diving, the regulations were insufficiently flexible to accommodate the diversity of diving work;
- confusion over diving competencies, the use of both recreational and professional standards and the use of deficient international recreational standards.

### 2. Regulatory burden

Some stakeholders reported increased compliance costs from:

- competency requirements;
- supervision requirements;
- attending medical fitness examinations;
- meeting additional risk-management requirements, including complying with documentation requirements, such as making dive plans and safety logs mandatory.

The options for change presented by SWA were:

1. maintenance of the status quo and to not change the regulations;
2. to amend the model WHS Regulations for diving work to streamline and clarify the categories of diving work and relevant competencies, or
3. to replace the prescriptive nature of the model WHS Regulations for diving work with outcome-based provisions and detail in guidance material.

SPUMS supports the second option and provided detailed reasoning behind our decision. Whether or not this will be the preferred option of SWA is anyone's guess. SPUMS also made comment on the ongoing deficiency of the regulations in covering compressed air and hyperbaric facility workers. Once the new SPUMS website is operational, links to the legislation and SPUMS' responses over several years will be made available for viewing by our members.

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**Key words**

Occupational diving; Standards; Medical society; General interest

**Jacek Kot, President, EUBS**

In September this year, the EUBS Annual Scientific Meeting was held in Geneva; the second time our Conference has been held in Switzerland. The previous meeting was organized in 1992 in Basel by our long-standing colleague, Jörg Schmutz. This time, the team of organisers clearly showed that there is a new generation of people devoted professionally to diving and hyperbaric medicine in that country. Indeed, it was a real pleasure to see their enthusiasm in hosting all participants. The organisation was excellent, the scientific standard was high and the social events memorable. It is fair to conclude that the conference was a great success and that would not have been the case without our colleagues, Rodrigue Pignel, Jean-Yves Berney, Marie-Anne Magnan, Marco Gelsomino, Michel Pellegrini and all those who contributed to this event.

Next year, our conference will be in Ravenna, Italy, 13–16 September. We all know Pasquale Longobardi's abilities in organising international meetings, so mark your calendar today and start preparing your scientific submissions! We have also started preparations for the next Tri-continental meeting, organised jointly with SPUMS and SAUHMA in 2018 to be held in Oman. Unfortunately, at the last moment we have received information that for political reasons some of our Israeli colleagues will not be able to attend there. We have taken immediate action to find a solution, either ensuring that all EUBS members will be able to participate without restrictions or looking for an alternative location. I hope that the situation will be clarified soon and members will be advised as soon as possible.

This year we also decided to modify our by-laws. This will be the first modification since 2008 and it has been expected as several significant changes to the Society have occurred in the meantime.

Firstly, we clarified the list of aims that now will “*maintain also co-operation between life sciences and other disciplines concerned with hyperbaric activity in the broadest sense*”, something the Society has, in fact, always done.

Secondly, we explicitly restricted the use of Society funds only to those aims listed in the By-laws, even though other practice has never occurred in the past.

Thirdly, we added descriptions of the different memberships which we introduced or modified at the beginning of 2016.

These include: *Full Members*, who have full voting rights, full membership privileges and will benefit from reduced fees for Society activities; *Undergraduate Members*, who will have the same benefits as Full Members (excluding voting rights), but will benefit from a reduced membership fee; *Corporate Members*, as previously; *Associate Members*, who do not need to be active in the medical or scientific field of diving or hyperbaric medicine and finally *Honorary Members*, who for selected cases of retired persons can be elected after 10 years' EUBS membership.

Fourthly, we included a formal statement that Executive Committee meetings may be held by web conferencing or other electronic means, so it seems that from now on we will officially use technologically from the 21st century!

Finally one of the most important changes to our Society for several years, in my opinion, is the formal description in the By-laws of our close cooperation with SPUMS, which results in co-publication of the *Diving and Hyperbaric Medicine* journal. Until now our collaboration has been based only on mutual recognition of resources, draft procedures, ‘gentlemen's agreements’ on how the aims should be achieved and separate written contracts on purely financial aspects. Now, the By-laws will enforce this initiative and ensure its flawless continuation into the future.

There are also some other minor modifications proposed. Please, go to the Membership section of our website, read the proposals carefully and give your vote when the electronic ballot is opened (you will be notified of this by e-mail). The approval of at least three-quarters of the members in good standing of the Society who vote upon the proposed amendments are required for their passage, so if you are unsure, just give trust to the Executive Committee (which you have elected personally) that all these changes will improve our future activities. The new text of the Constitution and Bylaws can be found on the EUBS Website. <[www.eubs.org](http://www.eubs.org)>.

As you read this message just before the end of 2016, please accept my best seasonal greetings to you and your families. I also wish to all of us that the next year should be prosperous for all our professional plans. Affectionately yours, Jacek.

**Key words**

Medical society; Membership; Constitutional amendments; General interest

# Original articles

## The demographics and diving behaviour of DAN Asia-Pacific members with and without pre-existing medical conditions

John Lippmann, David McD Taylor, Christopher Stevenson and Simon Mitchell

### Abstract

(Lippmann J, Taylor D McD, Stevenson C, Mitchell S. The demographics and diving behaviour of DAN Asia-Pacific members with and without pre-existing medical conditions. *Diving and Hyperbaric Medicine*. 2016 December;46(4):200-206.)

**Introduction:** This report examines Diver Alert Network Asia-Pacific (DAN AP) members with and without cardiac or respiratory conditions, diabetes or hypertension and compares their demographics, health and diving activities.

**Methodology:** Two online cross-sectional surveys of DAN AP members were conducted. The first sought information from 833 divers who applied for membership between July 2009 and August 2013 and who had declared the targeted medical conditions. The second, conducted between December 2014 and April 2015, was sent to 9,927 current members with known email addresses. The groups were compared for age, gender, body mass index, fitness, smoking and diving qualifications, history, currency and practices.

**Results:** Of 343 (41%) respondents to the first survey, 267 (32%) provided sufficient information for inclusion. Of 1,786 (18%) respondents to the second survey, 1,437 (15%) had no targeted medical condition and were included in the analysis. Those with medical conditions were on average 4.7 years older ( $P < 0.001$ ); more overweight or obese (68% versus 57%,  $P = 0.001$ ); took more medications (57% vs. 29%,  $P < 0.001$ ), smoked less (4% vs. 7%,  $P = 0.02$ ) and did less repetitive diving (median 75 vs 90,  $P < 0.001$ ). Other diving demographics were similar.

**Conclusions:** A substantial number of people are diving with medical conditions and there is a need to better understand the associated risks. Divers need to be well-educated about the potential impact such conditions may have on diving safety and should monitor their health status, especially as they age.

### Key words

Survey; Fitness to dive; Health surveillance; Cardiovascular; Scuba divers; Recreational divers

### Introduction

It is generally accepted that scuba divers need to have an appropriate level of physical and medical fitness in order to facilitate safe diving. Historically, conditions such as asthma, diabetes and many cardiac conditions were considered absolute contraindications.<sup>1-3</sup> Traditionally, scuba diving was the realm of the relatively healthy, fit and young although, as the sport evolved, individuals with a variety of medical conditions began to participate.<sup>4,5</sup> Data from the United Kingdom (UK) indicate that the average age of divers has increased over time, rising from 10% being over 50 years old in 1998 to 30% in 2015.<sup>6</sup> Long-time divers are ageing and the sport has become increasingly available to a broader-aged cohort of the population.

Associated with increasing age is an increase in co-existing disease, both known and occult.<sup>7-10</sup> Diving fatality reports reflect a rise in the ages of victims and this is likely a result of the combination of increased participation and increased risk imposed by co-morbidities.<sup>11,12</sup> Up to one third of cohorts of active Australian and USA divers continued to dive even with traditional medical contraindications.<sup>5,13</sup> Some divers had never sought diving medical advice about their conditions.

Diving medical organisations have progressively modified their advisories on diving with conditions such as asthma

and diabetes. The Divers Alert Network Asia-Pacific (DAN AP) is a non-profit membership-based association with a mission to improve recreational diving safety, and provides its members with access to diving injury insurance. Although membership applicants are required to declare pre-existing medical conditions, in most cases, no evidence of a fitness-to-dive assessment is required. DAN AP membership data reflect a growing representation from divers with asthma, diabetes, hypertension and a variety of cardiac-related conditions. As a result, there is an increasing need to learn more about the medical conditions of active divers and the impact, if any, that these conditions have on their diving practices and experiences.

The aim of this project was to examine the health status of a cohort of active recreational divers and determine the impact of co-existing disease on their diving practices. We surveyed DAN AP members with and without significant pre-existing medical conditions. We aimed to clarify the prevalence of significant medical conditions in active divers and identify any impact of certain predefined conditions on diving frequency, practice and outcome.

### Methodology

An anonymous, online, cross-sectional medical conditions survey (MCS) was conducted on a cohort of DAN AP

members who had declared that they suffered from a significant medical condition, including hypertension, diabetes, respiratory and cardiac conditions. A second similar cross-sectional general DAN members survey (GDMS) was conducted with the general DAN AP membership. The latter survey was conducted in order to obtain a control group for comparison (footnote). Ethics approvals were received from the Human Research Ethics Committees of Austin Health and Deakin University, both in Victoria, Australia.

#### MEDICAL CONDITIONS SURVEY

The survey targeted adults (>18 years old) who had joined DAN AP between 01 July 2009 and 01 August 2013. At the time of joining, DAN AP applicants for dive injury insurance are required to declare significant pre-existing medical conditions and, during the period under study, these were recorded in a database for research purposes. Those reporting an existing condition were surveyed using a two-part questionnaire. The first part sought details about the responders' demographics (e.g., age, gender, physical characteristics, general health and perceived fitness) and details of their diving history and activity, e.g., years of diving, total number of dives, dives per year, frequency of diving and the type of diving undertaken: depths, technical (self- and certification-defined) and repetitive diving. The second part sought details about certain 'targeted conditions' including cardiac (septal defects, myocardial infarction, arrhythmias, angina) and respiratory (asthma, pneumothorax, lung surgery) conditions, diabetes and hypertension. There were also specific questions about any impact these conditions had had on the responders' diving practices and any adverse incidents that had occurred.

In August 2013, an invitation to participate in the survey was sent to DAN AP members who had previously declared the conditions of interest. A reminder was sent in October 2013 and the survey was closed in December 2013. No inducements to participation were offered, and invitees were assured of their anonymity and that responding or otherwise would have no impact on their insurance status. All invitees had access to Part 1 of the questionnaire, as well as the set of questions relating to their declared condition(s). Participants were invited to enter their responses directly into an online, dedicated MYSQL database (Oracle, Redwood CA). Responses were then downloaded into an MS Excel database (Microsoft Corporation, Redmond WA) for collation and pre-analysis.

#### GENERAL DAN AP MEMBERS SURVEY

A separate survey containing similar demographic, diving history and activity questions was designed for all DAN AP members. This GDMS, which used the *Survey Monkey*

**Table 1**

Age and gender of invitees, responders and non-responders to a medical conditions survey (MCS) and a general DAN members survey (GDMS) (gender not known in GDMS invitees and hence non-responders); \* comparison of responders and non-responders

	Age (y) Mean (SD)	Gender (%F)
<b>MCS</b>		
Invitees	50.0 (12.0)	27
Responders ( <i>n</i> = 267)	52.1 (12.2)	31
Non-responders ( <i>n</i> = 566)	49.6 (12.4)	24
<i>P</i> -value *	< 0.01	0.02
<b>GDMS</b>		
Invitees	42.9 (11.9)	–
Responders ( <i>n</i> = 1437)	47.6 (11.7)	30
Non-responders ( <i>n</i> = 7961)	42.1 (11.8)	–
<i>P</i> -value *	< 0.001	–

platform, included some filtering questions about whether or not the responders had any of the 'targeted' or other significant medical conditions, and if they had participated in the MCS. Those with a positive response to either of these questions were excluded from the subsequent comparative analysis.

An invitation to participate was emailed to all current members (which would have included some who had participated in the MCS) using the email address known to DAN in December 2014. A reminder was sent in March 2015 and the survey was closed in April 2015.

The variables of interest for the divers with and without targeted medical conditions were compared. No *a priori* sample size calculation was undertaken as all DAN AP members were invited to participate. Statistical analysis was conducted using SPSS Version 22 (IBM, Armonk, NY; 2013). Groups were compared using the Student's *t*-test,  $\chi^2$ -test, z-test and Median Test for independent samples. The level of significance was set as  $\leq 0.05$ .

#### Results

##### MEDICAL CONDITIONS SURVEY

Eight-hundred-and-thirty-three DAN AP members with previously disclosed medical conditions were invited to participate. Age and gender were known and are shown in Table 1. Three-hundred-and-forty-three responses were received (41%) of which 267 (32%) contained sufficient information for inclusion. The medical conditions of interest included cardiac conditions (92 cases), hypertension (127), diabetes (24) and respiratory conditions, predominantly asthma (47). Some responders had multiple conditions.

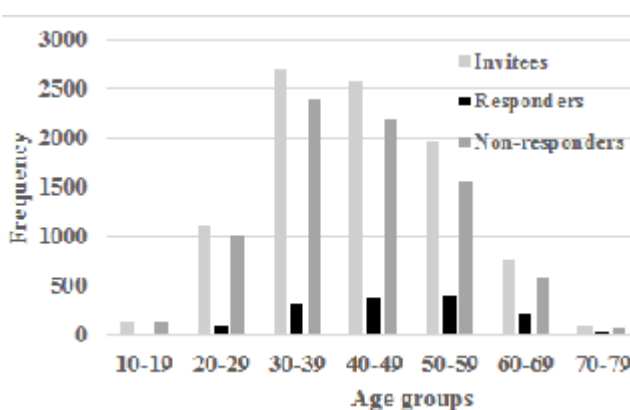
**Table 2**

Demographic and health information of 267 divers with declared targeted conditions and 1,437 without targeted medical conditions; \* not reported; † comparison excludes not reported; BMI – body mass index; ‡ 25 < BMI < 30 kg·m<sup>-2</sup>; § BMI ≥ 30 kg·m<sup>-2</sup>

	Group		<i>P</i> -value <sup>†</sup>
	No condition ( <i>n</i> = 1,437)	Medical condition ( <i>n</i> = 268)	
<b>Sex <i>n</i> (%)</b>			
Male	1,007 (70)	182 (68)	0.90
Female	430 (30)	81 (30)	
NR*	4 (2)		
<b>Age (y), mean (SD)</b>	47.3 (11.7)	52.4 (12.1)	< 0.001
<b>BMI (kg·m<sup>-2</sup>), mean (SD)</b>	26 (4.2)	27 (4.2)	0.001
Overweight <i>n</i> (%) <sup>‡</sup>	582 (41)	103 (42)	0.06
Obese <i>n</i> (%) <sup>§</sup>	233 (16)	63 (26)	< 0.01
<b>Fitness <i>n</i> (%)</b>			
very fit	97 (7)	18 (7)	0.19
fit	533 (37)	80 (30)	
moderately fit	719 (50)	146 (54)	
unfit	88 (6)	20 (8)	
not reported		3 (1)	
<b>Medications <i>n</i> (%)</b>			
Yes	414 (29)	151 (57)	< 0.001
No	1023 (71)	110 (41)	
not reported		6 (2)	
<b>Current smoker <i>n</i> (%)</b>	105 (7)	11 (4)	0.02

**Figure 1**

Proportions of invitees, responders and non-responders to a general DAN members survey (GDMS) according to 10-year age groups



#### GENERAL DAN AP MEMBERS SURVEY

Nine-thousand-nine-hundred-and-twenty-seven DAN AP members were invited to participate. Although the genders of these invitees were unavailable, the ages of 9,398 were known (Table 1 and Figure 1).

Of 1,786 respondents (18%), 1,086 (61%) reported that they were free from any medical conditions, and 1,437 (81%) reported being free from the targeted medical conditions. Data from respondents without the targeted medical conditions were analysed in this survey. The remaining 349 subjects were excluded (including 265 who indicated that they had participated in the MCS).

Figure 1 shows the age breakdowns of invitees, responders and non-responders to the GDMS. There were two invitees over 80 years old but neither responded and are not included in Figure 1. Responders were significantly older than non-responders ( $P < 0.001$ ). Table 2 shows the demographic and medical information of the 267 responders with adequate information in the MCS and of the 1,437 responders to the GDMS without targeted medical conditions.

The sex distributions of MCS and GDMS responders were similar, with approximately 30% female and 70% males in each group. However, the divers with the medical conditions were significantly older than those without, with a difference in the means of 4.7 years. Sixty-three percent of the medical condition group were aged 50 years or older, compared with 45% of the group without the medical conditions. The mean body mass index (BMI) of divers with medical conditions was significantly higher than those without. Sixty-eight percent of the medical condition group were overweight or obese compared to 57% of the GDMS respondents ( $P = 0.001$ ).

The self-reported fitness levels of the two groups were similar with over 90% of each group assessing themselves as moderately fit or fitter. The proportion of the medical condition group who took medications was almost twice that of those without. Although the proportion of smokers was low in both groups, the proportion of smokers in the group without the medical conditions was almost twice that of those with conditions.

Table 3 describes the diving history and characteristics of the



**Table 3**

Diving history and characteristics of survey participants; OW – open water diver; Tech – technical diver; DM – divemaster; Inst – instructor; Comm – commercial diver; > 30 m – dives deeper than 30 metres; \* hold commercial qualifications but still dive recreationally

	Group		P-value
	No condition (n = 1,437)	Medical condition (n = 268)	
<b>Years diving</b> , median (IQR)	11 (5, 21)	12 (6, 22)	0.79
<b>Qualifications</b> n (%)			
OW only	304 (21)	71 (27)	0.05
OW+	420 (29)	89 (33)	
Tech	174 (12)	30 (11)	
DM	237 (17)	42 (16)	
Inst	254 (18)	32 (12)	
Comm	48 (3)*	4 (1)*	
<b>Total dives</b> , median (IQR)	300 (120, 800)	350 (150, 850)	0.37
<b>Dives in past year</b> , median (IQR)	30 (20, 60)	30 (20, 50)	0.82
<b>Time since last dive</b> (months, %)			
< 1	58	54	< 0.001
1–6	34	22	
6–12	6	17	
> 12	2	7	
<b>Depth &gt; 30 m</b> (%), median (IQR)	10 (3, 25)	10 (3, 25)	0.77
<b>Decompression</b> (%), median (IQR)	1 (0, 5)	1 (0, 5)	0.93
<b>Technical</b> (%), median (IQR)	0 (0, 5)	0 (0, 5)	0.17
<b>Repetitive</b> (%), median (IQR)	90 (50, 100)	75 (25, 95)	< 0.001

responders to the MCS and the GDMS. The groups did not differ in the numbers of years that they had been diving or their reported total dives. However, more responders without targeted medical conditions were qualified as divemaster or higher (38% vs 29%). The data for decompression dives and technical diving are especially skewed. For example, in the group without conditions, 735 divers reported doing some percentage of decompression dives - some claimed 100% and some only 1% – with many doing no-decompression dives only, giving a median for decompression diving of 1% as shown in Table 3. Similarly 435 divers reported doing some technical diving but the median percentage for this type of diving was zero.

The groups did not differ in the numbers of dives conducted over the previous year, although the divers without medical conditions reported having dived more recently or in the proportion of dives deeper than 30 metres, decompression dives or technical dives. However, those with medical conditions had done significantly less repetitive diving.

Twenty-eight (10%) responders with medical conditions reported having had decompression illness (DCI) compared with 62 (4%) of those without ( $P < 0.0001$ ). Twenty-five of the 28 MCS divers who reported DCI were diagnosed with an intra-cardiac right-to-left shunt, predominantly a persistent foramen ovale. The most common diving-related injury reported by those with medical conditions was ear or sinus barotrauma (46, 17%). Two of the cases of ear barotrauma led to significant inner ear damage but both divers continue to dive.

## Discussion

The 70:30 male to female gender distribution between the groups is similar to the 2:1 male:female ratio currently reported by the Professional Association of Diving Instructors (PADI) for its certifications for 2009–2014.<sup>15</sup> Hence, the gender breakdowns appear to be similar to the general diving population. The significantly higher age of the responders with medical conditions is consistent with the increased incidence of co-existing disease with age.<sup>7–10</sup>

Although the mean BMI of respondents with conditions was higher, the absolute difference between the groups was small and not clinically significant. However, there was a significantly higher proportion of obese divers in the cohort with medical conditions. This is consistent with data from the general population that indicate an association between the presence of significant health conditions and being overweight or obese.<sup>15–18</sup> The older age of the respondents with conditions may contribute to the higher proportion of obese divers in this group. The proportions of those with medical conditions who were overweight or obese are very similar to those in a cohort of divers from the United Kingdom (66%).<sup>19</sup> However, the UK cohort (median age 46) were not specifically known to have medical conditions. This could indicate that UK divers are more likely to be overweight or obese than our responders without conditions; or could reflect a reporting bias. Alternatively, the cohort of 346 divers reported in an earlier study had lower BMIs than all of the above-mentioned groups with 46.8% overweight or obese. This was likely due to the substantially lower

age of the cohort, of which 83% were aged 50 years or less; compared to 40% in the MCS group and 58% of the GDMS group.

Both groups rated their fitness similarly. However, this must be interpreted with caution as self-reported fitness, especially without further questions about specific activities, does not always correlate well with that measured objectively.<sup>20–22</sup> The higher incidence of medication use among those with medical conditions was expected, given the type of conditions examined, such as hypertension and cardiac disease,<sup>23,24</sup> whereas in the 2002 study of a younger cohort only 13% reported taking regular medication.<sup>5</sup> The types of medications used will be discussed in a subsequent report that will detail the various conditions. However, given the rarity of testing medications under hyperbaric conditions and the effect of certain medications on circulation and cardiac function, medication usage in divers is an area deserving more scrutiny.

Only 4% of those with conditions were current smokers, compared to 7% of those without. This is consistent with data from UK divers<sup>19</sup>, and lower than the 11.3% reported in 2002.<sup>5</sup> It compares favourably with the percentage of smokers in the general population (approximately 13% in 2013 in both Australia and Singapore, the main bases of DAN AP membership at the time of the surveys).<sup>25,26</sup> This is likely the result of the increased awareness in recent years of the adverse effects of smoking on cardiovascular and pulmonary health, especially in those with existing health conditions. The smoking rate in the general population in Australia has steadily declined in the past decade and this is likely reflected in the data from the diver surveys.<sup>25</sup>

The groups did not differ in the number of years of diving; 30% of each group had dived for 20 years or more, which is consistent with both the relatively high responder ages and recent PADI data which indicate a median certification age of 29 years.<sup>14</sup> The median number of years of diving is also very similar to the 11 years reported in the previously-mentioned UK survey.<sup>19</sup>

The generally higher level of certifications in the divers without medical conditions suggests that the presence of a medical condition could be a disincentive or barrier to the pursuit of leadership-level diving qualifications. With these qualifications, there is a greater focus on fitness-to-dive issues. The reason why those without medical conditions participated in more repetitive diving is unclear, especially given that there was little difference in the proportions of deeper (> 30 metres), technical or decompression diving, or in the reported level of diving activity. Although speculative, this may reflect the older age of those with medical conditions and an acceptance of their potential vulnerability due to the condition and the desire not to push their physical limits.

The presence of a persistent foramen ovale (PFO) is known to increase the risk of neurological, cutaneous and vestibular DCI.<sup>27,28</sup> The higher incidence of DCI among those with medical conditions is likely due to the relatively high proportion of subjects with a diagnosed septal defect, predominantly PFO. Fatality data from both Australia and the USA point to an increase in the proportion of cardiac-related disabling injuries in divers.<sup>11,12,29</sup> Some of the victims were aware of their medical condition and were under treatment at the time. However, in many victims, the condition was undiagnosed and only became apparent at autopsy. There is a need for further research into the medical and diving histories of diving fatality victims for comparison with survivor groups, such as those in this study, in order to better evaluate the risk of diving with such medical conditions.

This study has several limitations:

- DAN AP members are probably not typical of the diving population at large. They are likely older with the associated increased likelihood of co-existing disease, have more available funds, may travel more, and may better understand their potential vulnerability and the need and benefits of having appropriate insurance.
- Some applicants for DAN membership may have been reluctant to declare medical conditions for fear of it affecting their ability to obtain or retain insurance coverage, although it was made clear that failure to declare a relevant condition may nullify coverage. As a result, there were likely to have been more than the 833 members invited to join the MCS who were suffering from the targeted health conditions. This is supported by the fact that around 20% of respondents to the anonymous GDMS reported having such a condition.
- Respondents to both surveys were older than non-respondents and some selection bias may have been introduced. Therefore, some results may not be representative of the entire DAN AP membership.
- The nature of some of the more historical questions may have introduced a recall bias.
- Many responses were excluded in the MCS survey due to missing replies to certain questions. This would have been improved if the survey had been designed requiring responses to certain key questions. *SurveyMonkey*, used for the GDMS, was more user-friendly and reliable and there were consequently fewer lost responses.

## Conclusions

A large proportion of DAN AP members are diving with potentially significant medical conditions. These members appear to be older, more obese, take more medication and smoke less than other members. There were few major differences in the nature or pattern of diving between divers with and without medical conditions, excepting that those with medical conditions did less repetitive diving. Also, a

greater proportion of divers with a history of intracardiac shunts had suffered DCI. The increased proportion of older divers, the higher likelihood of co-existing disease with age, and the fact that older divers with co-existing health conditions (particularly cardiac conditions) are increasingly represented in diving fatality reports indicate a need for further research into the impact of various medical conditions on divers in order to better determine the level of risk associated with these. Future reports from this project will examine the cohorts with particular conditions and what actions they take, if any, to accommodate these.

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### Conflicts of interest

John Lippmann is the Founder and Chairman of DAN AP. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers. This study is funded by DAN AP.

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# Provisional report on diving-related fatalities in Australian waters in 2011

John Lippmann, Christopher Lawrence, Andrew Fock, Scott Jamieson and Richard Harris

## Abstract

(Lippmann J, Lawrence CL, Fock A, Jamieson S, Harris R. Provisional report on diving-related fatalities in Australian waters in 2011. *Diving and Hyperbaric Medicine*. 2016 December;46 (4):207-240.)

**Introduction:** An individual case review of diving-related deaths reported as occurring in Australia in 2011 was conducted as part of the DAN Asia-Pacific dive fatality reporting project.

**Method:** The case studies were compiled using reports from witnesses, the police and coroners. In each case, the particular circumstances of the accident and, where available, details from the post-mortem examination are provided. A chain of events analysis was conducted for each case.

**Results:** In total, there were 30 reported fatalities (10 more than in 2010). These included 15 snorkel/breath-hold divers, 14 scuba divers and one diver using surface-supplied breathing apparatus. Twenty-four victims were males. The mean age of snorkelling victims was 49.6 (range 23–75) years and compressed gas divers 42.2 (range 23–55) years. Cardiac-related issues were thought to have been the disabling injury in the deaths of at least seven snorkel divers and five scuba divers. Immersion pulmonary oedema was implicated in at least one death; and three fatalities resulted from attacks by marine animals. Two novices died while under instruction/supervision after separation from their instructor in poor visibility.

**Conclusions:** Pre-existing medical conditions, separation and inadequate supervision and seafood collection in areas frequented by marine predators were once again features in several deaths in this series.

## Key words

Diving; Deaths; Scuba; Breath-hold diving; Surface-supply breathing apparatus (SSBA); Diving incidents; Case reports

## Introduction

Every year in Australia there are deaths associated with snorkelling and diving using compressed gas (i.e., scuba or surface-supplied breathing apparatus). Although some accidents are unavoidable, many might have been avoided through better education about the proposed activity and/or associated risks; appropriate medical screening; greater experience; common sense; improved supervision; or better equipment maintenance and design. The aim of the Divers Alert Network (DAN) Dive Fatality Reporting Project is to educate divers and the diving industry and to inform diving physicians on the causes of fatal dive accidents. This is in the hope of reducing the incidence of similar incidents in the future and of detecting, in advance, those who may be at risk. This report includes the diving-related fatalities between 01 January and 31 December 2011 that are recorded on the DAN Asia-Pacific (AP) database. When an accident is unwitnessed, it is often very difficult to determine what had occurred. Therefore, we have sometimes included considered speculation within the comments to provoke thought about the possible sequence of events.

## Methods

As part of its on-going research into and reporting of diving fatalities in Australia and elsewhere in the Asia-Pacific region, DAN AP has obtained ethics approval from the Human Research Ethics Committee, Department of Justice, Government of Victoria, Australia to access and report on data included in the Australian National Coronial Information System (NCIS). In addition, ethics approvals have been sought and obtained from various coronial offices

in certain Australian States and Territories. The methodology used for this report was identical to that described in this journal previously for the 2004 Australian diving-related fatalities.<sup>1</sup>

## Breath-hold and snorkelling fatalities (Table 1)

BH 11/01

This 32-year-old (y.o.) obese man had a history of lifelong asthma with frequent hospital admissions. He worked as a painter, which sometimes exacerbated his condition, and he smoked six cigarettes a day. He was taking prednisone and salmeterol and his wife reported that his asthma management had improved. He was reported to be a strong swimmer who snorkelled regularly. On this occasion, he and his niece went snorkelling off a rocky ocean shore as they often did together. It was early morning and the weather conditions were described as fine, with a light breeze and a slight swell, although the surface was choppy. The victim was wearing a mask and snorkel (possibly fins, but this was not stated) and was dressed in shorts and a t-shirt.

The pair had been snorkelling about 20 m apart and approximately 50–60 m from shore when the niece saw the victim standing on the reef in waist-deep water, obviously distressed and struggling to breathe. When she reached him, he had removed his mask and snorkel and complained that he could not breathe or swim. When he grabbed her for support they were washed off the reef by the swell and she struggled to stay afloat while supporting him. A short time later he became unconscious. After several minutes, she found some shallower reef to stand on and, after finding no

**Table 1**  
 Summary of snorkelling and breath-hold diving-related fatalities in Australian waters in 2011; BCD – buoyancy compensation device; BMI – body mass index; BNS – buddy not separated; BSB – buddy separated before problem; n/s – not stated

BH	Age (y)	Sex	Height (m)	Weight (kg)	BMI (kg·m <sup>-2</sup> )	Training	Experience	Dive group	Dive purpose	Depth (msw)	Incident (msw)	Weights		BCD	Disabling injury
												On	kg		
11/01	32	M	189	120	34	n/s	yes	BSB	recreation	n/s	surface	none	-	n/s	Asphyxia
11/02	27	F	167	57	20	n/s	nil	BSB	recreation	n/s	surface	none	-	n/s	Asphyxia
11/03	69	M	179	84	26	n/s	yes	solo	exercise	n/s	surface	none	-	n/s	Cardiac incident
11/04	30	M	177	78	25	trained	yes	solo	spearfishing	22	n/s	on	6.8	n/s	Asphyxia
11/05	56	M	187	96	25	n/s	n/s	BSB	recreation	n/s	surface	none	-	n/s	Cardiac incident
11/06	25	M	195	-	-	n/s	yes	solo	spearfishing	n/s	n/s	n/s	-	n/s	Asphyxia
11/07	49	M	194	102	27	n/s	n/s	BSB	spearfishing	n/s	n/s	none	-	n/s	Asphyxia; trauma
11/08	69	M	190	120	33	n/s	yes	BSB	recreation	n/s	n/s	none	-	n/s	Cardiac incident
11/09	59	F	155	65	27	n/s	yes	solo	recreation	n/s	surface	none	-	n/s	Cardiac incident
11/10	64	M	186	83	24	n/s	yes	BSB	spearfishing	n/s	n/s	on	2.0	n/s	Cardiac incident
11/11	62	M	171	92	32	n/s	nil	group	recreation	1–5	surface	none	-	n/s	Cardiac incident
11/12	60	M	179	83	26	n/s	n/s	group	recreation	n/s	surface	none	-	no	Asphyxia; cardiac incident?
11/13	75	M	178	93	29	n/s	yes	BNS	recreation	n/s	surface	none	-	no	Cardiac incident
11/14	23	M	184	105	31	n/s	nil	solo	spearfishing	5	surface	on	13.0	n/s	Asphyxia
11/15	44	M	182	102	31	n/s	n/s	BSB	recreation	n/s	surface	none	-	n/s	Asphyxia

signs of breathing, gave her uncle some rescue breaths. She saw some bystanders on shore and shouted to them for help. Some 15 minutes (min) later two men came to her aid to bring the victim to shore. Basic life support (BLS) was begun by bystanders and taken over by police and paramedics when they arrived a short time later. The victim failed to respond.

**Autopsy:** The autopsy was performed three days post mortem. Body mass index (BMI) was 34 kg·m<sup>-2</sup>. The heart was heavy, weighing 508 g (normal range, n.r. 331–469 g). There was ventricular hypertrophy of 15 mm (n.r. < 14 mm) on the left and 5 mm (n.r. < 4 mm) on the right. The coronary arteries were free from atheroma. The right and left lungs weighed 848 g (n.r. 446–880 g) and 942 g (n.r. 348–790 g) respectively and were heavy. There was no pulmonary oedema fluid or mucus plugging in the trachea. The lungs were congested but not described as overexpanded. Histology of the lungs showed changes of asthma. The cause of death was given as drowning subsequent to asthma.

**Toxicology:** nil

**Comments:** With the potential triggers of exercise, cold, salt water aspiration and anxiety, it is unsurprising that snorkelling sometimes precipitates asthma in a susceptible person. With his history of hospital admissions for severe asthma, this man was at risk of an exacerbation, unfortunately with fatal consequences due to the hostile environment and lack of readily accessible medical care.

**Summary:** 32 y.o. obese male; lifelong asthma with frequent hospital admissions; strong swimmer and experienced snorkeller; asthmatic attack; prompt buddy assistance but washed into deeper water; unconsciousness; drowning

BH 11/02

This 27 y.o. woman was an overseas tourist back-packing across Australia. Her travelling companions reported that she appeared to be fit and healthy and was not taking medications. She had told them that she was a poor swimmer and had only snorkelled twice, two days earlier. She was using a mask, snorkel and fins that were hired by one of her male companions, the fins being larger than ideal. She was wearing a bikini and shirt. The victim and one of her friends snorkelled in waist-deep water, while another swam to deeper water about 50 m away. The sea was calm and clear, with a water temperature of 28°C. The site is well-known for strong long-shore currents although there was no mention of this in the reports.

After an unknown time (but less than 30 min) the friend nearby indicated that he was returning to shore and she responded that she was fine. However, about two minutes later when the friend looked back, he could no longer see the victim snorkelling and was surprised to see her lying motionless on the shoreline. When he went to her, he found

her to be unconscious with water oozing from her mouth and nose. He began BLS and was soon assisted by some of the others. However, this was soon abandoned. The reason for this was variously given as “*she had coughed up a lot of water and blood on the beach and took a couple of breaths and appeared to be wheezing slightly*”, and she “*looked like she was gone*”.

With the help of others, she was carried to the carpark. BLS had been ceased for at least 20 min before some rangers arrived with an automated external defibrillator (AED) and oxygen equipment. They found the victim to be unconscious, apnoeic and cyanotic and so recommenced resuscitation. Once attached, the AED indicated that no shock was advised. Ventilations were hampered by the expectoration of blood and mucous, and resistance to inflation (partly resolved by increasing head tilt). On arrival, police assisted with the BLS, noting that the victim appeared to be “*quite stiff*” and that “*with every compression there was a slushing noise*”. Paramedics arrived approximately 75 min after the incident. After assessing that the victim had no palpable pulse, fixed dilated pupils and body stiffness, they pronounced her dead.

When checked later, the mask and fins appeared to have been in good condition, although possibly ill-fitting on the victim. The snorkel was missing when the victim was found and was not recovered in a subsequent search.

**Autopsy:** The autopsy was performed five days post mortem. BMI was 20 kg·m<sup>-2</sup>. The right and left lungs weighed 748 g (n.r. 358–714 g) and 734 g (n.r. 305–596 g) respectively. They were heavy, congested and oedematous. The upper airways were free of debris. The heart, which weighed 208 g (n.r. 213–361 g), was of normal size and configuration with no atherosclerosis of the coronary arteries. Superficial bruising of scalp, arms and legs was consistent with contact with rocks and evidence of vigorous CPR. The cause of death was given as drowning.

**Toxicology:** nil

**Comments:** This incident is testimony to how easily an inexperienced snorkeller can drown, even in shallow water, often as a result of inadvertent aspiration of water through the snorkel (or of water in a leaking mask). A confident swimmer is more likely to maintain control and stand. However, a person with little aquatic experience may sometimes not do this as readily and wearing fins can make this more difficult. Close and constant supervision is valuable. It is unfortunate that the initial rescuers aborted BLS efforts so early. There was virtually no chance of survival after the abandonment of resuscitation for 20 minutes or longer.

**Summary:** 27 y.o. woman; apparently healthy; poor swimmer and inexperienced snorkeller; intentional separation from buddy in waist-deep water; poor and intermittent early BLS; drowning

## BH 11/03

This 69 y.o. male was holidaying at a tropical coastal town. He had a history of atrial fibrillation, atypical chest pain (with a normal electrocardiogram (ECG) and echocardiogram), and prostate cancer (radical prostatectomy). The only medication he was taking was 150 mg aspirin daily.

He had been in the area for over a month and went snorkelling most days for exercise, using a regular route of 150 m around several buoys. Wearing bathers, mask and snorkel, the victim began his lap of the buoys, swimming 'freestyle'. His wife and some friends remained on the beach, reading and occasionally checking on the victim. However, at one point they lost sight of him and became concerned. He was soon seen about 75 m away and appeared to be floating motionless other than gently drifting in the current. They did not act immediately but a short time later became more concerned as he was still not swimming. When one of the friends swam out to the victim, he found him unconscious and floating with his entire head and snorkel submerged. The friend rolled the victim over onto his back and noted that he still had his mask in place with the snorkel in his mouth, but was cyanotic. The friend began towing the victim towards shore and was soon relieved by some bystanders, one of whom was a trained lifesaver. Two 'noodles' were placed under the victim to provide buoyancy. One of the rescuers tried unsuccessfully to palpate his carotid pulse and the lifesaver began rescue breathing while the victim was brought to shore. He was described as being a greyish colour with open eyes.

Once on the beach, BLS was performed for about 10 minutes, during which they rolled the victim onto his side at least six times to clear regurgitated water and vomit from his airway. BLS was then continued by two off-duty volunteer ambulance personnel who were nearby. A short time later, a local volunteer ambulance crew arrived. An oropharyngeal airway was inserted and oxygen-supplemented ventilations were provided using a manually-triggered oxygen ventilator (Oxy-Viva). An AED was attached, which indicated that the victim was in asystole. No advanced life support (ALS) was provided (the volunteer ambulance officers in that area are not trained in ALS) and resuscitation was ceased on the advice of a doctor (by phone) after a total of 25 minutes.

*Autopsy:* This was conducted six days post mortem. BMI was 26 kg·m<sup>-2</sup>. The heart weighed 440 g (n.r. 331–469 g). There was severe atherosclerosis of the coronary arteries with greater than 75% narrowing of the right and left anterior descending (LAD) coronary arteries and a 20 x 10 x 10 mm scar of the postero-lateral left ventricle. There was fusion of the right and non-coronary cusps of the aortic valve with calcification and sclerosis but no left ventricular hypertrophy. There was gastric aspirate in the upper airways. The right and left lungs weighed 674 g (n.r. 446–880 g) and 548 g (n.r. 348–790 g) respectively. They showed anthracosis

and bullous emphysema of the upper lobes, with marked pulmonary oedema and congestion. There was 100 ml of straw-coloured fluid in both pleural cavities. The cause of death was given as cardiac arrhythmia in a man with ischaemic and valvular heart disease following immersion. Toxicology: nil

*Comments:* It is likely that this man suffered from a cardiac arrhythmia and became unconscious. Being alone and quite a distance from shore, his chances of survival were poor. Given his significant cardiovascular disease, an arrhythmia could have occurred in many situations. However, the cardiovascular effects of immersion coupled with exertion may well have precipitated the event. Given that there was no measurable left ventricular hypertrophy, in the presence of aortic stenosis it is likely that the coronary artery atheroma was the more significant factor. However, even mild aortic stenosis increases the risk of sudden death.<sup>2</sup> The valvular pathology and the likely cardiac murmur should probably have been picked up by the echocardiogram and auscultation.

*Summary:* 69 y.o. male; severe coronary artery atherosclerosis, ischaemic heart disease and aortic valve stenosis; regular swimmer and snorkeller; snorkelling alone and distant from shore; cardiac incident

## BH 11/04

This fit, healthy, 30 y.o. man was an experienced scuba diving instructor and competent breath-hold diver and spearfisherman. He was not known to be taking any medications. After finishing work at 0300 h, he had a brief sleep before meeting two friends at 0600 h to go spearfishing from his boat. The weather was clear with a light wind, the sea was calm with little current, water temperature 19°C and visibility 20 m. The boat was anchored 50 m from a rocky coastline at a site with rocky, kelp-covered boulders and a depth of 22 metres' sea water (msw). He was wearing a mask, snorkel and long-bladed fins; a 3 mm wetsuit with hood; a quick-release weight belt with 6.8 kg of weights, a dive watch incorporating a dive computer, knife and speargun.

The trio snorkelled in a radius of about 50 m from the boat. The victim had done seven breath-hold dives, the deepest being 18 msw and the longest 1:43 min before they decided to return to the boat and go to another site. The victim remained in the water to ensure that the anchor was not snagged, then decided to have one more dive while his buddies remained in the boat. The others became concerned when he had not returned after almost 10 min. After a brief and unsuccessful surface scan, they went to a nearby boat to raise the alarm. One of the buddies commenced an underwater search and soon sighted the victim lying prone on the seabed with the speargun next to him and a speared fish floating nearby. The buddy was unable to reach the victim as it was beyond his depth capability.



Police divers retrieved the body almost 7 h later. The victim was lying at a depth of 21.5 msw with his all his equipment (including his weight belt) in place. There were obvious signs of facial barotrauma.

*Autopsy:* This was performed four days post mortem. BMI was 25 kg·m<sup>-2</sup>. Red discolouration around the eyes was consistent with mask squeeze although the tympanic membranes were intact. The heart weighed 354 g (n.r. 295–445 g) and was of normal size and configuration. There was no coronary artery atherosclerosis. There was frothy fluid in the mouth, larynx and trachea. The right and left lungs weighed 820 g (n.r. 410–892 g) and 774 g (n.r. 378–780 g) respectively, and there was 200 ml of straw-coloured fluid in both pleural cavities. The cause of death was reported as drowning.

Toxicology: nil

*Comments:* Four days after death when this autopsy was performed, some of the pulmonary oedema in the lungs may have manifested as fluid in the pleural cavities and so the diagnosis of drowning becomes more difficult the longer the post mortem delay. It is likely that the victim extended his breath hold in order to spear the fish, became unconscious during ascent and then sank to the bottom (evidenced by the facial barotrauma). His dive watch indicated that this last dive was to 21.5 msw for a time of 25:57 min but this dive profile was not informative as he might have only reached this maximum depth when unconscious. Given that the victim had been submerged for almost seven hours, the time indicated on the watch was unreliable. Although the police investigator suggested that pre-dive hyperventilation was likely a contributing factor (and it might have been), neither buddy reported that the victim hyperventilated prior to diving. This case again highlights the importance of the 'one-up-one-down' principle in breath-hold diving, i.e., where one diver remains on the surface and watches the other while underwater. However, in this case, a buddy may not have been able to retrieve him owing to the depth.

*Summary:* Fit, healthy, 30 y.o. male; experienced scuba instructor and breath-hold diver; spearfishing alone while others returned to boat; speared fish and failed to surface; drowning (likely apnoeic hypoxia)

BH 11/05

The victim was a 56 y.o. male with a family history of heart disease and a highly stressful job. He rarely visited a doctor, although six years earlier he had undergone a medical assessment, including a stress ECG, for his employment. At that time, he was diagnosed with hypertension and hypercholesterolaemia and advised to have an angiogram, which he refused. He was not taking any prescribed medications but often took cold and 'flu' tablets and drank alcohol regularly. His wife stated that it was not unusual for him to consume at least six full-strength beers per day. Of late, he had been exercising more than usual; swimming,

cycling and bush walking. His snorkelling experience was unknown.

He and his wife were local tourists visiting a small semi-tropical island. The 2 km track to the beach required a steep climb and the victim was slow and became short of breath. Once at the beach, the wife donned snorkelling equipment and swam to a shallow wreck approximately 80 m from shore. She set out alone as the victim was slow to put on his gear. The water temperature was around 24°C and the victim was wearing a bathing costume.

On reaching the wreck, the wife looked back and saw her husband standing in the water and signalling to her to come back. He yelled to her that he was returning to shore. She continued to snorkel but soon heard him calling out that he needed help. When she reached her husband, he told her that he had panicked and lost his way. He was standing in chest-high water and she noticed that he was becoming cyanotic and "*had a rattling sound in his chest*". He soon had difficulty standing and became incoherent. The wife supported the victim's head above the water and dragged him towards shore. His eyes were closed, he was silent and was unable to float. There was "*foam and syrup coming from his mouth*". A short time later another person arrived and BLS was commenced and continued for 10–15 min without any response.

*Autopsy:* This was performed four days post mortem. BMI was 25 kg·m<sup>-2</sup>. The heart was heavy, weighing 570 g (n.r. 331–469 g). There was 75% stenosis of all three major coronary arteries and left ventricular hypertrophy of 15–20 mm (n.r. < 14 mm). The upper airways were clear of fluid but the lungs were very heavy, the right and left lungs weighed 1370 g (n.r. 446–880 g) and 1220 g (n.r. 348–790 g) respectively. There was moderate pulmonary oedema. Ocular fluid showed sodium [Na<sup>+</sup>] 108 mmol·L<sup>-1</sup> and chloride [Cl<sup>-</sup>] 99 mmol·L<sup>-1</sup>. The post mortem vitreous [Na<sup>+</sup>] + [Cl<sup>-</sup>] (PMVSC) was 207 mmol·L<sup>-1</sup> which did not suggest drowning (a PMVSC of 259 mmol·L<sup>-1</sup> or greater indicates salt water drowning provided the body is not immersed for more than one hour<sup>3</sup>). Cardiac troponin I was 49.09 ng·ml<sup>-1</sup> (n.r. 0.10 ng·ml<sup>-1</sup> *in vivo*; range at post mortem not yet established). The cause of death was given as ischaemic heart disease.

Toxicology: nil

*Comments:* There were multiple warning signs that this man had ischaemic heart disease and was probably not fit to undertake this activity. Given the extent of his heart disease at autopsy and the recent exertion it is unsurprising that this incident occurred, whether or not in the water. It is unfortunate that BLS was abandoned so soon. However, this probably made no difference to the outcome as ALS was not promptly available. Although there is a small hospital relatively close to the site, there was no mobile coverage and medical assistance could not be activated without a substantial delay.

*Summary:* 56 y.o. male; severe ischaemic heart disease; heavy drinker; hypertension and hypercholesterolaemia; infrequent medical assessment; exertion leading to dyspnoea; anxious and disoriented in water; cardiac incident

BH 11/06

This 25 y.o. male was reported to have been healthy despite a recent back injury. He was taking no regular medications but used recreational drugs, predominantly cannabis and methyl amphetamines. A friend reported him to be a good swimmer and snorkeller. He and some friends were by a lake (in fact, a large irrigation holding dam). Although there was no flowing water, there were lots of potentially hazardous reeds in the water. The victim decided to go spearfishing while his friends went bushwalking. Before leaving he had consumed two cans of rum and smoked some cannabis, but reportedly was lucid and happy. He was wearing shorts and heavy shoes and carrying a mask and snorkel, and a speargun, which his friend told him was an illegal model.

When the victim failed to return as agreed, the friends became concerned, called the police and a search was commenced. A camper reported having seen the victim walking alone long after he was expected to meet his friends. The next day, he was sighted by searchers but retreated into the bush. His body was found floating in the lake the following morning, wearing shorts, shoes and a mask. The snorkel and speargun were not found.

*Autopsy:* This was conducted four days post mortem, revealed water immersion changes of hands and feet and marked decomposition changes with discolouration marbling and skin slippage. His weight was not reported. The heart, which weighed 290 g (n.r. 295–445 g), was of normal size and configuration and there was no atherosclerosis. There was a small amount of frothy fluid in the upper airways. The right and left lungs weighed 500 g (n.r. 410–892 g) and 459 g (n.r. 378–780 g) respectively, and were variably expanded and soft. There was a large accumulation of haemorrhagic fluid in the left pleural cavity. The cause of death was given as “*probable drowning due to methamphetamine and alcohol intoxication*”.

*Toxicology:* Alcohol 0.109 g·100 ml<sup>-1</sup>; amphetamine < 0.007 mg·kg<sup>-1</sup> (contaminant of methyl amphetamine); methyl amphetamine 0.20 mg·kg<sup>-1</sup>; THC not detected (however, metabolites of cannabis were detected, suggesting past cannabis use).

*Comments:* Toxicology revealed methamphetamine based on body cavity blood. Normally, toxicology is performed on femoral venous blood but this was probably not available due to decomposition. Cavity blood may be inaccurate due to post-mortem redistribution of drugs. In addition, some of the alcohol detected could have been from post-mortem decomposition. It is likely that the victim was drug-affected, became disoriented and was unable to return to the agreed

meeting place. It was speculated that he hid from the rescuers out of concern that he would be in trouble for having an illegal speargun. However, there remain many questions about his state of mind and what led to his apparent drowning. Methyl amphetamine can have toxic effects on the heart and this level of drug could have directly caused death, although the circumstances probably do not suggest it. Methyl amphetamine also predisposes to erratic behaviour and is associated with an increased risk of self-harm.

*Summary:* Healthy 25 y.o. man; experienced swimmer and snorkeller; recent use of alcohol, cannabis and methyl amphetamine; spearfishing alone; avoided searchers; drowning

BH 11/07

A fit 49 y.o. local with no significant medical history, this man was a strong swimmer and experienced scuba diver and spearfisherman. He was the skipper of a large barge delivering supplies to an island north-west of the Great Barrier Reef (GBR). After anchoring the vessel near a small islet, the skipper and a crew member set off in a tender which they anchored close to the shore and began spearfishing. The victim was wearing a mask, snorkel, fins, a stinger suit and gloves and was carrying a speargun and towing a float with a wire hook attached. The weather was clear, the sea calm, with visibility of 10–15 m, and there was a current in excess of 2–3.5 km·hr<sup>-1</sup>. The site was a coral reef at depths of 3–6 msw.

The victim dived several times for periods up to 1.5–2 min before calling his buddy to him and showing him that he had already caught two fish. These were attached to the wire hook on his float. When the victim dived again, the buddy scared off a small reef shark that was trying to take the fish. The pair separated but the buddy reported that he checked for the victim’s float every 25 min or so. He also moved the tender several times as they were drifting with the current.

After about an hour, when the buddy was repositioning the tender, he saw the victim’s float and noticed one end of the line was floating on the surface, no longer attached to the float. When he swam to it he noticed that the victim’s spear gun was attached to the line and hanging at a depth of about 4 msw. He became concerned when he could not see the victim and boarded the dinghy and kept a lookout for about 30 min before dragging in the victim’s float and line with the speargun. The speargun was partially loaded, as if this had been done hurriedly, the fish were no longer attached to the float’s hook, which was bent, and the float line looked frayed as if it had been torn, rather than having been a clean cut.

A full air and police vessel search was initiated. The victim’s body was found the next morning, floating approximately 200 m from where he was last seen. There was evidence of

severe trauma consistent with an attack by a large marine animal. The site was known to be the home of a large (4 m) saltwater crocodile which was reported to be very territorial.

*Autopsy:* This was performed four days post mortem. BMI was 27 kg·m<sup>2</sup>. There were numerous haemorrhagic 10 mm puncture marks on the head, chest, abdomen, arms and legs. There were also facial and rib fractures and puncture wounds of the lung and liver, with intra-abdominal haemorrhage. The heart weighed 365 g (n.r. 331–469 g) and was normal in size and configuration with minimal atheroma of the coronary arteries. The upper airway contained fluid. The right and left lungs weighed 588 g (n.r. 446–880 g) and 497 g (n.r. 348–790 g) respectively, and showed moderate pulmonary oedema. The cause of death was recorded as drowning secondary to a crocodile attack.

*Toxicology:* Alcohol 0.039 g·100 ml<sup>-1</sup> on cavity (not femoral) blood, some or all of which may be due to decomposition

*Comments:* The pattern of injuries suggested a crocodile rather than a shark attack, the animal having been attracted to the catch. If he had hurriedly tried to re-load his speargun, as suggested by the buddy, it is possible that he had seen the creature and attempted to defend himself. It is unknown whether or not the victim was aware of the large crocodile which lived at that site. If so, it was imprudent to snorkel there, especially essentially solo. The facial fractures, but no intracranial injury, and rib fractures with puncture injuries to the lungs would probably have incapacitated him and caused drowning rather than directly causing death.

*Summary:* Healthy 49 y.o. male; strong swimmer and experienced spearfisherman; intentional separation from buddy; speared fish attached to float; severe trauma consistent with marine animal attack; drowning (likely subsequent to crocodile attack)

#### BH 11/08

This 69 y.o., obese man and his wife were overseas tourists visiting the GBR. He had a history of non-insulin dependent diabetes mellitus (NIDDM) and hypertension for which he was taking a variety of unidentified medications. He was a competent swimmer and had snorkelled before, although not for some time. He and his wife were on a day trip on a large tourist yacht moored 70 m from shore. A detailed snorkelling brief was given and participants were asked to declare any medical conditions. The victim made no declarations.

The conditions were described as clear with a light wind and very little current. The victim was fitted with mask, snorkel and fins and a wetsuit. He and his wife entered the water together but soon separated as she was having trouble swimming. Sometime later she saw her husband “*bobbing up and down between the boat and shore*”. She tried to swim to him but others reached him first and towed him to shore. The victim was unconscious, apnoeic and cyanotic and

BLS was commenced by a crew member and a passenger. Supplementary oxygen was provided. Possibly 10 min had elapsed from the time he was sighted to the commencement of BLS. He was then transported by boat to a clinic at a nearby resort. On arrival, some 30–40 min after the victim was found, the nurse noted that the victim’s pupils were fixed and dilated and that he was regurgitating water and stomach contents. She attached an AED but no shock was advised. BLS was continued for 25 min without a response.

*Autopsy:* This was conducted four days post mortem. BMI was 33 kg·m<sup>2</sup>. The heart weighed 410 g (n.r. 331–469 g) with prominent left ventricular hypertrophy and an area of scarring. There was severe coronary atherosclerosis of the right and LAD coronary arteries. There was fluid (possibly gastric content) in the upper airway. The pathologist reported that the lungs showed “*no evidence of drowning*” (sic). The right and left lungs weighed 780 g (n.r. 446–880 g) and 740 g (n.r. 348–790 g) respectively, with evidence of mild pulmonary oedema. The cause of death was given as coronary atherosclerosis.

*Comments:* It is likely that this man suffered from a cardiac arrhythmia, became unconscious and subsequently drowned. It is probable that he had been unconscious and apnoeic for some time before being noticed and rescued.

*Summary:* 69 y.o., obese man with a history of NIDDM, hypertension, coronary artery atherosclerosis; competent swimmer; some snorkelling experience; separated from buddy; cardiac incident

#### BH 11/09

This 59 y.o. woman was visiting Australia with her husband and daughter. The husband, who was her doctor, reported that she had a history of NIDDM, hypercholesterolaemia and asthma, underwent regular health checks with him, was well-controlled and medicated (medications unreported) and in good health at that time. He also stated that she had snorkelling experience from “*half a dozen*” previous holidays and that she always became anxious before snorkelling. There was no report about her swimming ability.

They were with 83 other passengers on a large charter vessel on the GBR. The crew gave a briefing to all intending snorkellers while en route to the dive site. Along with other safety information, the briefing included the importance of notifying a crew member of any significant medical conditions and a list of conditions of concern (which included diabetes and asthma) was handed around the group. However, snorkellers were not required to complete a medical declaration form and the victim did not report that she suffered from a medical condition. The conditions were reported to be sunny with a light wind, a calm sea and slight swell. Visibility was 20–25 m and the depth of the site was 0–7 msw. The captain acted as a lookout.

After donning a wetsuit and taking a mask, snorkel, fins and a 'noodle' floatation aid, the victim told a crew member that she was anxious and asked to be accompanied by a guide. She entered the water with the noodle under her chest and holding a 'boogie board' supported by a guide. The guide stated that the victim soon appeared to relax and enjoy the snorkelling and that he stayed with her for 15–20 min, after which she requested to snorkel alone. The guide agreed and, after watching her for 5 min, he swam off to monitor others. He assumed that she would join a buddy but this did not seem to occur, although she swam near others.

A short time later, a photographer filmed the victim snorkelling and apparently well although, about five minutes later, she was seen drifting motionless in the slight current. The guide called to her and, when she did not respond, he swam to her. When he grabbed her he saw her mask and snorkel sinking below. He quickly turned her over and, finding her to be unresponsive, signalled to staff on the boat, some 30–40 m away. He then dragged the victim onto his boogie board and started in-water rescue breathing. When the tender arrived, "*within a minute*", the victim was dragged aboard and BLS was commenced and continued after the victim was brought aboard the main vessel. An AED was soon attached and no shock was advised, so BLS was continued and supplementary oxygen provided. A doctor and a nurse who were passengers assisted with BLS, which continued until the arrival of paramedics almost two hours later. The victim failed to respond.

*Autopsy:* This was performed one day after death. BMI was 27 kg·m<sup>-2</sup>. The heart weighed 325 g (n.r. 285–439 g) and showed left ventricular hypertrophy and focal scarring. There was 90% stenosis of the left main and LAD coronary arteries. The other two vessels were less than 25% narrowed. There was some scarring of the myocardium but no contraction band necrosis. There was fluid in the trachea. The right and left lungs weighed 657 g (n.r. 305–817 g) L and 549 g (n.r. 287–695 g) respectively, and showed moderate pulmonary oedema. The cause of death was given as drowning owing to ischaemic heart disease.

*Comments:* This appears to have been a silent cardiac-related death, which occurred close to other snorkellers. In light of the substantial coronary artery atherosclerosis, it is likely the victim suffered from an arrhythmia, became unconscious and subsequently drowned. The dive operator was criticised by the workplace authority for failing to ensure that the victim was paired with a buddy when she separated from the guide. However, she was close to others and being with a buddy would likely have made little or no difference to the outcome. The rescue appears to have been done swiftly and resuscitation efforts were prompt and appropriate. The mask and snorkel were never recovered so it is not known if there was any problem with these.

*Summary:* 59 y.o. woman with a history of NIDDM,

hypercholesterolaemia and asthma not declared and reportedly stable; anxious, relatively inexperienced snorkeller; snorkelling without buddy but near others; 'silent' drowning (cardiac-related)

BH 11/10

This 64 y.o. overseas visitor had no known medical history. He was a competent swimmer and experienced snorkeller. He, his son, and a friend went spearfishing along a sea wall. There was a 18 km·h<sup>-1</sup> wind, a slight swell and a slight current. He was wearing 'speedos'; mask, snorkel and fins; a weight belt with 2 kg of weights and was carrying a speargun.

The group entered the water and swam along the sea wall. The friend caught several fish and returned to shore with them. After a short time he watched the others turn back and he signalled the victim, who indicated that all was fine. The son swam together with his father most of the way back. However, when he reached a point where waves were breaking, he swam ahead and reached shore (about one hour after entering and 20 min after turning back). When he looked for his father, he noticed that he hadn't moved and had largely submerged with only a fin visible, about 25–50 m from the wall.

The son and his friend swam over to the victim who was unconscious and motionless and his face looked grey. He was still wearing his diving equipment. They dragged him onto a rock and began BLS, complicated by a lot of regurgitated water and by waves crashing onto the rock. A bystander soon arrived with a surf board onto which they dragged the victim and brought him to shore, where BLS was continued. Two nurses who witnessed the incident took over the resuscitation efforts. An ambulance arrived and transported the victim to hospital where he was pronounced dead.

*Autopsy:* This was conducted four days post mortem. BMI was 24 kg·m<sup>-2</sup>. The heart weighed 420 g (n.r. 295–445 g) and was normal in size and configuration. The coronary arteries showed a pin-point lumen of the LAD, 80% narrowing of the right, 75% narrowing of the left main and 60% narrowing of the left circumflex. There was sub-endocardial fibrosis and contraction band necrosis. The foramen ovale was closed. There was no fluid in the upper airways. The right and left lungs weighed 568 g (n.r. 410–892 g) and 561 g (n.r. 378–780 g) respectively, and showed areas of under- and over-inflation, haemorrhage and pulmonary oedema. The cause of death was given as drowning owing to cardiac arrhythmia due to ischaemic heart disease.

*Comments:* This victim had significant atherosclerosis which, combined with the effort of swimming against a current and encountering breaking waves, may have caused a cardiac dysrhythmia and subsequent unconsciousness. Alternatively, the victim might have been swamped by a breaking wave and simply drowned.

*Summary:* 64 y.o. male; no medical history although significant coronary atherosclerosis at autopsy; experienced swimmer and snorkeller; spearfishing with others; separation; BLS unsuccessful; drowning (cardiac-related)

BH 11/11

This man was a 62 y.o. interstate tourist. He was obese and a year earlier was diagnosed with what his wife described as a “weakened heart” and was taking carvedilol and frusemide. He had visited his doctor before the trip and was told that he was fine to “have a holiday and live life normally”. He and his wife went on a large charter vessel to snorkel on the GBR. His swimming competency was unknown but he had never snorkelled before.

Whilst en route to the destination island, the snorkel guide gave a briefing and explained the use of the snorkelling equipment. She claimed that she had asked the participants to indicate to her if they were suffering from any condition that could cause them to go unconscious, and stated that no-one, including the victim, reported any medical conditions. However, some other witnesses reported that there was no question about medical conditions. There were no declaration forms circulated. On arrival, the vessel moored 100–120 m from shore and the snorkelling groups were ferried to shore on a glass-bottomed boat. There they were fitted with mask, snorkel and fins. The victim was wearing shorts and no wetsuit. The weather was reported as clear, windless and the water was calm.

The victim and his wife were in a group with two others, led by a guide who was towing a rope attached to a large rectangular float made from PVC pipe. This was capable of supporting several swimmers if required. The victim and his wife held onto the float. The snorkelling area was 1–5 msw deep and the guide assessed the groups’ snorkelling ability as they swam around her. There were lookouts on the shore and the boat. The guide towed the float for some time with the others holding onto it. After about 25 min, the victim tugged on the float as he lifted his head. His mask was on his forehead. The guide asked the victim if his mask was OK and he nodded to indicate that he was, but did not speak. She asked if he was “having a good time” and he smiled but, again, did not speak.

The group snorkelled for another 10 min, holding onto the float, before heading towards shore. When the guide turned and saw the victim vertical in the water and leaning heavily on the float, she again asked if he was okay. Although he answered in the affirmative, she was not convinced as he was pale and looked anxious. He began to cough, became more distressed and tried to climb onto the float. The guide signalled to the tender, about 40 m distant, which soon came alongside. The victim was helped into the tender but soon collapsed onto his hands and knees, very dyspnoeic and moaning. Shortly afterward he became unconscious and apnoeic.

BLS was commenced by the crew (with a ratio of 30:3) and an AED and oxygen equipment were brought from the main vessel. The AED was attached but no shock was advised. The ambulance service was called and a doctor remained on the line while BLS continued. After 45 minutes without signs of recovery, the doctor advised that resuscitation efforts be ceased.

*Autopsy:* This was conducted three days post mortem. BMI was 32 kg·m<sup>-2</sup>. The heart was heavy, 484 g (n.r. 331–469 g) and showed left ventricular hypertrophy and focal scarring. The left main and left circumflex coronary arteries were 90% narrowed by calcific atheroma and the right coronary was 50% occluded. The upper airways contained frothy fluid. The right and left lungs weighed 1012 g (n.r. 446–880 g) and 851 g (n.r. 348–790 g) respectively and showed moderate pulmonary oedema. The cause of death was given as cardiac arrhythmia owing to ischaemic heart disease.

*Comments:* It is likely that this man suffered from a cardiac arrhythmia due to his cardiac disease combined with the effects of immersion. He died despite what appears to have been the prompt application of BLS, including the attachment of an AED. Like many others on these GBR trips, he failed to declare his heart condition, if in fact he was asked to do so. If the question was raised, he might have felt this was unnecessary given his recent medical clearance. It is far preferable for an operator to require a written declaration as it may make the person think more about his or her response.

*Summary:* 62 y.o. male; obese; history of cardiac condition; ischaemic heart disease; first time snorkelling; well supervised; prompt BLS and AED shock; cardiac incident

BH 11/12

This 60 y.o. man took time out from a business trip to Australia to go snorkelling on the GBR. He had a history of hypertension (diagnosed one year earlier) for which he was taking perindopril. His swimming ability and snorkelling experience were unreported. He was a passenger on a 20-metre tourist vessel carrying 78 passengers, which moored on a reef. The weather was described as sunny with a strong wind (approx. 35–45 km·h<sup>-1</sup>). The water was very choppy with visibility of around 5 m, and there was a strong surface current. The victim was wearing a mask, snorkel, fins and a ‘shortie’ wetsuit. He was not wearing a flotation snorkelling vest. He entered the water with a group but became separated from the others.

None of the three snorkelling guides in the water or a lookout on the lower deck of the boat detected a problem. However, a passenger raised the alarm when she noticed that the victim had been motionless for several minutes. When an instructor swam to check the victim, he was found to be unconscious with his snorkelling equipment still in place. The tender arrived almost simultaneously and the victim was dragged aboard. His eyes were open, his face was bloated,

his jaw clenched and white, frothy sputum was coming from his mouth. He was rolled onto his side to clear his airway before BLS was begun.

On arrival at the main vessel, BLS was continued with supplementary oxygen. The skipper called the emergency services and contacted a nearby boat to ask for an AED as there was none on board. BLS was continued by the crew and when an AED was attached, 10–15 min later, no shock was advised. A helicopter with medical crew arrived approximately 15 min later and ALS was implemented. The victim was evacuated to hospital but was pronounced dead after 90 min of unsuccessful resuscitation.

*Autopsy:* This was conducted three days post mortem. BMI was 26 kg·m<sup>-2</sup>. The heart weighed 420 g (n.r. 331–469 g) and there was equivocal left ventricular hypertrophy with scarring of the posterior wall of the left ventricle, and dilatation of the right ventricle. The coronary arteries showed up to 60% narrowing of the LAD and right coronary arteries. There was no fluid in the upper airways. The right and left lungs weighed 653 g (n.r. 446–880 g) and 540 g (n.r. 348–790 g) respectively and appeared overinflated and showed moderate oedema. The cause of death was given as drowning.

*Comments:* It appears that, although this man set out snorkelling with a group, he was not paired with a buddy so his oversight was left to the lookout and in-water guides; this proving to be ineffective. It is unclear how many snorkellers were in the water at the time but it is probable that there were many. It is likely that he got into difficulties in the rough conditions and current, and unconsciousness was possibly caused by a cardiac arrhythmia or aspiration, followed by drowning. The operator subsequently changed its practice to ensure that any lookout was positioned on the upper deck in order to better observe the snorkellers and sea conditions.

*Summary:* 60 y.o. male; history of hypertension; unknown swimming and snorkelling ability; snorkelling amongst group in choppy conditions and strong current; unconsciousness not noticed by lookout and in-water guides; BLS by crew; AED attached after delay and no shock advised; ALS by helicopter medical staff; drowning (possibly cardiac-related)

BH 11/13

This 75 y.o., male overseas tourist, with a history of coronary angioplasty and cervical spine surgery, was on a day trip to a popular island on the GBR. He was reported to have been a competent swimmer but an inexperienced snorkeller, having only snorkelled on two occasions in Fiji wearing a life jacket. A standard snorkel briefing by means of a DVD was conducted on the vessel en route to the island and potential snorkellers were advised to notify staff if they suffered from certain medical conditions. The victim did not do so. He and two friends hired snorkelling equipment from the dive shop

(at which there was a sign outlining the potential hazards of diving with various health conditions). The victim declined the offer of a life jacket as it would incur an extra charge. The weather was overcast but the sea was calm and clear. No current was reported.

The three entered the water from steps adjacent to a jetty. The victim was wearing mask, snorkel, fins and a full length Lycra suit with hood. After snorkelling for a short time, he complained to one friend that his mask was leaking. The friend, a certified diver, reassured him and suggested that they swim towards the jetty, which they did. Soon afterwards, the victim said that he wanted to return to shore. He spoke clearly and did not appear to be distressed. They headed towards shore with the buddy close beside the victim, who was swimming using long breaststrokes to propel himself and appeared to be moving easily through the water. The buddy held the victim's hand to provide reassurance and towed him for the last few metres, noting that he felt very relaxed. However, when he rolled the victim over he saw that he was cyanotic with his eyes widely open and staring.

The buddy called for help and dragged the victim up the steps of the jetty. Unable to palpate a pulse, he gave the victim some rescue breaths. Staff from the dive shop arrived moments later with an AED and oxygen equipment and began BLS. The victim was rolled onto his side to drain fluid from his airway. Supplementary oxygen was delivered via a resuscitation mask, the AED was attached but no shock was advised. About 10 min later, an anaesthetist and a nurse (tourists) who were nearby took over resuscitation efforts. A laryngeal mask airway (LMA) was inserted and adrenalin given to no avail. Resuscitation was ceased after 45–50 min.

No faults were found with the snorkelling equipment.

*Autopsy:* This was performed two days post mortem. BMI was 29 kg·m<sup>-2</sup>. The heart weighed 325 g (n.r. 331–469 g), the size and configuration being normal. All major coronary arteries showed proximal near occlusion by severe calcific atherosclerosis with stents in the LAD and right coronary arteries. There was microscopic but not macroscopic fibrosis with some small vessel disease. The right and left lungs weighed 545 g (n.r. 446–880 g) and 429 g (n.r. 348–790 g) respectively. They appeared hyper-inflated with moderate pulmonary oedema. The cause of death was given as drowning (cardiac-related).

*Toxicology:* Ephedrine/pseudoephedrine 1.4 mg·kg<sup>-1</sup> (potentially toxic range)

*Comments:* It is probable that this man with significant ischaemic heart disease suffered from a cardiac arrhythmia and subsequently drowned. The arrhythmia was likely to have been precipitated by a combination of immersion and possibly aspiration and/or stimulant use. The therapeutic use of pseudoephedrine in the presence of ischaemic heart disease has been associated with myocardial infarction.<sup>4</sup>

The victim's buddy did not recall a snorkel briefing on the boat so it is unclear whether or not the victim attended, and/or paid attention to such a briefing. Had the victim declared his previous cardiac procedure as required, it is likely that he would still have snorkelled albeit under supervision from a staff member in a patrolled area. However, given that he was closely supervised and showed no signs of distress, this would likely have made no difference.

*Summary:* 75 y.o. male; history of coronary angioplasty and cervical spine surgery; competent swimmer but inexperienced snorkeller; calm conditions with little current; closely supervised by friend; leaking mask; silent unconsciousness; prompt BLS and ALS; AED attached - no shock advised; potentially toxic level of ephedrine/pseudoephedrine; drowning (cardiac-related)

BH 11/14

This 23 y.o. male was an overseas national studying in Australia. Although obese, he looked strong and claimed that he had previously been an athlete. He had a history of severe chronic cramping in his calves. His swimming competency was not reported but he was an inexperienced snorkeller who had bought his equipment on-line and likely had no training in its use. He and a friend had practiced snorkelling together previously, during which the victim demonstrated releasing his weight belt.

He and this friend drove to the vicinity of the dive site late at night and slept in the car for four hours before the victim set out spearfishing. His friend remained on shore as a lookout as his equipment, recently purchased online, had not arrived in time for this outing. The site was a rocky ocean beach. It was early in the morning and there was a light fog, a slight breeze, the sea was described as flat with no swell and visibility of 15 m. Although not reported, the water temperature would have been around 16–18°C. The victim wore a mask, snorkel and fins; a 5 mm two-piece wetsuit, with hood, gloves and boots; a weight belt with 13 kg of weights and a knife in a leg scabbard. He carried a speargun with an inflatable float and 15 m of thin nylon cord attached. Much of the line was tied into a ball in order to shorten it.

He snorkelled around a large rock about 150 m from shore. He returned to shore 30 min later to rest and drink some water, telling his friend that he felt tired and that one fin felt a bit tight. After a short break the victim spearfished again for a short time before returning to shore to clean some fish. When he re-entered the water again, his friend noticed that the float's cord had become partly unfurled.

Approximately 10 min later, he began to splash and signalled that he was trouble. He submerged and then reappeared once before re-submerging. The friend ran to the nearby carpark where he asked a bystander to call for help. He then had a short aborted swim towards the float before returning to

the carpark and borrowing a board and paddling to where he had last seen the victim, possibly some 20 min earlier. He could not locate his friend and, when the police arrived after another 15 min, they asked him to return to shore. The search was continued by life savers and police and the victims' body was finally found by police divers, 4 h after he was last seen, about 200 m from shore and 50 m from his float. He was unconscious, lying face-up on the seabed at a depth of 5 msw. His mask was around his neck, with the snorkel on the sand nearby. His weight belt was in place and it required two police divers to lift him to the surface.

There was a small cut on the victim's face and foam was coming from his mouth. No resuscitation attempts were made. The police noted that the victim's knife was tucked under his weight belt and that the cord for the dive float had several tangles. The quick-release on his weight belt was operational. At one point the cord attached to the float appeared to have been cut and was almost severed.

*Autopsy:* An autopsy was not conducted due to family objections, although a CT scan performed six days post mortem showed no fractures, gas and or pneumothorax. BMI was 31 kg·m<sup>-2</sup>. There were abrasions on the left eyelid, left lip and right knee and a bruise on the left lower leg. The cause of death was given as consistent with drowning.

*Comments:* The float line used by this victim was unsuitable for the purpose in that it was thin and easily tangled. It is likely that the victim became entangled in the line and tried to cut it but, being substantially overweighted, was unable to stay afloat. Given his history of leg cramps and his complaint about a tight fin, it is possible that he suffered from a cramp which would have made it more difficult to remain on the surface. Although he had previously shown his friend that he was aware of how to release his weight belt, not surprisingly he failed to do so when it was absolutely needed and likely drowned as a consequence of this. Given the victim was snorkelling alone without ready assistance, there was little chance of a prompt and successful rescue.

*Summary:* 23 y.o. male; obese but apparently healthy; history of chronic leg cramps; relatively inexperienced snorkeller; overweighted; spearfishing alone; signalled for help before submerging; possible entanglement in float line/leg cramps; drowning

BH 11/15

This 44 y.o. male was apparently fit and healthy, albeit obese. His medical history, swimming ability and snorkelling experience were unknown. He was one of three teachers and 15 students who were participating in a snorkelling experience activity conducted by a third-party adventure operator. The students had varied swimming and snorkelling abilities, with some being poor swimmers and inexperienced snorkellers. The group went snorkelling off an ocean beach

where rocky reef can provide some protection from the waves, although the site is well-known for large swells and rip currents. The weather was described as very windy with a rough sea and a swell of 2–3 m, in addition to a strong long-shore current and several rip currents. The group was divided into two smaller groups, each guided by an instructor from the adventure operator. Each person was wearing a mask and snorkel, fins and a wetsuit.

As they were preparing to snorkel, a large wave crashed across the top of the reef and swept the victim and some students into a rip which dragged them into deeper water. The victim was heard to call out “*help, help, I’m going to die*” and was assisted by one of the instructors who guided him into water in which he could stand. The instructor then left him in order to rescue some students. At least four of the students needed to be rescued.

Shortly after, the instructor again heard the victim call for help and saw him being swept under by waves. He yelled to him to “*keep your head up and kick for shore*” before going to help some struggling students to shore. Approximately 3 min later, the instructor swam to the victim who was unconscious and floating face-down about 20 m from shore. He towed the victim to shore where BLS was commenced. When paramedics arrived shortly afterwards they found the victim to be in asystole and implemented ALS. They noted that there was a little water in the airways. Resuscitation efforts were continued for approximately 30 min without success.

*Autopsy:* Only an external examination and CT scan were performed one day post mortem. The CT scan showed fluid levels in the maxillary sinuses and increased lung markings consistent with pulmonary oedema. BMI was 31 kg·m<sup>-2</sup>. The heart was described as slightly enlarged by the forensic pathologist but normal by the forensic radiologist. There was gas in the portal system and right side of the heart attributed to early decomposition (and resuscitation). The cause of death was given as drowning.

*Comments:* It is very fortunate that this incident did not result in multiple fatalities. The conditions were unsuitable for snorkelling, especially for an inexperienced group and an alternative site should have been arranged. Some other operators later reported that they either cancelled activities for that day or re-directed them to a more sheltered location. The staff of the adventure operator made a serious error of judgement in taking the group to snorkel in those conditions. The company was subsequently prosecuted by the relevant workplace authority “... for failing to ensure persons were not exposed to risk”. A fine of \$180,000 was imposed. In the absence of internal examination in a 44 y.o., it is not possible to completely exclude cardiac disease.

*Summary:* 44 y.o. male; obese but apparently fit and healthy; unknown swimming and snorkelling ability; very rough sea and rip current; drowning

## Scuba diving fatalities

SC 11/01

This 51 y.o. woman was described as fit and healthy, although obese. She was an experienced scuba diver who had logged over 950 dives and held open-water and deep diving qualifications. Other than the first dive-related incident described below, she had no significant medical history and appeared to have been taking no medications at the time of her death. Approximately one year before her fatal accident, the victim suffered an acute episode of immersion pulmonary oedema (IPE). She was evacuated and hospitalised but recovered quickly. She had been referred to a cardiologist for a stress ECG and echocardiogram, both of which were reported to have been normal. Contrary to advice from an experienced diving medical specialist, she continued to dive, completing more than 50 incident-free dives over the next year. In order to obtain particular insurance for a forthcoming dive trip, she consulted another experienced dive medical specialist for a second opinion. After carefully reviewing the victim’s clinical history, this doctor leaned towards a diagnosis of salt water aspiration syndrome (SWAS) rather than IPE and advised that a similar episode would be unlikely if aspiration was avoided.

She was participating in a night dive from shore. There was a moderate wind and the water was choppy. Surface water temperature was about 22°C reducing to 19°C at depth and was described as comfortable. She was wearing a mask, snorkel and fins; a 5 mm semi-dry suit; a weight belt with 5.8 kg of weights; a BCD; a scuba unit with an air-integrated dive computer and 9-L cylinder filled with air; a slate and a torch.

The victim was with three others, in two buddy pairs. They swam on the surface for about 30 m before descending and working along the sloping bottom to a maximum depth of 18 msw. For most of the dive the victim appeared to be fine and responded affirmatively to the buddy’s regular okay signals. However, after about 25 min, at a depth of 14 msw, she signalled that she was not okay. They decided to return and they swam underwater up the slope and towards the shore. Each time the buddy enquired if she was okay she responded in the negative. On reaching a depth of 7 msw, the buddy held her hand and they slowly ascended and surfaced in a sheltered area, with a dive time of 37 minutes.

At the surface, she vomited a brown, lumpy liquid. She was trying to cough and had an audible wheeze. She stated faintly that she could not breathe and she continued to vomit. Her BCD was inflated and she rolled over onto her back as the buddy towed her towards the shore. The buddy could hear her wheezing and struggling to breathe. She was still conscious and complained that she could not breathe, but tried to kick her legs to assist the buddy towing her. The buddy towed her approximately 100 m to thigh-deep water beside rocks. She was assisted onto the rocks. It was believed that she did



not inhale any water during the rescue. She then became unconscious and apnoeic, and her buddy commenced BLS. This produced regurgitation of stomach contents and some bloody sputum. Others assisted until paramedics arrived about 15 min later. ALS was implemented but she failed to respond after 30 min of resuscitation and was pronounced dead at the scene.

When tested, her equipment was in good working order and met the required specifications. There was a pressure of 60 bar remaining in the tank and this air met the required purity standards. Her dive computer indicated that her respiratory minute volume fluctuated from over 30 L·min<sup>-1</sup> early in the dive to 10 L·min<sup>-1</sup> for much of the dive, with periods of increased consumption during the ascent phases.

*Autopsy:* This was performed two days post mortem. BMI was 32 kg·m<sup>-2</sup>. The heart weighed 310 g (n.r. 285–439 g) and was normal in size and shape. There was no left ventricular hypertrophy (13 mm, n.r. < 14 mm) and less than 25% narrowing of the right coronary artery. There was a segment of coronary artery bridging in the left anterior coronary artery 25 mm long and 3 mm deep. There was 30 ml of bloodstained fluid in the pericardial sac, rib fractures and haemorrhage in the myocardium. There was contraction band necrosis of the myocardium on histology. The airways contained white frothy fluid. The right and left lungs weighed 835 g (n.r. 305–817 g) and 579 g (n.r. 287–695 g) respectively, and were markedly oedematous and crepitant but not hyper-expanded. There was microscopic sub-pleural alveolar hyper-expansion. The cause of death was given as immersion pulmonary oedema/scuba diver's pulmonary oedema.

*Comments:* This case was reported previously in DHM and was discussed in detail at that time.<sup>5</sup> Despite the victim's previous episode, which was severe enough to require air ambulance evacuation and hospitalisation, she remained determined to dive and did so against diving medical advice. She was a medical professional and had read much of the available literature on IPE but believed that if she avoided aspiration (one possible trigger for her previous episode) she would be safe. She was aware from her reading that a recurrence rate of possibly 30% had been reported for IPE in scuba divers.<sup>5</sup> The second medical opinion, although providing some reassurance, would have made little or no difference to her intention to continue to dive. Ironically, the victim had been involved in the unsuccessful resuscitation of another victim of suspected IPE four years earlier. The superficial coronary bridging noted at autopsy is relatively common and unlikely to be clinically significant.<sup>6</sup> The pericardial fluid, rib fractures and myocardial haemorrhage were likely a result of vigorous resuscitation. The contraction band necrosis may have been caused by vigorous resuscitation. However, this has been described in other cases of IPE and similarities to Takosubocardiomyopathy/reversible myocardial dysfunction, a stress-related cardiac syndrome have been noted.<sup>7</sup>

*Summary:* 51 y.o. woman; obese but relatively fit and apparently healthy; experienced scuba diver; previous incident of IPE; subsequent investigations unhelpful; conflicting medical advice; fatal IPE

SC 11/02

This 48 y.o. man was reported to have been relatively fit, healthy and active, although obese. He was taking diclofenac for a previous shoulder injury. A competent swimmer who had been scuba diving for three years, he had logged over 100 dives both in Australia and overseas. He held advanced open water certification but had not dived for more than six months. He and his daughter were on a day-trip on a large vessel on the GBR. They were among a group of six certified divers under the supervision of an instructor. It appears that the operator provided him with a stinger suit, BCD, 10.7-L tank and weight belt (with four weights, likely totalling 5.5 kg). It is unclear whether or not the rest of his equipment was his own. The weather was cloudy with a light wind, the water was calm with a temperature of 28°C; there was a mild current and visibility was 7–8 m.

The group entered the water from a large pontoon and descended to 7 msw for a short period and then to around 14 msw. The victim appeared to have difficulty equalising his ears (as had been the case on some previous dives) and hovered some 3 msw above the rest of the group. After about 15 min when the guide signalled to the divers to check their air, the victim signalled back that he had 150 bar. However, seconds later he signalled that he wanted to surface. The instructor reported that the victim's ascent was rapid, although he did not appear to be panicking. After promptly escorting the other divers to a safety stop, the instructor surfaced next to the victim who was already floating on the surface. He further inflated the victim's BCD and they made eye contact, although nothing was said.

After turning away briefly to signal for assistance, the instructor turned back and saw white frothy sputum coming from the victim's mouth immediately before he fell forward face-down, unconscious. The instructor ditched the victim's weight belt and held his head out of the water until the tender arrived. The victim was transferred to the pontoon where BLS was commenced by staff members and a vacationing doctor. Supplemental oxygen was provided via a bag-valve-mask and an AED was attached; no shock was advised. Resuscitation efforts, which included adrenaline administration, continued for 90 minutes. However, the victim remained asystolic and was pronounced dead when paramedics arrived.

When later checked, there was 130 bar of air remaining in the victim's tank. Testing revealed an oil content six times higher than the recommended purity standard.<sup>8</sup> No faults were found with the rest of the equipment.

**Table 2**

Summary of scuba and surface-supplied diving-related fatalities in Australian waters in 2011; BCD – buoyancy compensation device; BMI – body mass index; BNS – buddy not separated; BSB – buddy separated before problem; BSD – buddy separated during; CAGE – cerebral arterial gas embolism; GNS – group not separated; GSB – group separated before; IPE – immersion pulmonary oedema; nad – no abnormality detected; n/i – not inflated; n/s – not stated; PBt – pulmonary barotrauma; + sufficient air (to surface safely); ++ 1/4–1/2 full tank; +++ >50% full

SC	Age (y)	Sex	Height (m)	Weight (kg)	BMI (kg·m <sup>-2</sup> )	Training	Experience	Dive group	Dive purpose	Depth (msw)	Incident (msw)	Weights on/off kg	BCD	Remaining air	Equipment test	Disabling injury
11/01	51	F	167	89	32	Yes	experienced	BNS	recreation	18	14	buddy off	inflated	++	nad	IPE
11/02	48	M	172	91	31	Yes	experienced	GNS	recreation	14	11	rescuer off	inflated	+++	some issues	PBt
11/03	29	F	172	68	23	Yes	experienced	solo	cave	n/s	n/s	n/s	inflated	nil	some issues	Asphyxia
11/04	38	M	185	100	29	Yes	limited	BSD	wreck	28	surface	n/s	inflated	+	nad	Asphyxia
11/05	55	M	172	77	26	Yes	limited	BSB	recreation	4	surface	rescuer off	inflated	n/s	some issues	Cardiac incident (IPE?)
11/06	23	F	178	78	25	in training	nil	BSB	training	11	n/s	on	n/i	+	nad	Asphyxia
11/07	37	M	185	97	28	Yes	experienced	BNS	recreation	n/s	surface	n/s	n/s	n/s	nad	Cardiac incident (IPE?)
11/08	47	M	175	122	40	Yes	some	solo	recreation	n/s	surface	n/s	n/s	n/s	some issues	Cardiac incident
11/09	52	M	171	111	38	Yes	experienced	BNS	recreation	21	n/s	self off	removed	n/s	nad	Cardiac incident
11/10	40	M	189	107	30	Yes	experienced	BSB	cave	15 mfw	n/s	on		nil	n/s	Asphyxia
11/11	32	M	178	68	22	Yes	some	solo	spearfishing	12	n/s	n/s	n/s	n/s	n/s	Trauma
11/12	28	F	156	70	29	in training	nil	GSB	training	5	n/s	rescuer off	n/i	++	nad	PBt/CAGE? asphyxia?
11/13	47	M	162	77	29	Yes	limited	solo	hunting	5	surface	rescuer off	n/i	nil	nad	Asphyxia? cardiac incident?
11/14	56	M	172	80	27	Yes	experienced	BSB	recreation	3	surface	off	inflated	nil	some issues	Asphyxia
SS																
11/01	50	M	-	-	-	Yes	experienced	solo	commercial	25	surface	n/s	n/s	+++	-	Trauma? (no body)

*Autopsy:* This was performed one day post mortem. A CT scan was reported to be consistent with barotrauma, with gas in the veins of the liver and in the lungs. BMI was 31 kg·m<sup>-2</sup>. The heart weighed 405 g (n.r. 331–468 g) and appeared normal. There was less than 25% coronary artery narrowing, although there was some microscopic fibrosis. Gastric contents were present in the upper airways. The right and left lungs weighed 700 g (n.r. 446–880 g) and 530 g (n.r. 348–790 g). They did not appear hyper-expanded and pulmonary oedema was not conspicuous. The cause of death was given as “*barotrauma*”.

*Comments:* There is insufficient detail about timing of the CT scan and the distribution of the gas to be certain of the given diagnosis; gas, particularly in the liver, is frequently artefact. The interpretation of post-mortem CT scans is complex due to post-mortem decompression artefact, resuscitation and decomposition. Reports must indicate how long after death the scan was done and whether there was significant gas on the right and left sides of the heart, aorta and brachiocephalic vessels if they are to be meaningful. The sudden ascent and loss of consciousness on the surface are suggestive of pulmonary barotrauma and cerebral arterial gas embolism (CAGE). There is little evidence of drowning and only mild cardiac fibrosis and no history of syncope. Something triggered the sudden ascent. It is possible that the high oil content in the victim’s air caused him to feel unwell and might have been the precipitant for his rapid ascent. The autopsy included no details of an ear examination so there was no evidence of ear barotrauma as a possible precipitant for the ascent.

*Summary:* 48 y.o., obese man; apparently healthy; experienced diver; appeared to have equalisation difficulty; rapid ascent; white frothy sputum and unconsciousness on surfacing; high oil content in breathing air; pulmonary barotrauma

SC 11/03

This 29 y.o. woman was fit and healthy and had no significant medical history. She was an experienced and accomplished cave diver, experienced in solo diving and well known for her exploration achievements. Due to her relatively slim physique, she was known to be able to penetrate narrow restrictions that larger divers were unable to explore. On the day of the incident, the victim was with a group of nine divers, however she had decided she would dive solo (in spite of a request to the contrary from the dive supervisor). They were exploring a vast, complex, flooded underground network of passages, with a total known length of 11 km. The site is only accessible to members of the Cave Divers Association of Australia (CDAA), which controls access to it.

The victim was diving a ‘side-mount’ configuration with a harness and wing-style BCD, wearing a mask (with spare in pocket) and fins; a drysuit with undergarments, hood, boots

and gloves; a canister torch (with two back-ups in pockets); a dive computer and separate timer; two 12-L steel cylinders (air) each fitted with a regulator, demand valve and contents gauge; a line cutter and a reel (in pocket); and a wrist slate and pencil. Prior to diving, the victim had recorded that her intended dive time was 220 min. Water temperature was 14°C.

She entered the cave with a buddy but intentionally separated within a short time. The area that she’d set out to explore was approximately a 30 min swim from the entrance (approximately 600 m distance). Others became concerned when she was 30 min overdue and the police were notified. However, the police were not able to do the type of diving required so experienced members of the CDAA became involved in the search and subsequent recovery.

The victim’s body was finally sighted late that night. She was beyond a very narrow restriction that searchers were unable to pass. Over the next three days CDAA divers made multiple dives to clear the restriction and retrieve the equipment. This was complicated by the narrow passage and substantial silting, the work often being conducted in zero visibility. The victim’s body was finally recovered four days after she set out. She was found lying face-down with her mask in place but her demand valve out of her mouth. She appeared to be positively buoyant and her body was at 90 degrees to her guideline, where she appeared to be trying to swim into a blind-ending gap. Her BCD harness had been unclipped, the drysuit inflator disconnected and her cylinder was unclipped from the harness. When checked, this cylinder was empty and the gauge had flooded. Her second cylinder was found towards the entrance to the cave on the other side of the restriction to where the victim was found and about 5 m from her. The attached gauge read 176 bar. When tested, the regulators were found to be in relatively poor condition, although serviceable and unlikely to have contributed to the accident.

*Autopsy:* This was performed five days post mortem. The body showed decomposition changes and, because of this, assessment for barotrauma was not possible, although erect chest X-rays were taken. BMI was 23 kg·m<sup>-2</sup>. The heart weighed 297 g (n.r. 240–376 g) and was normal. There was a 10 x 2 mm segment of myocardial bridging in the LAD coronary artery (not significant) and no atherosclerosis. Histologically there were two focal microscopic areas of mononuclear cells with focal myocyte necrosis which were thought to be incidental. The airways showed putrefactive haemolytic staining. The right and left lungs weighed 868 g (n.r. 344–750 g) and 568 g (n.r. 291–653 g) respectively, being heavy and hyperinflated. There was 150 ml of dark red fluid in the left pleural cavity and 50 ml in the right (fluid in the lungs appears to migrate into the pleural cavities during the post-mortem interval). The cause of death was given as freshwater drowning.

*Toxicology:* Alcohol: 0.014 g·100 ml<sup>-1</sup> (due to putrefaction); carboxyhaemoglobin (COHb): 3% (within normal range)

*Comments:* The victim was an experienced diver pushing into a very restrictive and silty new tunnel. She broke a fundamental rule of cave diving by proceeding deeper into the cave with only a single gas supply, and it appears she ran out of air before relocating the line and negotiating her way back to safety.

*Summary:* 29 y.o. woman; healthy; experienced cave diver; high risk exploration dive in very restrictive cave; solo dive with inadequate briefing of dive buddies as to plan, silting and loss of orientation; intentional separation from redundant gas supply; out of air; drowning

SC 11/04

This 38 y.o. man was described as overweight and unfit. His swimming and snorkelling competence was largely unknown. He had a history of hypertension, for which he was taking perindopril, and asthma, for which he used salbutamol infrequently. He was not taking any 'preventer' medication for asthma. At the time of a diving medical just over 12 months earlier, his blood pressure was 142/80; FVC 4.66 L, and FEV<sub>1</sub> 3.89 L (83%); he was declared 'fit to dive'. He completed an advanced open water certification in Thailand several weeks later. In total, he had done 10–12 dives; which possibly included three dives to around 30 msw in Thailand. He had not dived beyond 18 msw in temperate Australian waters, in which the incident occurred. It appears that he had not dived for almost a year. His last recorded blood pressure was 163/93, two months prior to the incident. Eight days prior, he had used a borrowed salbutamol inhaler and had taken some over-the-counter cold and flu medication for an upper respiratory track infection several days before diving.

On this day, 11 divers, including an instructor with two students and a novice divemaster set out to dive a wreck from a large charter vessel. The divemaster was planning to dive but was unable to do so owing to an equipment problem. The victim had hired equipment, which included mask, snorkel and fins; wetsuit with booties; BCD with 5.5 kg of integrated weights; and a scuba unit (including 'octopus' and dive computer) with a 10.5-L steel cylinder. The boat was anchored at the wreck site in a depth of 28 msw. The sky was cloudy, the wind was reported to have been 22 km·h<sup>-1</sup> and the sea choppy, with swells up to 1.5 m. There was a moderate current. The water temperature was around 20°C and visibility 5 m.

The victim entered the water with his regular buddy (a friend, also a novice diver, with whom he had done all of his dives) and another buddy pair. They descended from the stern, rather than down the anchor line as advised, probably because of the current and rough surface conditions. The victim took a compass bearing and they set off towards the wreck. After a short time, the other buddy pair signalled that they were going to ascend but the victim and his buddy continued their dive.

After a dive time of 14 min, the buddy was low on air so the pair began their ascent. However, at a depth of 14 msw, the buddy ran out of air so the victim donated his 'octopus' and the pair continued the ascent to the planned safety stop. After about 20 seconds at the stop the victim looked at his gauge and brought them to the surface. He appeared to be fine and orally inflated his BCD. They exchanged some words but the victim was difficult to understand as he had his snorkel in his mouth. He waved to the boat, some 100 m away, to indicate where they were. The pair then began to swim towards the boat, the victim on his front on snorkel; the buddy lying on his back and kicking against the current. The boat was picking up other divers.

The buddy stated that the victim appeared to be fine while snorkelling but thought that the current and swell was pushing his friend away and they became separated, the victim often being out of sight due to the swells. After about 10 minutes, the buddy saw the victim 25 m away before losing sight of him and swimming to the boat. A surface search soon located him, floating motionless, face-down although partially rolled onto his side. He was unconscious with his mask in place, but his demand valve was not in his mouth. He was brought onto the boat and rolled onto his side to clear his airway. He was apnoeic, so BLS was commenced as the boat sped towards the nearest jetty; a 15-minute trip. The divemaster was initially unable to ventilate due to airway resistance, despite what he believed to be adequate head-tilt. Compressions were begun and a small amount of water came from the mouth with each compression. After the first set of compressions, the victim was again rolled onto his side and more water was drained and when BLS was re-commenced the chest now rose with the ventilations. The rescuer was unable to obtain a seal with a resuscitation mask so supplementary oxygen was not administered. Paramedics arrived soon after the boat reached the jetty and ALS was commenced. A defibrillator was attached but no shock was delivered. The victim was transported to hospital by ambulance and ALS was continued for a short time before resuscitation was ceased, some 40–45 min after the commencement of BLS.

When later tested by police, all equipment performed appropriately. There was a pressure of 30 bar remaining in the cylinder and the residual air met relevant purity standards. The dive computer indicated that the victim had exceeded the recommended ascent rate of 9 m·min<sup>-1</sup> but not excessively so.

*Autopsy:* This was performed two days post mortem. Supine X-ray examination revealed increased opacity in the lungs consistent with pulmonary oedema; but no gas. There were a few small gas bubbles in the anterior cerebral arteries of doubtful significance. BMI was 29 kg·m<sup>-2</sup>. The heart weighed 354 g (n.r. 331–469 g) and was normal in size and shape. The left ventricle measured 14 mm (n.r. ≤ 14 mm). There was 50% stenosis of the LAD and right coronary arteries macroscopically, and moderately severe

atheroma histologically. There was myocyte hypertrophy but no fibrosis of the myocardium. There was blood-tinged pulmonary oedema in the upper airways. The right and left lungs weighed 880 g (n.r. 446–880 g) and 668 g (n.r. 348–790 g) respectively. These were heavy and crepitant but not over-expanded and showed moderate pulmonary oedema. There were no histological changes of asthma. Ocular fluid showed  $[Na^+]$  153 mmol·L<sup>-1</sup>,  $[Cl^-]$  124 mmol·L<sup>-1</sup> (PMVSC 277 mmol·L<sup>-1</sup>), consistent with salt water drowning.<sup>3</sup> The pathologist gave the cause of death as unascertained but considered drowning to be a possibility. The coronary artery disease and hypertension were not deemed to be sufficient to account for sudden cardiac death and the possibility of a cardiac channelopathy could not be excluded.

Toxicology: Paracetamol: 10 mg·L<sup>-1</sup> (within therapeutic range)

*Comments:* The autopsy findings, while not specific, are consistent with drowning. Given this diver's and his buddy's inexperience and the fact that they had not dived for more than 11 months, it was unwise and inappropriate that they attempted this dive, especially in the prevailing conditions. Several of the other divers had abandoned the dive due to the swell. The equally inexperienced buddy running out of air supports the inappropriateness of the dive. Despite his inexperience, the victim appeared to have been well-controlled underwater, assisting his out-of-air buddy and surfacing without any apparent problems. However, it is likely that he aspirated water and became unconscious while snorkelling back to the boat. It is unknown whether or not asthma played any part in his incapacitation. Without the immediate aid of a competent buddy and a rapid response from the crew, drowning was inevitable. It appears that no-one could competently use the available oxygen equipment and it is unclear how suitable this was for the circumstances.

*Summary:* 38 y.o. man; unfit; history of hypertension and asthma; used inhaler infrequently; recovering from URTI; rough surface conditions and moderate current; assisted out-of-air buddy to surface; controlled ascent; separation while snorkelling back to boat in rough conditions; drowning

SC 11/05

The victim was a 55 y.o. male who was described as active and apparently very fit, being a keen cyclist who trained at least three times a week. However, he had a history of hypertension and mild mitral valve incompetence, and an echocardiogram two years earlier showed mild aortic and mitral valve regurgitation and mild left atrial dilation. He also had a history of exercise-induced tachycardia and post-exercise syncope, both of which had been investigated with a Holter monitor without a cause being found. He held an advanced open water certification but had little diving experience. He had only recently purchased his own scuba equipment which he had used for the first time on a pier dive one week earlier. At that time, while he was changing into his wetsuit he twisted and felt sudden back pain, for

which he received subsequent physiotherapy and was taking diclofenac.

On the day of the incident, he was participating in a group dive with about 20 divers and he was in a sub-group with two other divers. They geared up and walked about 150 m along a pier before entering the water. He mentioned that his back was bothering him but seemed otherwise well and not breathless. He was wearing mask, snorkel and fins; a one-piece 6 mm wetsuit with an additional 1 mm hooded vest; a BCD with scuba unit; and a weight belt (weight unreported). There was a fresh wind, mild current and some surface chop and the water temperature was 18°C. The visibility was 2–3 m.

The victim and his buddies entered the water and descended to a depth of approximately 4 msw. After about four minutes, he indicated to his buddy that he wished to ascend, which they did, surfacing about 12 m apart in a relatively sheltered area. One of his buddies asked him if he was okay, to which he answered "yes", despite the buddy noticing bleeding from his nose. He said that he would be fine swimming across to the landing alone. After confirming that one of the divemasters on the pier was watching the victim, the buddies continued their dive.

The victim had to swim under the pier to reach the landing. He was observed to be swimming normally until he swam under the pier and the view was obscured. However, he was soon seen to float into view on the other side. His BCD was inflated and he was floating on his back, with his head backwards and apparently unconscious. Blood-stained frothy sputum was oozing from his mouth.

One of the divemasters on the pier immediately jumped into the water and towed him to the landing. There, several divers removed his weight belt and BCD and tried to lift him onto the landing, a task that proved to be too difficult. Another diver, who was a very good swimmer, quickly towed the victim to the shore where the emergency services (fire rescue) were waiting and soon commenced resuscitation. The time from when he was first noticed unconscious until BLS was commenced was estimated to be 8–10 min. When ambulance paramedics arrived they found the victim to be cyanotic with fixed, dilated pupils. His airway was soiled with vomit and water. When attached, the defibrillator indicated that the victim was in asystole and ALS was implemented. After about 20 min there was return of spontaneous circulation (in the form of atrial fibrillation). The victim was transported to hospital where he died several hours later.

When tested, the remaining air in the cylinder was found to have a water content of  $215 \pm 21$  mg·m<sup>-3</sup> ( $182 \pm 18$  ppm), over four times higher than the 50 mg·m<sup>-3</sup> recommended.<sup>8</sup>

*Autopsy:* This was performed four days post mortem. BMI was 26 kg·m<sup>-2</sup>. The heart weighed 377 g (n.r. 331–469 g),

the atria appeared dilated (80 ml), there was left ventricular hypertrophy 18 mm (n.r.  $\leq$  14 mm) and right ventricular hypertrophy 9 mm (n.r.  $\leq$  4 mm). The mitral valve showed thickening and myxoid degeneration of the anterior valve leaflet consistent with mitral valve prolapse. There was less than 10% narrowing of the LAD coronary artery. Histology of the heart showed mild to moderate perivascular and pericellular fibrosis and scattered microscopic sub-endocardial scars in the left ventricle. No contraction band necrosis was described. The upper airways contained thin blood-stained fluid mixed with gastric contents. The right and left lungs weighed 1250 g (n.r. 446–880 g) and 1276 g (n.r. 348–790 g) and were heavy, congested and oedematous. There was 150 ml straw-coloured fluid in the right pleural cavity and 100 ml in the left. There was an early aspiration pneumonia. The right and left kidneys weighed 143 g (n.r. 132–206 g) and 144 g (n.r. 139–209 g) respectively. The left kidney showed focal scarring and chronic interstitial inflammation and fibro-intimal thickening of arteries and arterioles (due to hypertension). The cause of death was given as “*unascertained*”.

Toxicology: Morphine 0.21 mg·L<sup>-1</sup> (within therapeutic range)

*Comments:* This man exercised regularly and strenuously despite mitral valve incompetence. The episodes of post-exercise syncope may have been discounted due to the negative Holter investigations. However, in a formal fitness-to-dive assessment this would have required further investigations. There were a number of risk factors for IPE as the possible disabling agent. The dilated atria may be an indication of elevated left (and right) atrial pressure in the context of mitral valve incompetence. It has been suggested that a high starting left atrial pressure is likely to put the diver at increased risk of IPE.<sup>9</sup> Another way of viewing this case is as an out-of-hospital cardiac arrest due to cardiac arrhythmia. Given his history of tachycardia and post-exercise syncope, this cannot be discounted.

*Summary:* 55 y.o. man; history of hypertension, mitral valve incompetence, post-exercise syncope and recent back pain; complained of back pain before dive; surface after only 4 min at 4 msw; became unconscious shortly after controlled ascent; cardiac related? IPE?

SC 11/06

This 23 y.o. woman was a physically healthy overseas backpacker. Two and a half years earlier, she had begun treatment for panic attacks and insomnia for which she had been taking citalopram. However, she had recently seen her doctor who described her as “*in excellent mental health*” and they agreed that she should systematically reduce her dosage in order to become medication-free.

She and some friends were on a three-day scuba diving and snorkelling cruise on the GBR on a live-aboard sailing vessel. Prior to any aquatic activities, the group were

required to sign a disclaimer and declaration. Among other things, this included a statement that the person was not taking any medication that carried a warning about any impairment of physical or mental abilities or psychological problems including panic attacks. The victim failed to declare anything. The passengers were given a pre-dive/snorkel briefing, which, among other things, included advice on staying together and at the same depth as the instructor, but none on what to do in the event of separation or weight belt release. On the first day, the victim and her three friends participated in a shallow introductory dive from a beach in calm conditions, which she appeared to enjoy. The next afternoon, she went on another dive with two friends. They were taken by the tender to the site where the instructor, who had just taken another group, was awaiting them. The conditions were cloudy with a light wind, the sea was calm, the current slight and the visibility varied from 0.5–3 m. The victim was wearing mask, snorkel and fins, a BCD and scuba unit with 8.3-L cylinder; a wetsuit and hood and a weight belt with 5.5 kg of weights.

They initially descended to 4 msw (where the instructor adjusted their buoyancy) and then to 6.5 msw. The instructor led the group from the front, with the students following behind in single file, as instructed. The instructor turned to check on them every minute. One buddy reported that she saw the victim and instructor linking arms and signalling and swimming together at one point before separating. She last saw the victim swimming below her. This buddy reported that the water was at times so cloudy that she could not see beyond her outstretched arm.

One of the group swam ahead so the instructor set off to retrieve her. When they returned shortly afterwards, he signalled the remaining diver to ascend. On surfacing, the instructor asked the tender driver to check for bubbles. None were visible so he descended again and located the victim at a depth of 11 msw. She was unconscious with her demand valve out of her mouth. By this time she had been missing for possibly 3–4 min. He brought her to the surface, her gear was ditched and she was dragged onto the tender. She was pale and apnoeic and a lot of water and froth flowed from her mouth. One of the friends, a nurse, assisted by the instructor, began BLS which was complicated by regurgitated stomach contents. BLS continued after the victim was transferred to a faster boat and taken to the clinic on a nearby island resort where the nursing staff were waiting. An AED was attached but no shock was advised. Adrenaline was administered and resuscitation was continued for a short time, without any response.

When later tested by police, the equipment was found to be in “*average and serviceable condition*”. A pressure of 50 bar remained in the tank. The carbon dioxide content (658 ppm) and water content (220 mg·m<sup>-3</sup>), of the air were both in excess of the then current standards of 480 ppm and 50 mg·m<sup>-3</sup> respectively.<sup>8</sup>

**Autopsy:** Early decompositional changes were noted at the autopsy, performed two days post mortem. The CT scan showed gas within the vessels consistent with decomposition and resuscitation. BMI was 25 kg·m<sup>-2</sup>. The heart had a normal configuration (weight not recorded) and the coronary arteries were widely patent. Frothy fluid was noted in the mouth and nose, with gastric contents and blood-stained fluid in the airways. The lungs were overexpanded and voluminous, crossing the midline. The right and left lungs weighed 530 g (n.r. 305–817 g) and 500 g (n.r. 287–695 g) respectively. There were no pleural effusions. The cause of death was given as drowning.

**Toxicology:** Citalopram 0.16 mg·kg<sup>-1</sup>; desmethylcitalopram 0.05 mg·kg<sup>-1</sup>

**Comments:** It seems clear that the instructor erred in taking three very inexperienced divers in such poor visibility. He had just dived the site so the conditions would have been known and he could have abandoned the dive or reduced the ratio. Leading such a group from the front can (and has) lead to problems as it is relatively easy for one of the divers to be left behind, even with regular checking. This is especially fraught with danger in such poor visibility. The victim was remiss in failing to declare her medical history and medication. Given her history of panic attacks, it is possible that she became distressed in the poor visibility and may well have panicked when separated from the group. However, this is not restricted to those with a history of anxiety. In addition, being an uncertified diver and largely untrained in the use of a BCD and untrained in ditching her weight belt, she would have found it difficult to surface. This was likely compounded by reduced buoyancy as her depth increased. Aspects of the supervision of the dive were in breach of the local Code of Practice<sup>10</sup> (subsequently superceded<sup>11</sup>) and the investigating coroner found that “*the failure to comply with the correct procedures contributed to the death. Had she been constantly and properly supervised she would have been seen to be in difficulties earlier and she would have received assistance and it is unlikely that she would have drowned.*” Although the carbon dioxide and water content exceeded relevant standards, these would not have impacted on the incident.

**Summary:** 23 y.o. woman; healthy; history of panic attacks; failed to declare medical history or medication (citalopram); introductory dive in poor visibility; instructor:student ratio 1:3; separation; drowning

SC 11/07

This 37 y.o. male had a history of depression for which he was taking duloxetine. His medical history also included drug (cannabis and methyl amphetamine) and alcohol abuse and seizures subsequent to this. His last medical consultation was for a driving medical assessment, three months prior to the incident. His records indicate that he had apparently been seizure-free for nine years and off anticonvulsant medication for the past eight years. However, his wife indicated that

three years earlier, the victim had briefly lost consciousness while on a bus and had not reported this to his doctor. It is likely that he also suffered from sleep apnoea and, the previous week, had complained of feeling very tired and having indigestion.

He held an advanced open water certification, owned his own equipment and had logged more than 100 dives. He and his buddy, with whom he dived bi-monthly set out to dive from a long jetty. They donned their equipment and walked approximately 800 m to the site. The victim mentioned that he was thirsty, attributing this to “*a couple of glasses of wine the night before*”. The weather was described as “*rough and windy*”. He was wearing his own scuba diving equipment including a BCD with 10 kg of integrated weights; a 12.5-L steel cylinder; an 8 mm full wetsuit with hood, boots and gloves, a dive computer and camera.

The victim and his buddy descended from the pier and dived to a maximum depth of 7 msw. They stayed close together and the victim appeared to be fine, he and his buddy regularly giving and responding to okay signals. After about 20 min, they agreed to turn around and return to the jetty. A short time later when they were close to the jetty, the buddy saw the victim quickly ascend to the surface and followed him. They both stood on a reef in waist-high water and the victim said that he “*wanted to catch his breath*”. The buddy reported that this was not unusual as the victim was not very fit. After a few minutes they put on their masks and started to swim back to the jetty underwater as the swell had increased. The victim’s dive computer records indicate that after descending, he ascended rapidly and swam the rest of the way on the surface. It is unclear if he was using his demand valve or snorkel. His buddy met him at the steps to the landing. He was climbing slowly and breathing heavily.

When they were both on the landing, the victim became very dyspnoeic, was retching and looked pale. His buddy asked if he was okay but he was too dyspnoeic to answer. After helping him to remove his fins, the buddy followed the victim up the stairs to the next level, supporting his cylinder to lessen his load. However, he collapsed and fell backwards onto the buddy and down several steps. He was unconscious and apparently apnoeic. Two bystanders lifted the victim up the stairs and laid him on his back. What was variously described as brown-green liquid and creamy white-yellow foam oozed from his nose and mouth. The rescuers rolled the victim into the recovery position before commencing BLS. They were unwilling to provide rescue breaths due to the continued outflow of what became pink frothy sputum. Instead, one of the divers’ demand valve was used to ventilate the victim. On arrival approximately 15 min later, paramedics continued resuscitation efforts for a short time without success.

When examined by police, the equipment was found to be functioning well and the remaining air (a pressure of 20 bar) met the required purity standards.

**Autopsy:** This was performed three days post mortem. An erect chest X-ray taken the day prior to autopsy showed no apparent gas bubbles in the heart. There were a few small bubbles in the right atrium of doubtful significance due to the post-mortem delay. BMI was 28 kg·m<sup>-2</sup>. The heart weighed 481 g (n.r. 331–469 g), with equivocal left ventricular hypertrophy of 15 mm (n.r. ≤ 14 mm) and right ventricle 5 mm (n.r. ≤ 4 mm). There was mild mitral valve prolapse but no coronary atherosclerosis. The upper airways contained a small amount of blood-stained froth. The right and left lungs weighed 806 g (n.r. 446–880 g) and 821 g (n.r. 348–790 g) respectively, and were oedematous and congested. Ocular fluid showed [Na<sup>+</sup>] 138 mmol·L<sup>-1</sup>, [Cl<sup>-</sup>] 121 mmol·L<sup>-1</sup> (PMVSC 259 mmol·L<sup>-1</sup>), borderline for salt-water drowning.<sup>3</sup> The cause of death was given as drowning.

**Toxicology:** duloxetine 0.16 mg·L<sup>-1</sup> (within therapeutic range); cannabis 2 µg·L<sup>-1</sup> (consistent with recent cannabis use but not acute intoxication)

**Comments:** There are several scenarios that could account for this victim's death, although none seems overly convincing. It is evident that he became breathless underwater. Given the relative experience of the victim and that his equipment was found to be functioning properly, it is unlikely that he aspirated water during the dive. Witness reports varied. One of the witness statements appeared to imply that the victim might have become partly and briefly submerged after collapsing and falling down the stairs and, if true, this could explain the salt-water aspiration. On the basis of the PMVSC the evidence for drowning as the cause of death (and therefore asphyxia as the disabling injury) is weak.<sup>3</sup> The most likely cause for impairment was cardiac arrhythmia associated with mitral valve prolapse. However, given the pulmonary oedema, mild cardiac enlargement and the shortness of breath prior to death this could represent IPE.

**Summary:** 37 y.o. male; history of depression, drug and alcohol abuse and seizures; experienced diver; unwell previous week; pier dive; rough conditions; dyspnoea; collapsed on exit; cardiac-related

SC 11/8

This 47 y.o. man was severely obese with a family history of diabetes, cardiac arrhythmias and ischaemic heart disease. His medical history included intellectual impairment with speech difficulties, hypertension (verapamil and enalapril) and reflux oesophagitis (pantoprazole). He was certified as an open water diver approximately one year earlier, at which time he was assessed as fit-to-dive by a doctor without any diving medical training. He had logged a total of six open water dives and had purchased most of his own equipment. On this day, he hired a wetsuit and cylinder and went solo diving from a jetty from which he had dived several times before. As on other occasions, his mother accompanied him but remained on the jetty after helping him into his wetsuit.

He was wearing mask, snorkel and fins; a full wetsuit with hood and boots; BCD with attached scuba set; weight belt (weights unreported but said to be appropriate by police investigator) and a wrist-mounted dive computer.

He was seen entering the water from the steps. Soon after he was noticed to be “*flopping around with arms and legs splashing*” trying to ‘duck-dive’ before eventually submerging. A witness noted that there appeared to be excessive bubbles rising to the surface. Several minutes later some witnesses reported that they heard a loud sound of escaping air and one saw the victim holding onto a pylon with his regulator out of his mouth and free-flowing. He appeared to be heading towards the stairs. When he was next seen a few minutes later, the victim was floating face-down on the surface drifting in the current about 50 m from the jetty. His cylinder was noted to be sitting lower than usual and displaced to one side. A bystander swam to him, found him to be unconscious but was unable to tow or remove him from the water; a task that was later achieved by surf club members in their boat. The victim was recovered from the water but no resuscitation was attempted. He had been in the water for up to 10 min.

When examined, his equipment was found to be functional and in good condition, although the tank strap was threaded incorrectly and the tank had slipped out of position. The dive computer had logged a dive time of 105 seconds.

**Autopsy:** This was performed three days post mortem. A CT scan (prior to autopsy) revealed no air embolism or evidence of barotrauma. BMI was 40 kg·m<sup>-2</sup>. The heart was heavy, weighing 500 g (n.r. 331–469 g). There was lipomatous hypertrophy of the interatrial septum (25 mm, n.r. ≤ 6 mm) (this can cause arrhythmias and sudden cardiac death). The right ventricular free wall and pulmonary outflow tract showed fatty and fibrous infiltration which the cardiac pathologist suggested may represent arrhythmogenic cardiomyopathy. There was a 40–50% stenosis of the LAD coronary artery. The upper airways contained a film of liquid but no froth or gastric contents. The right and left lungs weighed 571 g (n.r. 446–880 g) and 543 g (n.r. 348–790 g) respectively, with normal expansion and mild to moderate pulmonary oedema. Ocular fluid showed [Na<sup>+</sup>] 142 mmol·L<sup>-1</sup>, [Cl<sup>-</sup>] 120 mmol·L<sup>-1</sup> (PMVSC 262 mmol·L<sup>-1</sup>), suggesting salt water drowning. The cause of death was given as arrhythmogenic cardiomyopathy with lipomatous hypertrophy of the interatrial septum. **Toxicology:** enalapril 0.01 mg·L<sup>-1</sup>; enalaprilat 0.1 mg·L<sup>-1</sup>; verapamil 0.33 mg·L<sup>-1</sup>

**Comments:** This was likely a sudden cardiac death secondary to a cardiac arrhythmia in the presence of structural cardiac disease. Sudden death due to arrhythmogenic cardiomyopathy is often associated with exercise. Given that the victim was alone, there was a delay to rescue, no immediate access to an AED and no attempt at resuscitation,



he had little chance of survival. Although the scenario described would often end in drowning, the only evidence of salt water aspiration at autopsy was the PMVSC. It was reported that a fitness-to-dive assessment was made by a sports medicine doctor who was untrained in diving medicine. This assessment revealed a number of issues including the victim's obesity, hypertension and a family history of heart disease, including arrhythmia. There is no evidence that further investigations were performed to assess the victim's cardiovascular fitness. Given the victim's intellectual disability, it is concerning that efforts do not appear to have been made to further stratify the overall risk profile to enable an informed decision to be made by the victim and his family.

*Summary:* 47 y.o. male; intellectual impairment; severe obesity; history of hypertension and reflux; novice diver; certified fit-to-dive by doctor without dive medical training; diving solo from jetty; difficulty descending; tank slippage; cardiac-related

SC 11/09

This man was 52 y.o. and moderately obese. His medical history is unknown, other than his girlfriend of two months stating that she had not known him to be taking any medications. He was an experienced scuba instructor who had reportedly done over 1,000 dives. His buddy was his girlfriend, a novice who had logged 12 dives. They were among a group of 11 divers and four staff who set out in a large Zodiac to a popular marine reserve surrounding some rocky islets where tropical currents mix with temperate waters. There was a slight breeze and the sea was relatively calm, a strong current was running and the water temperature was 20°C. The victim was wearing a mask, snorkel and fins; a 5-mm one-piece wetsuit over a vest with hood; a BCD with some integrated weights (weight not stated); a scuba unit with a hired 15-L steel cylinder filled to 200 bar; and he was carrying an underwater camera. He appeared to be fine before entry, although possibly not as jovial as usual. He had woken up with a sore throat and complained that his hood was tight and causing his throat to hurt more.

The victim and his buddy entered the water first and initially descended to 13 msw over 3 min, stopping regularly to take photographs. They swam against a strong current as they worked their way down to 21 msw, where the visibility was poor. They continued to swim against the current, for a time holding hands. However, about 16 min into the dive, the victim appeared to be disoriented and became almost stationary. He coughed loudly before grabbing his buddy's arm and signalling that he wished to ascend. He then ascended rapidly to the surface, omitting the usual safety stop. The buddy ascended behind the victim and, on surfacing, noticed that he was surrounded by what she described as "yellow vomit" and his regulator was out of his mouth. He had taken off his mask, hood and BCD and was trying to ditch his weights. When the buddy swam to

him and asked if he was okay, he answered "no", so she waved to the boat, some 200–300 m away. The victim was cyanotic, gasping, coughing and vomiting and becoming increasingly unresponsive.

The boat soon arrived and the skipper noted that the victim was incoherent and that substantial foam was coming from his mouth. After some effort by the buddy and the skipper, the victim was dragged aboard. The skipper rolled him onto his side and provided oxygen first aid. Two other instructors came aboard from another boat and found the victim to be unconscious, apnoeic with no palpable pulse, fixed, dilated pupils and foam "pulsing" from his mouth. They began BLS and continued during the 10-minute journey to the beach and until relieved by paramedics. A defibrillator was attached and several shocks were given without success before he was transported to hospital where he was pronounced dead.

His scuba unit, mask, snorkel and weights were retrieved later that day. No equipment issues were noted in the report, although the full equipment report was unavailable.

*Autopsy:* This was performed four days post mortem. BMI was 38 kg·m<sup>2</sup>. The heart was significantly enlarged and weighed 684 g (n.r. 331–469 g) with left ventricular hypertrophy of 25–35 mm (n.r. ≤ 14 mm). The left ventricle weighed 336 g (n.r. < 250 g) and there was severe narrowing of the LAD coronary artery, and moderate to severe narrowing of the dominant right coronary artery. There was a short myocardial bridge of uncertain significance. Myocyte hypertrophy was present. The kidney vessels showed hypertensive changes. The upper airways were clear. The right and left lungs weighed 690 g (n.r. 446–880 g) and 758 g (n.r. 348–790 g) respectively. They were moderately hyper-inflated but pulmonary oedema was not described. The cause of death was attributed to "the combined effects of coronary artery heart disease and bridging of the [LAD] coronary artery".

*Comments:* Although his girlfriend was unaware of any medical history or of his taking any medications, this may be unreliable. The police report had no indication of whether or not a medical history was sought other than through her. The enlarged heart and coronary artery disease created the risk of collapse and sudden death at any time, whether on land or in the water. The exertion of swimming against a strong current probably triggered a cardiac arrhythmia. These investigators considered IPE as a possible cause of this diver's demise. However, the extent of the enlargement of the heart and narrowing of the coronary arteries makes death directly due to heart disease more likely.

*Summary:* 52 y.o., obese man; unknown medical history; experienced diving instructor; became distressed at depth after swimming into strong current and ascended rapidly; severe coughing, dyspnoea, vomiting and frothy sputum on surface; cardiac-related

## SC 11/10

This 40 y.o. male was very active and relatively fit, albeit obese. He was an experienced scuba diver who first trained as a cave diver 10 years earlier, attaining the highest level of cave diver training four years later. His medical history included hyperthyroidism; multiple fractures resulting from a rock climbing accident; night sweats and palpitations. An ECG one year earlier indicated a normal QT interval.

He and his buddy went diving in a fresh water cave system. They had not dived this complex maze cave for 11 months and 18 months respectively, although they both had considerable prior experience in the site. The victim spent the weekend diving this particular cave with a buddy who was reasonably well known to him, although they had dived together only once before this weekend. On the previous day, the pair performed two uneventful dives of 70 and 120 minutes duration and a maximum depth of 15 metres of fresh water (mfw). That night, the pair joined other divers for dinner but the victim retired early complaining of an “*ear spin*”. No further mention was made of this the next day.

On the day of the accident, the divers made an uneventful 70 min dive (max. depth 15 mfw). Each diver used two 12-litre cylinders and they both returned with plenty of gas. Two and a half hours later, the pair commenced their second dive. The victim’s equipment included a mask and fins; drysuit with undergarments, hood, socks and boots; two 9-L steel cylinders worn ‘sidemount’, and a 7.9-L aluminium ‘stage’ cylinder attached to his harness. He also wore a weight belt with 3.8 kg of weights and carried several torches, reels and cutting tools. He appears to have been familiar with this configuration. He was carrying slightly smaller cylinders than his buddy.

The plan was to swim to a distant part of the cave (max depth 15 mfw), breathing from then dropping a ‘stage’ cylinder en route that would be collected and used during the exit. Navigation to their destination in the cave is complex so the pair marked any junctions on the cave line with personal markers (clothes pegs on this occasion). Close to the limit of their penetration, the buddy passed through a restrictive part of the cave and continued on a few minutes further to the end, before turning to exit. At this point, he noticed the victim was no longer behind him. Back at the restriction and at two other places during the swim out, he noted significant clouds of silt, suggesting that the victim disturbed the floor or ceiling of the cave. On the way out of the cave, the buddy noted that the victim’s markers and his stage cylinder had been removed so he continued to exit, assuming the victim to be just ahead of him. As he got close to the entrance of the cave, he discovered markers either still in place or dropped on the floor, and finally the victim’s illuminated back-up torch activated, on the floor. The buddy reached the exit and performed 35 min of decompression before surfacing.

On surfacing, he was informed the victim had not yet

appeared. The dive supervisor, already concerned that the pair was overdue, immediately raised the alarm and sent the buddy and another diver back into the cave to briefly search. Neither diver saw the victim until they were exiting the cave, when they finally saw him floating against the ceiling, just 30 m into the cave at a depth of 6.4 mfw. It was clear the diver was dead and so they exited, awaiting formal recovery later that evening. The recovery divers found the victim to be positively buoyant and hence difficult to extricate from the ceiling of the cave.

Examination of the victim’s equipment found all three cylinders to be empty. His primary light, which was known to be faulty, was almost flat. His drysuit was flooded with approximately 20 L of water, however, the suit itself was not damaged in any way. Analysis of both divers’ computers showed the victim exited the cave just ahead of the survivor, and the time to exit was similar to the penetration time, suggesting that the exit was unhurried.

*Autopsy:* This was performed three days post mortem. Erect chest X-rays showed ill-defined opacity in the left mid and upper zones, consistent with aspiration/drowning and gas in the heart and great vessels of the neck. BMI was 30 kg·m<sup>-2</sup>. There was a ring of pallor on the neck and congestion above it consistent with the neck seal of the drysuit. The heart was normally formed and weighed 495 g (n.r. 331–469 g). The left ventricle measured 16 mm posteriorly and 17 mm at the septum (n.r. ≤ 14 mm) and weighed 282 g, while the right ventricle weighed 89 g. There was mild coronary atherosclerosis. There was a large quantity of gas in the right atrium and a smaller quantity of gas in the left atrium which was attributed to post mortem decompression artefact. There was foamy blood-stained fluid on the face and in the upper airways. The right and left lungs weighed 1024 g (n.r. 446–880 g) and 1026 g (n.r. 348–790 g) respectively and showed mild to moderate oedema, but were normally inflated with some fibrous adhesions. Ocular fluid showed [Na<sup>+</sup>] 145 mmol·L<sup>-1</sup>, [Cl<sup>-</sup>] 127 mmol·L<sup>-1</sup> (PMVSC 272 mmol·L<sup>-1</sup>). The body had been immersed for approximately 9 h. The cause of death was given as “*unascertained*”.

*Comments:* Based on gas usage from previous dives that weekend, it was calculated that the victim was carrying approximately 118 minutes of dive gas (less than the 120 minutes planned for the dive). The victim turned for home at the 53 min mark, and the dive time back to near the entrance was 100 minutes total dive time, leaving far less than the accepted norm of a 33% safety margin (rule of thirds). Hence, any minor problems encountered on the dive which increased the victim’s breathing rate or stress levels, may have contributed to the diver running out of air very close to the cave entrance. It is possible that the diver became more and more positively buoyant during the exit phase of the dive, making the swim more arduous and hence increasing gas consumption. The large volume of water inside the drysuit raises the possibility of an intentional flood

in an attempt to correct this. It is highly likely that this cave diver ran out of air and subsequently drowned.

The elevated post mortem vitreous  $[Na^+]$  and  $[Cl^-]$  are difficult to explain as a product of drowning as Tank Cave contains fresh water. Because of the possibility of diffusion across the external surface of the eye, the PMVSC test has only been postulated as valid for post-mortem immersion times less than an hour, and only in salt not fresh water. Studies of fresh water drowning have suggested that vitreous  $[Na^+]$  is related albeit erratically to the length of the period of immersion.<sup>12</sup>

*Summary:* 40 y.o. male; relatively fit, history of hyperthyroidism, multiple fractures, night sweats and palpitations; experienced cave diver but lacked currency in this complex dive site; ambitious dive planned with inadequate gas planning; buddy separation; possible buoyancy issues contributed to increased gas consumption; out of air; drowning

#### SC 11/11

This man was a healthy, 32 y.o. overseas national who had recently begun working in Australia. He had certified as an open water diver two years earlier and had done approximately 25 dives. He and two friends were on a private vessel anchored offshore of a large island in temperate waters. The island is a popular diving and fishing location and large sharks are known to visit the surrounding waters. The weather was rainy, cloudy and overcast, there was a gentle breeze ( $15 \text{ km}\cdot\text{h}^{-1}$ ) and the sea was relatively calm with a 1 m swell and the visibility was around 20 m. The dive site had a sandy bottom and a large reef ledge. The friends dived first, while the victim remained on the boat, but they returned to the boat empty-handed.

The victim moved the boat closer to the reef, anchoring in a depth of 12 msw before diving alone. He was wearing mask, snorkel and fins; a full one-piece 3-mm wetsuit, boots and gloves; standard scuba diving equipment including a BCD and steel cylinder, a dive knife and carried a spear gun. It is unknown if he wore a weight belt or integrated weights. After about 20 min, one of the friends decided to move the boat closer to where the victim's bubbles were seen, some 100 m distant. However, before he could do so, he saw a large plume of bubbles rise to the surface. After raising the anchor and moving towards where these bubbles had been, the friend saw a pool of blood in the water along with some "internal organs" and the victim's body floating to the surface. One of his arms was missing and he had massive chest and abdominal injuries with some exposed organs. His fins were in place but his scuba unit and mask were missing.

Using the boat hook, the friends dragged the victim's body onto the transom, covered it with a blanket and secured it. No resuscitation attempts were made. A large shark, reported to be a white pointer (*Carcharodon carcharias*) more than

3 m long surfaced next to the boat and followed it until it gained speed. On arrival at the island, death was confirmed by a nurse practitioner. A shark expert confirmed that the injuries were consistent with those from a white pointer shark in excess of 3.5 m long.

*Autopsy:* The autopsy was performed four days after death. There were multiple traumatic injuries, with part of the left chest wall and the left lower lobe of the left lung missing, and traumatic amputation of the left arm. The injuries were consistent with a shark although no tooth fragments were recovered. BMI was  $22 \text{ kg}\cdot\text{m}^{-2}$ . The heart weighed 350 g (n.r. 295–445 g) and was normal with no atherosclerosis of the coronary arteries. There was frothy fluid in the upper airways. The right lung weighed 352 g (n.r. 410–892 g). The cause of death was given as multiple injuries due to shark attack.

*Toxicology:* Alcohol  $0.013 \text{ g } 100 \text{ ml}^{-1}$  (probably artefactual); naproxen  $2 \text{ mg}\cdot\text{L}^{-1}$  (sub-therapeutic)

*Comments:* Spearfishing is well known for attracting sharks and this diver was unfortunate that a large shark was in the vicinity at that time. Being alone may have increased the likelihood of attack, although given the size of this shark and the severity of the injuries, having a buddy may well have made no difference.

*Summary:* 32 y.o. male; healthy; spearfishing on scuba alone at site where large sharks are known to visit; shark attack (probably white pointer); trauma

#### SC 11/12

This 28 y.o. woman was a healthy non-smoker who did not declare any medical conditions on her pre-training medical questionnaire. She was an overseas tourist who had just arrived in Australia two days earlier. She enrolled in an open water course, which was planned over two-and-a-half days. She had previously done the theory component of the course on-line and, on the first day, she completed her theory test and was orientated to the equipment, including assembly and disassembly in the classroom. The only pool training was done earlier on the day of the accident and this reportedly included at least 1.5 h "underwater time". The instructor described her as a competent swimmer although apparently not one who swam regularly. This was her first open-water dive. She mentioned being exhausted after the morning session and fell asleep on the bus en route to the dive site. She did not communicate this to the instructor.

The dive site was a sheltered cove, a popular training site. The sea was reported to have been calm, no current, water temperature about  $18^\circ\text{C}$  and visibility initially around 5 m. The victim was wearing standard scuba equipment including a 10-L cylinder, a 5-mm wetsuit with a separate hood and a weight belt with 8.2 kg of weights. The divers entered the water in two groups. The group with the victim consisted of an instructor, seven open water students and a relatively

inexperienced certified diver who was doing a refresher dive as part of further training. The other group included an instructor with six students.

The group with the victim entered from the shore, submerged and swam underwater an estimated distance of 75–100 m. The victim's buddy reported that the victim initially had some buoyancy/orientation issues and that she lagged behind her several times. The group explored the site for about 28 min, when the instructor checked the students and all appeared to be present and well. At this point, the victim's pressure gauge was reported to have read 120 bar. The maximum depth reached was approximately 5 msw.

During the dive, the instructor reported that she turned and checked the students every couple of minutes as the visibility became very low (possibly 0.5–1 m) as a result of a lot of sand being kicked up by the divers, making it impossible for the instructor to see all her students. The group turned towards shore and after about another minute, when the instructor checked her students, she noticed one was missing and signalled the group to surface. The victim was not there, so the instructor sent the other students to shore and called out to her colleague, who was on the surface, that a diver was missing. The instructor then exited the water and climbed to a vantage point to look for bubbles while her colleague began an on- and in-water search.

The other instructor found the victim approximately 50 m from where her group had surfaced. She was unconscious, lying on her back on the seabed. Her mask was in place and clear but her regulator was out of her mouth. The rescuer quickly brought the victim to the surface, ditched her weight belt, removed her mask and checked for breathing. Breathing was absent, so he gave two rescue breaths, removing her BCD on the way and continuing rescue breathing periodically while towing her to shore with the aid of some students. Meanwhile the victim's instructor was trying to arrange for an ambulance.

Once on shore, the rescuer confirmed that the victim was unconscious and apnoeic and so began BLS, helped by one of the students. The victim's instructor soon returned and took over the rescue breaths which were complicated by the regurgitation of water and vomit. She had difficulty maintaining a clear and open airway and heard gurgling and felt resistance with every rescue breath. No supplementary oxygen was readily available. Paramedics arrived after about a further 20 min and took over resuscitation efforts but the victim failed to respond.

The victim's BCD, regulator and tank were found to be functioning correctly. The gauge indicated a pressure of 70 bar and the remaining air was found to be compliant with Australian Standards. Her weight belt was recovered by police on the following day, approximately 20 m from shore and at a depth of 5 msw. Her dive computer records

indicated that about 35 min into the dive (possibly three minutes after she was last seen) the victim did a fast ascent from 5.2 msw to 1.25 msw and then sank to the bottom where she remained motionless for 23 min before being taken rapidly to the surface by the rescuer.

*Autopsy:* This was performed one day after death. Supine X-rays of the chest showed possible gas in the left neck vessels. BMI was 29 kg·m<sup>-2</sup>. The heart weighed 234 g (n.r. 285–439 g) and was normal. The coronary arteries showed no atherosclerosis. There were fine gas bubbles in the right ventricle and the pulmonary artery but not in the left ventricle. There was a moderate amount of watery fluid in the upper airways with gastric contents. The right and left lungs weighed 426 g (n.r. 305–817 g) and 390 g (n.r. 287–695 g) respectively and showed moderate pulmonary oedema, but were not over-expanded. The cause of death was given as drowning but the underlying precipitant was not determined.

*Comments:* This totally inexperienced diver was tired before the dive and overweighted with some buoyancy problems during the dive. Coupled with low visibility and separation from the group, this would have made a potent recipe for panic. It is likely that, after looking around for several minutes, she did a rapid ascent towards the surface and became unconscious from either a CAGE or aspiration, sank to the bottom and drowned. In the absence of a CT scan performed within eight hours of death it is difficult to evaluate the possibility of pulmonary barotrauma/CAGE, but the gas distribution at autopsy is not very convincing despite the evidence of a rapid ascent. Aspiration of water and drowning appears more likely associated with separation, poor visibility, overweighting and anxiety. Given that the visibility had deteriorated so substantially making it difficult to adequately monitor the students, it would have been prudent for the instructor to suspend or abort the dive.

*Summary:* 28 y.o. healthy woman; competent swimmer; first open water dive; tired prior to entry; poor visibility from students stirring up sand; one instructor for seven trainees and one 'refresher' diver; separated; unconscious underwater for 25 min; BLS unsuccessful; drowning

SC 11/13

The victim was a 47 y.o. male who worked as a bricklayer. He smoked 15 cigarettes a day and drank alcohol regularly. He had a history of a work-related shoulder injury and depression. However, one year earlier he had an episode of chest pain associated with hemiparesis and slurred speech which self-resolved after five minutes and was never investigated. He was also noted to have suffered from occasional angina-like chest pain at work. Prior to being certified as an open water diver, he underwent a medical assessment with a doctor with relevant training. He declared that he had recovered from the shoulder injury, was not

taking any medications, and specifically denied any history of heart problems, chest pain, epilepsy, diabetes, asthma or any other medical conditions. He was subsequently certified as 'fit-to-dive'. The victim had enrolled in a rescue diver course during which he was unable to complete satisfactorily one of the swimming tests as the instructor believed he was too unfit. However, he purchased his own equipment and began diving fortnightly with friends. By the time of his death, the victim had logged 19 dives; most appeared to have been shallow shore dives.

On this occasion, the victim had planned to dive with a friend. However, when his would-be buddy called in sick, the victim asked his wife to act as a lookout on the beach. She described him as very safety conscious. The weather was fine with a light wind, the sea was calm with visibility of around 6 m, and the water temperature was 16°C. The victim was wearing mask, snorkel and fins; a full-length 5-mm wetsuit with hood, boots and gloves; BCD with 11.7 kg of integrated weights, a scuba unit with 10.5-L tank and he carried a catch bag.

He entered the water from the sand and proceeded to swim around a rocky outcrop. After almost an hour, his wife saw him surface beyond the rocks and about 150 m away. He was laying on his back and trying to fin towards shore but struggling to make headway. She yelled to him to ask if he was okay, to which he answered "no". The wife ran towards him along the rocks and saw that he looked very unwell. After running back to the beach and asking a bystander to call the emergency services on her mobile, the wife returned to the victim who was now lying face-down in the water. She entered the chest-high water rolled him over and saw that he was apneic and cyanotic and was making gurgling sounds.

She supported the victim, removed his dentures, mask and hood and gave some rescue breaths. She was soon joined by a bystander who took over the rescue breathing and the wife attempted to give chest compressions while they supported him in the water. It was difficult to prevent water washing over the victim's face and the woman giving rescue breaths reported hearing gurgling from the airway with each ventilation. They eventually managed to remove his uninflated BCD (which was dragging him under) and to tow him to the shore, which took some time. Ambulance paramedics were waiting and immediately took over resuscitation. The victim was found to be asystolic, cold and cyanotic. He had widespread crackles on ventilation as well as upper airway fluid which was cleared with suction. ALS was implemented without effect and resuscitation was ceased after approximately 30 min.

When tested, his equipment was found to be in good condition and functional and the remaining air (only 5 bar) met relevant purity standards. His dive computer indicated that he had dived to a maximum depth of 5.3 msw for a total of 46 minutes. His catch bag contained 104 abalone

and weighed 17.5 kg, whilst his BCD was rated with a maximum lift of 17.2 kg.

*Autopsy:* This was performed three days after death. Post-mortem CT scan (nine hours after death) showed small bubbles of gas in the right side of the heart, and gas filling of the hepatic but not portal veins. There was no other substantial intravascular gas. There was diffuse interstitial opacity throughout the lungs, consistent with pulmonary oedema and fluid levels in the upper airways and sinuses. BMI was 29 kg·m<sup>-2</sup>. The heart weighed 400 g (n.r. 331–468 g) and appeared normal. The LAD showed a 40% stenosis by atheroma. The foramen ovale was not described. Histology showed no scarring. The upper airways were clear. The lungs were heavy and expanded with the right and left lungs weighing 985 g (n.r. 446–880 g) and 790 g (n.r. 348–790 g) respectively. There was moderate pulmonary oedema. Ocular fluid showed [Na<sup>+</sup>] 142 mmol·L<sup>-1</sup>, [Cl<sup>-</sup>] 114 mmol·L<sup>-1</sup> (PMVSC 256 mmol·L<sup>-1</sup>) which does not suggest salt water drowning.<sup>3</sup> The cause of death was given as "a sudden natural event, probably cardiac in nature, leading to a sudden cardiac arrhythmia and his subsequent death". Toxicology: Cannabis 15 ng·ml<sup>-1</sup> (indicating recent use)

*Comments:* Although this man was used to physical labour at work, he had been out of work for two months and records indicate a weight gain of 8 kg since his diving medical five months earlier. He remained a heavy smoker and, less than two months before the incident, the victim's instructor found him too dyspnoeic to complete a required 150 m rescue swim (with fins) during a post-basic course. It is probable that the gas in the heart and liver represented decomposition or resuscitation artefact. Typically, a 40% stenosis of the LAD coronary artery is not deemed to be sufficient stenosis to cause sudden death. However, the previous events involving chest pain raise the possibility of underlying cardiac dysfunction. Dragging along a catch bag weighing 17 kg would have been very strenuous, especially without compensating by adding air to his BCD. He might have become unconscious from a cardiac arrhythmia, despite the absence of supporting pathology. Alternatively, he might have become so dyspnoeic that he was unable to support himself in the water, aspirated and drowned. Ditching his catch bag and inflating his BCD might have changed the outcome but he was probably not thinking clearly enough to realise this. Finally, IPE is a possible but unlikely cause of his demise. On balance, the available information appears to suggest a cardiac-related death rather than a primary drowning. Given the episode of hemiparesis and slurred speech it would have been useful to know if the foramen ovale was patent.

*Summary:* 47 y.o. male; history of shoulder injury, angina-type pain, possible TIA; unfit; not a strong swimmer and inexperienced diver; failed to declare significant medical history at recent diving medical; diving alone; reasonable conditions; carrying catch bag weighing 17 kg; struggling on surface with uninflated BCD; cardiac-related

## SC 11/14

The victim was a 56 y.o. male who was described by his wife as “*fit and healthy with no known medical conditions*” and who was taking no medications. A pre-employment medical, conducted nine months earlier, was unremarkable. He had been certified as a diver for 11 years and was reported to have done hundreds of dives. He and his wife, also an experienced diver, set out on a shore dive at a site with both sheltered inlets and exposed waters either side of rocky platforms. The wind speed was reported to have been 15–20 knots and the seas were rough beyond the inlets. The water temperature was not reported. He was wearing mask, snorkel and fins; a 5 mm two-piece wetsuit with attached hood; a scuba unit with BCD, 10.5-L steel cylinder, regulator with ‘octopus’ and gauges; and a weight belt with an unknown amount of weight.

The pair entered the water and descended to a depth of about 3 msw above a rocky reef. His wife reported that the water above them appeared turbulent and that they were dragged along by a strong current. After about 10 min, his wife indicated that she wanted to ascend, which they did, surfacing into rough water with waves breaking on nearby rocks. The site was littered with submerged boulders and kelp. The victim, who appeared “*in control and calm*”, suggested that they inflate their BCDs and return to shore by lying on their backs and finning. However, while doing so, she lost sight of him.

On reaching some rocks and exiting the water, his wife noticed the victim near to where they had surfaced. He was floating face-up with his BCD inflated and moving only with the motion of the sea. When she called to him and he failed to respond, she became concerned and alerted others. A bystander entered the water and dragged the victim to the rocks. At one point a rush of air was heard escaping from the victim’s equipment. The rescuer assessed him to be unconscious and rolled him onto his side. By this time, it is likely that he had been unconscious for approximately 15 min. Water, and some frothy sputum, was seen flowing from his mouth and he was also bleeding from a head wound. Unable to detect any signs of breathing or a palpable pulse, the rescuer began BLS and continued, with the help of others, for around 25 min until paramedics arrived and implemented ALS. When the victim failed to respond after a further 17 min, he was pronounced dead at the scene.

When inspected, the cylinder valve was broken, the cylinder was empty and showed signs of heavy impact with a hard surface. The demand valve and hose had been torn from the first stage regulator and were missing, as was the victim’s mask and weight belt. The remainder of the equipment was functional.

**Autopsy:** The autopsy was conducted three days after death. A CT scan (7.5 h post mortem) revealed no evidence of

gas in the heart (either the right or left ventricles) or in the cerebral vessels, and no gas in the soft tissues. BMI was 27 kg·m<sup>-2</sup>. There was some patchy consolidation of the lungs, consistent with drowning. There was a 40 mm bruise on the left parietal scalp but no underlying head injury, and a 20 mm bruise on the right side of the tongue. The heart weighed 406 g (n.r. 331–469 g). The right coronary artery was 60% occluded by calcified atherosclerosis, with no evidence of an unstable plaque. The LAD coronary artery showed approximately 30% narrowing and the circumflex coronary artery less than 10% narrowing by atherosclerosis. The left ventricle showed mild concentric hypertrophy (15 mm; n.r. ≤ 14 mm). Histology showed microscopic fibrosis and subendocardial haemorrhage. There was over 20 ml of gas in the right ventricle at autopsy, although there was no gas in the left ventricle and none obvious in the inferior vena cava. There was pulmonary oedema fluid and water in the mouth and upper airways. The right and left lungs weighed 1212 g (n.r. 446–880 g) and 1108 g (n.r. 348–790 g) respectively, being over-expanded and very heavy. There was severe pulmonary oedema consistent with the diagnosis of drowning. There was anthracosis and mild chronic lung disease. The cause of death was given as drowning following a head injury in a man with ischaemic heart disease.

**Toxicology:** Nicotine

**Comments:** Although experienced, these divers made a fundamental error in choosing to dive at this unknown site in unsuitable conditions. They were likely unaware of the presence of the strong current which swept them into treacherous waters. It appears that the victim was thrown against a submerged rock and there was evidence of damage to the tank to support this, but it is unknown if this was the likely cause of his unconsciousness, or subsequent to him becoming unconscious. Given the presence of moderate ischaemic heart disease, it is possible that the exertion of making headway in the rough sea triggered a cardiac arrhythmia, leading to unconsciousness and subsequent drowning. His demand valve was torn away during the rescue causing depletion of the air supply.

**Summary:** 56 y.o. male; no significant medical history; experienced; swept into rough water by current; thrown against submerged rocks; drowning (significant ischaemic heart disease at autopsy, possible cardiac contribution)

### Surface-supplied breathing apparatus fatality

#### SS 11/01

This 50 y.o. man was described as a “*fitness and health fanatic*” although his medical history was not available. He was an experienced diver of more than 27 years, and had worked as a commercial abalone diver for the past 4–5 years. He was diving from a companion’s 6.4 m boat. The skipper remained on the boat to haul in the catch bags as they

surfaced, and to shell the abalone. The victim was wearing a mask and fins; a full wetsuit with booties and gloves; a weight vest; and had a Shark Shield attached by a belt. He was using surface-supplied breathing apparatus (SSBA). There was a moderate wind (28 km·hr<sup>-1</sup>) and conditions were described as “workable”. The depth of the site was 25 msw.

Approximately 10 min after the victim entered the water, the skipper noticed a change in tone of the compressor and believed that the victim was about to send a bag to the surface. He drove the boat towards the diver’s bubbles and soon the diver surfaced beside the boat. The skipper stated that he then saw the victim dragged underwater by a large shark (or sharks). He hauled in the air line, which was severed.

The skipper stated that he circled for “ages” but never saw any sign of the victim. He failed to mark the location with a shotline or GPS, and did not attempt to call the emergency services by radio or mobile phone. He reported the incident to the abalone co-operative when he returned to shore several hours later. They in turn contacted the ambulance after which the police were finally notified. The skipper could not, or would not, provide clear details of the location and, by the time police searchers arrived in the general vicinity, a search was limited by poor light. That and subsequent searches found no trace of the victim or his equipment.

*Comments:* This incident was the subject of a particularly thorough coronial investigation, triggered by concerns at the skipper’s failure to mark the sight or contact emergency services, changes in parts of his account of the incident, and reluctance to assist police to locate the site. He claimed that his inactions and actions were a result of his distress. The Coroner concluded that the victim was taken by a shark and was critical of some of the companion’s actions and inactions. Given that no equipment was recovered, it is unknown whether or not the victim’s Shark Shield was activated at the time of the attack. His companion reported that he sometimes turned the device off when on the bottom but had it activated during descent and ascent.

*Summary:* 50 y.o. male; apparently healthy; experienced abalone diver; solo; collecting abalone on SSBA; attacked by large shark(s); body never found

## Discussion

Summaries (chain of events analysis) of the possible sequence of events in these incidents are shown in Tables 3 and 4.

## PRE-EXISTING HEALTH CONDITIONS

Pre-existing health-related conditions are believed to have been a likely or possible contributor to at least 10 (67%) of the snorkelling, and up to 9 (60%) of the compressed gas-related deaths as indicated in Table 3. One experienced

snorkeller died directly as the result of asthma which was not well-controlled and was likely exacerbated by common triggers in the diving environment, which include exertion, salt water aspiration and cold. The disabling injury is believed to have been cardiac-related in at least seven (47%) of snorkelling victims, and possibly five (33%) of the deceased compressed gas divers. This is consistent with the increased proportion of cardiac-related incidents in divers over more recent times.<sup>13</sup> Some of these individuals clearly should not have been diving or snorkelling based on their known medical history. Data from various surveys indicate that it is likely that more than 20–30% of active divers have a significant medical condition that may adversely affect their diving safety.<sup>14,15</sup> Therefore, it is important to learn more about the risks associated with diving with clinically significant co-existing medical conditions.

## MEDICATIONS

Some of the divers (scuba and snorkel) in this series failed to declare that they were taking medications as required to do so by some dive operators on their pre-dive or snorkel medical declaration form. This is not uncommon and has been evident in earlier reports by these investigators. It is likely that some people may not report their medication use as they believe it to be irrelevant, while others for fear of not being permitted to dive. When prospective divers do report medication use, it can raise an issue for the operators who are in the position of having to decide whether or not to let the person participate in the planned activity. Some operators have a blanket policy of not allowing the declarant to dive and this may often be unfair to the potential diver, depending on their health condition and their medication. Some operators have an arrangement with a local diving doctor whom they consult in such circumstances and this should be encouraged. There have been anecdotal reports of dive staff advising the declarant to complete another form without declaring the condition or medication. The casual use of stimulants such as pseudoephedrine should probably be avoided if there is an elevated risk of heart disease.<sup>4</sup>

## SHARK AND CROCODILE ATTACKS

Two of the victims died as a result of attacks by sharks (SC 11/11 and SS 11/01), and one by a crocodile (BH 11/7). All of these victims were collecting seafood at the time; two spearfishing and one harvesting abalone. This was the first known fatal crocodile attack on a diver or snorkeller in Australia since 2005.<sup>16</sup> These were also the first witnessed fatal shark attacks on divers in Australia since 2004.<sup>17</sup> However, attacks by sharks on divers are well documented. The International Shark Attack file has recorded 72 attacks by sharks on divers (scuba, SSBA and free-) worldwide from 1990–2009.<sup>18</sup> Of 218 recorded shark attacks on divers worldwide, 67 (31%) occurred in Australia. Fortunately, most attacks are not fatal. The fatality rate dropped from 34% in 1990–1999 to 12% in 2000–2009.

**Table 3**

Chain of events analysis of breath-hold diving-related fatalities in Australian waters in 2011;  
 AVD – aortic valve disease; CAD – coronary artery disease

Case	Predisposing	Trigger	Disabling agent	Disabling injury	Cause of death
BH11/01	Health-related	Exertion? aspiration?	Medical-related (asthma)	Asphyxia	Drowning
BH11/02	Lack of experience/skills; poor supervision	Unknown (aspiration?)	Unknown	Asphyxia	Drowning
BH11/03	Health-related	Exertion; immersion	Medical-related (CAD, AVD)	Cardiac incident	Cardiac-related
BH11/04	Poor supervision; activity- related (deep/long dive)	Extended apnoea	Apnoeic hypoxia	Asphyxia	Drowning
BH11/05	Health-related	Environ-related (immersion); exertion	Medical-related (CAD)	Cardiac incident	Cardiac-related
BH11/06	Health-related (alcohol/ drug use)	Unknown	Unknown	Asphyxia	Drowning
BH11/07	Activity-related (spearfishing)	Environ-related (crocodile)	Crocodile attack	Trauma; asphyxia	Drowning
BH11/08	Health-related	Environ-related (immersion); exertion	Medical-related (CAD)	Cardiac incident	Cardiac-related
BH11/09	Health-related	Environ-related (immersion); anxiety?	Medical-related (CAD)	Cardiac incident	Drowning
BH11/10	Health-related	Environ-related (sea conditions); exertion	Wave action? Medical-related (CAD)	Cardiac incident	Drowning
BH11/11	Health-related	Environ-related (immersion); exertion	Medical-related (CAD)	Cardiac incident	Cardiac-related
BH11/12	Health-related; poor planning & supervision	Environ-related (conditions); exertion	Medical-related (CAD); aspiration?	Cardiac incident? asphyxia?	Cardiac- related? Drowning?
BH11/13	Health-related	Environ-related (immersion); aspiration; stimulant use	Medical-related (CAD)	Cardiac incident	Drowning
BH11/14	Poor planning (solo); inexperienced	Equip-related (loose line, tight fin)	Entanglement, leg cramp; buoyancy-related	Asphyxia	Drowning
BH11/15	Poor planning (conditions) poor supervision	Environ-related (rough, rip)	Aspiration	Asphyxia	Drowning



**Table 4**

Chain of events analysis of compressed gas diving-related fatalities in Australian waters in 2011; CAGE – cerebral arterial gas embolism; IPE – immersion pulmonary oedema; LADCA – left anterior descending coronary artery; PBt – pulmonary barotrauma

Case	Predisposing	Trigger	Disabling agent	Disabling injury	Cause of death
SC11/01	Health-related (previous IPE)	Environ-related (immersion)	IPE	IPE	IPE
SC11/02	Equipment problem (oil in air supply)	Gas supply-related; equalization problem?	Ascent-related	PBt	PBt/CAGE
SC11/03	Activity-related (confined); poor planning and communication; attitudinal	Environ-related (silted, narrow passage); diver error	Gas supply-related; entrapment	Asphyxia	Drowning
SC11/04	Inexperienced; poor planning and supervision; health-related	Environ-related (rough, current)	Unknown	Asphyxia	Drowning
SC11/05	Health-related	Environ-related (immersion); exertion?	Medical-related (valvular heart disease; IPE?)	Cardiac incident; IPE?	Cardiac-related
SC11/06	Poor organisation and supervision; health-related?	Environ-related (poor visibility); anxiety/stress?	Unknown	Asphyxia	Drowning
SC11/07	Health-related	Environ-related (immersion); exertion	Medical-related? IPE?	Cardiac incident; IPE?	Cardiac-related
SC11/08	Health-related; poor planning (solo)	Exertion	Medical-related (septal hypertrophy)	Cardiac incident	Cardiac-related
SC11/09	Health-related	Environ-related (current)?	Cardiovascular disease; bridging of LADCA	Cardiac incident	Cardiac-related
SC11/10	Activity-related (confined); poor planning and buddy supervision	Gas supply-related	Gas supply-related; entrapment	Asphyxia	Drowning
SC11/11	Activity-related	Environ-related (shark)	Shark attack	Trauma	Trauma
SC11/12	Unsafe supervision	Environ-related (poor visibility); anxiety	Ascent-related	PBt/CAGE? asphyxia?	Drowning
SC11/13	Health-related	Exertion	Buoyancy-related; health-related	Asphyxia? cardiac-related?	Cardiac-related
SC11/14	Poor planning (conditions); health-related?	Environ-related (rough)	Impact-related (head with rocks)	Asphyxia	Drowning
SS 11/01	Activity-related	Environ-related (shark)	Shark attack	Trauma?	Unknown (no body)

## AIRWAY PROBLEMS FROM STOMACH CONTENTS AND FLUIDS DURING RESUSCITATION

Regurgitation of stomach contents is the most common complication in the resuscitation of a drowning victim and has been reported to occur in more than 65% of persons who require rescue breathing alone, and in 86% of those who require CPR.<sup>19</sup> In addition to water and other stomach contents, rescuers are often faced with the discharge of pulmonary oedema fluids, which can be confronting to the inexperienced. Difficulties with airway management due to regurgitation and frothy discharge were specifically mentioned in 8/30 (27%) of cases in this series but might have occurred in more. In most cases, turning the victim onto their side helped to clear the stomach contents, although, in some cases this had to be repeated several times. Whereas the presence of vomitus in the airway can often lead to further aspiration injury and impairment of oxygenation and needs to be cleared, frothy discharge is relatively benign and need not interrupt resuscitation.<sup>20</sup>

## IN-WATER RESCUE BREATHING AND/OR CHEST COMPRESSIONS

One of the rescuers of victim SC11/13 attempted in-water chest compressions. Some early manikin studies reported that sufficient compression depth could feasibly be achieved on a manikin in the water in ideal circumstances.<sup>21,22</sup> However, the results are very unlikely to be transferable to humans and attempts at in-water compressions should be discouraged.<sup>23,24</sup> In this incident, and in two of the snorkelling fatalities (BH 11/01 and BH 11/03), rescuers attempted in-water rescue breathing (IWRB). There is some evidence that this can be beneficial to the survival of a drowning victim, especially if they are not yet in cardiac arrest.<sup>19,25</sup> IWRB has been shown to be an effective technique when performed by trained lifesavers but often has the potential to delay the victim reaching surface support such as the boat or shore.<sup>20,26</sup> Each rescue is different and the individual circumstances need to be considered. It has been recommended that two initial rescue breaths be given as soon as the rescuer reaches an unconscious and apparently apnoeic diving (or snorkelling) victim. If surface support is less than five minutes away, intermittent rescue breaths should be administered while towing or supporting the victim until the victim is removed from the water and vital signs are assessed. If surface support is more than five minutes away, rescue breaths should be given for one minute before the victim is towed (without further rescue breaths) to the nearest surface support.<sup>23,24,27</sup>

## OTHER ISSUES WITH RESUSCITATION

### *Premature cessation*

It was reported that the victim in BH11/02 was recovered relatively quickly and BLS was begun promptly. However, this was interrupted after a short time as “*she looked like*

*she was gone*”. Although efforts were later recommenced, this was after a considerable delay and any opportunity to resuscitate the victim was lost. Lay rescuers are encouraged to continue resuscitation efforts until: the victim responds or begins breathing normally; it is impossible to continue; a healthcare professional takes over BLS or a healthcare professional directs that BLS be ceased.<sup>28</sup> In SC11/04, it was reported that one of the rescuers used a demand valve to try to ventilate the victim. This technique is not recommended for several reasons including: (1) the difficulty in obtaining an airtight seal using a diving demand valve with mouthpiece; (2) the flow rate from a demand valve when purged is very high, often several hundred litres per minute. Such high flow rates easily cause gastric insufflation and consequent regurgitation. By comparison, oxygen resuscitation equipment is limited to 40–60 L·min<sup>-1</sup> and (3) whereas oxygen resuscitators are fitted with one or more pressure relief valves to prevent pulmonary barotrauma, diving demand valves are not. In circumstances where a rescuer is reluctant to perform mouth-to-mouth or mouth-to-mask ventilation due to the presence of regurgitated stomach contents or other discharge, and/or fear of cross infection, it is better to perform compression-only CPR rather than not attempting or continuing BLS. However, rescuers should be aware that the risk of cross infection in such circumstances is very low.<sup>29</sup>

### *Defibrillation*

With the growing awareness of the potential benefits of public access defibrillation, an increasing number of dive operators have added AEDs to their first aid equipment. This should be encouraged. In five cases in this series, AEDs were available at or near the site of the incident but, in all cases, when these were attached, there was no shockable cardiac rhythm. It is apparent that access to an AED does not always lead to successful resuscitation. There is no doubt that early defibrillation can increase the survival rate for out-of-hospital cardiac arrest. This is especially so if the arrest was due to a primary cardiac cause where it has been reported that possibly half of victims are found with an initial shockable rhythm.<sup>30</sup> For every minute that defibrillation is delayed, there is approximately a 10% reduction in survival if the cardiac arrest was from ventricular fibrillation.<sup>31</sup> By contrast, only 6–8% of drowning victims are found with an initial shockable rhythm. Asystole and pulseless electrical activity are the most commonly detected rhythms consistent with cardiac arrest from other non-cardiac aetiologies.<sup>30,32,33</sup> Key predictors in the survival of drowning victims are the emergency medical response time and being found in a shockable rhythm.<sup>34</sup> In diving scenarios there are often delays in the recognition and rescue of victims, compounded by the fact that these activities are often conducted distant from medical care. However, an increasing number of diving fatalities are due to primary cardiac causes and, if recognition and rescue are swift and the opportunity for subsequent drowning minimised, prompt defibrillation may be more beneficial.

## FATALITIES INVOLVING DIVE STUDENTS

This series includes the deaths of two divers under instruction. The first (SC 11/06) was undertaking her second 'scuba experience', and the other (SC 11/12) was on her first open-water training dive. In both cases, the divers became separated from their instructor and the rest of the group in poor visibility, which should have been anticipated by the instructor. Another common factor was that the instructors led the groups from the front, turning around regularly to check on the students. These circumstances were similar to those discussed in an earlier fatality report (SC 09/03).<sup>35</sup> It is often preferable for the students to swim closely on each side of the instructor, abreast with the instructor. With such inexperienced divers and substantially diminished visibility, an instructor or guide should have a low tolerance for aborting a dive or reducing the ratio rather than run the risk of losing the divers, with possible tragic consequences.

## BUDDY OVERSIGHT

Lack of, poor or breakdown of the buddy system was evident in 22/30 (73%) of these incidents and is a recurring theme in diving-related mortality.<sup>13</sup> Five of the victims (three snorkel and two scuba) were intentionally diving solo, three with a lookout on shore. Although these lookouts became aware of the problems (some after unknown delays) rescue efforts were delayed and unsuccessful. There appears to have been intentional separation from the buddy in five cases, including the two cave diving victims. Unintentional separations occurred as a result of poor underwater visibility, rough surface conditions, current, lack of attention as well as differing surface swimming speeds when returning to shore or boat.

## DITCHING OF WEIGHTS IN AN EMERGENCY

Although ditching one's weights is not appropriate in many circumstances, if a diver is in danger of becoming unconscious in the water it is important to attain positive buoyancy. This is done by either inflating the BCD, ditching weights, or both. In a review of 351 Australian compressed gas diving-related fatalities, almost three quarters of the victims were found with their weights in situ.<sup>36</sup> In this current series, all of the snorkel/breath-hold divers who were wearing weights failed to ditch them. In addition, at least seven of the 14 scuba divers were still wearing their weights at the time of attempted rescue or recovery.

This highlights an on-going problem of divers being reluctant, or unable, to ditch their weights when they get into trouble. It is likely that, on many occasions, by the time the diver recognises the need to ditch weights, they are too incapacitated to do so. Dive instructors should ensure that they devote appropriate training time to this important factor to imbue the skill. Divers need to remain cognizant of the importance of gaining positive buoyancy in an emergency and practice the skill periodically, at least mentally. In

addition, if a diver is planning to use a different weighting system to usual (e.g., changing from a belt to integrated weights), a thorough familiarisation is recommended.

## CAVE DIVING

After more than 25 years of fatality-free cave diving in Australia, this year's reported deaths makes three within two years.<sup>37</sup> The Cave Diving Association of Australia (CDAA) was formed in 1973 after a series of deaths in Australia and, through a combination of training and site control, has had an enviable safety record. In each of the three recent cases, we have seen major departures from the established rules of cave diving. In both cases in this report, this has revolved around gas planning and buddy separation. The five rules of cave diving were established in the 1970s and 1980s and remain equally valid today. These rules are:

- Seek proper training and remain within the limits of your training.
- Maintain a continuous guideline to open water.
- Reserve two thirds of the breathing gas for exit.
- Never exceed the maximum operating depth of your breathing gas.
- Use complete, functioning and appropriate equipment; this includes appropriate redundant equipment such as three dive lights.

In case SC11/03, the victim removed equipment to enter a narrow restriction. She was well known for her ability to do this and despite a number of previous incidents had always managed to get out. This had undoubtedly influenced her attitude ("*normalisation of deviance*") as shown by her disregard of the site rule of diving in buddy pairs and leaving her redundant gas source outside of the restriction. The second death, SC11/10 also shows elements of normalisation of deviance. As an experienced cave diver, he should have been more than aware of the gas requirement for the planned dive. Given that this dive required some decompression, let alone the 'thirds' rule, it seems inexplicable that he could have got the calculation so wrong. Both these cases stress the need for divers who are operating in overhead environments (cave or decompression obligation) to adhere to the safety rules for this type of diving. The fact that both were experienced, highly competent divers proves that experience alone will not provide safety in these circumstances. In both cases, buddy separation was also a major factor.

## IMMERSION PULMONARY OEDEMA IN DIVERS

There is little doubt that the victim in SC11/01 died as a result of IPE (defined by some as scuba divers pulmonary oedema, SDPE). This case, reported previously,<sup>5</sup> was typical in that it occurred in a middle-aged female with a previous history of dyspnoea with immersion. On the fatal dive, she was witnessed to have dyspnoea that worsened with ascent and she had associated blood-stained frothy sputum. Although tests after her first episode showed no evidence

of cardiac disease or dysfunction, there had been a delay prior to testing. At autopsy, cardiac histology revealed “*acute interstitial haemorrhage with associated contraction bands within myocytes*”. The significance of these findings is not entirely clear as it can occur during resuscitation but is also consistent with those of Takotsubo cardiomyopathy (TC) and reversible myocardial dysfunction (RMD).<sup>38,39</sup> It has been reported that TC/RMD may sometimes be the precipitant of IPE, and may explain the underlying cause of fatality.<sup>7</sup> It is possible that individuals with altered myocardial function may be at risk of IPE and caution should be exercised with regards to their fitness-to-dive. There were several other cases in this series that might have involved IPE. These include SC11/05, SC11/07 and SC11/09. However, without the benefit of a clinical history of dyspnoea with diving, snorkelling or swimming, and appropriate histological evidence, it is difficult to determine this with any confidence.

#### POST-MORTEM VITREOUS SODIUM AND CHLORIDE

The search for a diagnostic test for drowning has been long and in general, disappointing. A number of the cases included PMVSC levels in ocular fluid, A PMVSC of 259 mmol·L<sup>-1</sup> or greater indicates salt water drowning provided that the body is not immersed for more than one hour.<sup>3</sup> The results in case SC11/10 appear to be a false positive salt water drowning result as Tank Cave is fresh water. However, the body was immersed for around nine hours. Previous studies suggest that electrolyte results in vitreous from fresh water are more variable and subject to diffusion.<sup>12</sup> A water sample from the dive site should probably be taken for comparison.

#### POST-MORTEM DELAY

In many cases there is a delay of several days between death and autopsy. Such a delay can make diagnosis more difficult, particularly in the diagnosis of drowning, because of post-mortem redistribution of fluid. Early CT scan examination can be useful in overcoming the effects of the delay and is becoming more widespread, but is not yet universal. The diagnosis of AGE in the absence of an early CT scan is problematic.

#### CORONIAL REPORTS

The purpose of this on-going review of deaths in association with diving is to identify areas in which changes can be suggested to further reduce the incidence of such deaths. The predominant source of the necessary data is the records of Coronial investigations and these investigators are very grateful to the State and Territory Coroners, and the National Coronial Information System (NCIS) for their on-going support with this research and for their efforts in obtaining and providing the relevant documents. These include police reports, witness statements, medical histories, ambulance

records, pre-autopsy CT scans, autopsy, toxicological reports and coronial findings. With scuba and SSBA divers, access to prompt (within eight hours is the target) pre-autopsy CT scans can help to determine the presence of gas embolism. Equipment reports and gas analyses are invaluable in trying to ascertain if and how equipment faults played a part in the death. Dive computer downloads can provide good records of some of the victim's actions and the delay to recovery.<sup>40</sup> When reports are unavailable, important information can be missed.

The fundamental duty of a coroner is to make findings as to the identity of the deceased, where, when and how the death occurred, and the medical cause of death. Increasingly, in Australia, much of the focus of coronial investigations has turned to the prevention of death and to improvements in public health and safety. To this end, many coroners consider and report more broadly on the circumstances which preceded the fatal conclusion. The focus of the police investigation on behalf of the coroner is influenced by their reading of the type of investigation data required to satisfy their particular coroner. This is apparent in the documents which form the basis of this report.

Another factor to be considered in reading this report is that forensic pathologists only record what they can demonstrate or observe at autopsy, whereas the authors of this report interpret the events from the viewpoint of what safety lessons can be learned, and what was the most likely reason for the cascade of events which ended fatally.

#### LIMITATIONS OF THE STUDY

As with any uncontrolled case series, there are inevitable limitations and uncertainties associated with our investigations. These include:

- Incomplete case data. Fatalities are sometimes unwitnessed, and reports provided by any witnesses and by police vary in their likely reliability, as well as the content and expertise of the investigators.
- Autopsy reports can sometimes be unreliable as a result of the difficulty of determining the presence of CAGE in the absence of relatively prompt post-mortem CT scans, and the inability to detect evidence of cardiac arrhythmias, among other factors. Care must be taken to critically examine the available evidence and minimise speculation when determining the likely disabling injuries.
- Classification of cases into a sequence of four events (trigger, disabling agent, disabling injury, cause of death) using root cause analysis requires a single choice for each component event, which may omit important factors in some cases because, at each level, multiple factors rather than a single one may be at play.
- Limited annual case data; 30 deaths are too few to reliably determine trends.

## Conclusions

There were 30 reported diving-related fatalities during 2011; 15 while snorkelling and/or breath-hold diving, 14 while scuba diving and one while using SSBA. Pre-existing medical conditions, separation and inadequate supervision, and collecting/hunting seafood in areas frequented by large marine predators were noted features in this series. Contributory or causal factors associated with these deaths included: pre-existing medical conditions (predominantly cardiac); apnoeic hypoxia; entrapment/entanglement; solo diving and/or poor supervision; poor dive planning or conduct; inexperience; adverse diving conditions and diver error. With snorkellers, the likely disabling injuries were cardiac causes, asphyxia and trauma. In scuba divers, the disabling injuries appear to have been asphyxia, cardiac-related causes, IPE and CAGE. Factors that may reduce mortality in the future include better dive planning and supervision; the avoidance of solo diving and snorkelling and improved buddy oversight and improved medical screening of older divers and/or those with a pre-existing medical condition.

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John Lippmann is the Founder and Chairman of DAN AP. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers. This study was funded by DAN AP.

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# Estimating the risk of a scuba diving fatality in Australia

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## Abstract

(Lippmann J, Stevenson C, Taylor D McD, Williams J. Estimating the risk of a diving fatality in Australia. *Diving and Hyperbaric Medicine*. 2016 December;46 (4):241-246.)

**Introduction:** There are few data available on which to estimate the risk of death for Australian divers. This report estimates the risk of a scuba diving fatality for Australian residents, international tourists diving in Queensland, and clients of a large Victorian dive operator.

**Methodology:** Numerators for the estimates were obtained from the Divers Alert Network Asia-Pacific dive fatality database. Denominators were derived from three sources: Participation in Exercise, Recreation and Sport Surveys, 2001–2010 (Australian resident diving activity data); Tourism Research Australia surveys of international visitors to Queensland 2006–2014 and a dive operator in Victoria 2007–2014. Annual fatality rates (AFR) and 95% confidence intervals (95% CI) were calculated using an exact binomial test.

**Results:** Estimated AFRs were: 0.48 (0.37–0.59) deaths per 100,000 dives, or 8.73 (6.85–10.96) deaths per 100,000 divers for Australian residents; 0.12 (0.05–0.25) deaths per 100,000 dives, or 0.46 (0.20–0.91) deaths per 100,000 divers for international visitors to Queensland; and 1.64 (0.20–5.93) deaths per 100,000 dives for the dive operator in Victoria. On a per diver basis, Australian residents are estimated to be almost twenty times more likely to die whilst scuba diving than are international visitors to Queensland, or to lower than fourfold on a per dive basis. On a per dive basis, divers in Victoria are fourteen times more likely to die than are Queensland international tourists.

**Conclusions:** Although some of the estimates are based on potentially unreliable denominator data extrapolated from surveys, the diving fatality rates in Australia appear to vary by State, being considerably lower in Queensland than in Victoria. These estimates are similar to or lower than comparable overseas estimates, although reliability of all such measurements varies with study size and accuracy of the data available.

## Key words

Deaths; Diving incidents; Recreational diving; Survey; Statistics

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## Introduction

Scuba diving is an ‘adventure sport’ which many consider to be a dangerous activity.<sup>1</sup> Media publicity about shark attacks and divers being left at sea likely serve to increase this perception. It is important for both the diving industry and the general community to have a reasoned perspective of the level of risk, based on estimated activity and incidents, rather than media perceptions. There are few available data on which to estimate the risk of fatality for Australian divers and much of these data have considerable limitations. Earlier reports explored estimates for Australia (including overseas travellers) but these were based on limited data and were affected by methodological errors, predominantly the combination of activity data from two surveys which used different methods of data collection.<sup>2,3</sup> In this study, individual estimates are based on single data sources.

To estimate a fatality rate for divers, it is necessary to obtain both an accurate numerator (i.e., the number of deaths over a time period) and denominator (i.e., a measure of diving activity over that same period). In Australia, we can be reasonably confident in the accuracy of the number of dive-related fatalities reported each year because of our effective coronial reporting system and the active involvement of the Divers Alert Network Asia-Pacific (DAN AP) in collection of relevant data and its access to the National Coronial Information System (NCIS). As with most other countries,

it is difficult to find a reliable estimate of Australian diving activity. Denominators, the measure of risk exposure, can be based on the number of divers, the number of dives or time at risk. Where reasonably sound activity data are available, the fatality rate per dive is a better measure of actual exposure risk than is a per person death rate, which provides no detail of actual diving exposures. The actual hours of exposure time provides the best denominator to establish an accurate measure of incident risk.<sup>4</sup> However, in the diving population this is rarely reported and, therefore, not available.

In this report, data on the diving activity of Australian-based divers and the associated fatalities are examined to provide ‘best guess’ estimates of the risk of death for Australian divers overall, as well as for subsets of divers in Queensland and Victoria.

## Methodology

Numerators were obtained from the DAN AP dive fatality database.<sup>5</sup> DAN AP systematically collects data from all States and Territories through media and diver reports, the National Coronial Information System (NCIS) and coronial offices throughout Australia. Denominator data were sought by: (1) A literature search for suitable Australian activity data; (2) Diving records of a large diving charter operator in Victoria.

**Table 1**  
Search terms

Search No.	Search items
#1	scuba OR snorkel* OR diving
#2	survey* OR rate* OR statistic* OR census OR participa* OR count
#3	Australia OR Queensland
#4	death* OR fatal*
#5	risk OR estimat*
#6	#1 AND #2 AND #3
#7	#1 AND #4 AND #5

## LITERATURE SEARCH

Diving activity data for Australia from 1980 to 2015 inclusive were sought through searches of the *South Pacific Underwater Medical Society Journal* and *Diving and Hyperbaric Medicine*, other relevant sporting activity reports, liaison with industry bodies and internet searches. Search engines accessed were Google, Google Scholar, Medline, CINAHL, Heath Source (Nursing/Academic Edition), Sportsdiscus, Psychinfo, Global Health, Academic Search Complete, Informit and Embase. Details of the search terms are shown in Table 1. The inclusion criteria for relevant articles were: (1) There was a measure or estimate of diving activity either from survey, recorded dives, tank fills or membership/insurance counts; and (2) data were available for at least five consecutive years.

Three sources of denominator data met the inclusion criteria. These were: (1) The Australia-wide Participation in Exercise, Recreation and Sport (ERASS) Surveys;<sup>6–15</sup> (2) Tourism Research Australia Surveys of International visitors to Queensland (Tourism Research Australia, April 2015, with permission);<sup>16,17</sup> (3) Victorian dive operator records from 2007 through 2014 (confidential communication, 2015).

## ERASS NATIONAL SPORTING PARTICIPATION SURVEYS 2001–2010

The ERASS data were collected via telephone-based surveys conducted on behalf of the Australian Sports Commission (ASC) from 2001 through 2010, inclusive (by AC Neilson Research 2001–2007 and Newspoll Market and Social Research 2008–2010).<sup>6–15</sup> The basic questionnaires changed little over the years. The surveys utilised random samples of at least 3,400 Australian residents over 15 years of age, per quarter. Participants were asked about their sporting activities, including scuba diving, during the previous year.

## TOURISM RESEARCH AUSTRALIA SURVEYS OF INTERNATIONAL TOURIST ACTIVITY IN QUEENSLAND

Since 2006, Tourism Research Australia has consistently conducted annual surveys of international and national tourists who have visited various Australian States and Territories.<sup>16,17</sup> The International Visitor Survey (IVS)

samples annually 40,000 departing, short-term international visitors over 15 years of age. It is conducted in the departure lounges of major international airports and utilises computer-assisted personal interviewing. Participants are shown a list of activities which includes scuba diving and snorkelling. The survey results are weighted to data on international visitor numbers over the period, provided by the Department of Immigration and Citizenship, with the assistance of the Australian Bureau of Statistics.

In earlier research, based on the IVS, interviewees who indicated that they had been diving in Queensland in a 12-month period from April 2006 were given a supplementary questionnaire on the number of times they had dived.<sup>18</sup> The resulting data were based on interviews with 1,685 scuba divers and indicated an average of 3.7 dives each. It was assumed that a similar number of dives per person could be applied for the years 2006–2014 and these figures were used to estimate the total number of dives conducted for these years and subsequently the per dive fatality rate.

As the IVS contains relatively few diving-related data for most parts of Australia, most were not investigated further due to the increased potential for measurement bias. However, on the advice of Tourism Australia (which oversees the surveys), the international visitor data for Queensland were assumed to be based on sufficiently large samples which ranged between 1,795 and 2,155 diver respondents annually from 2006 through 2014.

## DIVE CHARTER OPERATOR

Data were collected from the largest dive charter operator in Victoria which has up to six boats of various sizes and conducts charters for divers, snorkellers and sightseers. It operates an average of four days per week and up to seven days in the summer months. Each dive is logged and scuba activity records from mid-2006 were available.

## STATISTICAL ANALYSIS

Estimates were considered to be significantly different if their respective 95% confidence intervals did not overlap. Annual fatality rates (AFR) and 95% confidence intervals (CI) were calculated based on an exact binomial method as implemented in the Binomial Test in the R statistical package.<sup>19</sup>

## Results

Over the 10-year period, the mean annual number of Australian residents who went scuba diving was 84,767 (95% CI 61,767–107,748). Between them, these participants conducted an average of 1,552,728 dives per year (95% CI 1,125,985–1,979,472). In total, there were 129 scuba diving-related fatalities in Australia from 2001–2014. These were both Australian residents and international tourists.



**Table 2**

ERASS-derived estimates of the number of divers and dives conducted, recorded deaths, and estimated AFRs 2001-10 (95% CI)

Year	Sample size	Divers (residents)	Dives/person (Australians)	Dives	Deaths in Australia	Deaths overseas	Deaths total	Deaths/100K divers	Deaths/100 K dives
2001	13,640	79,379	18.7	1,484,387	11	0	11	13.86 (6.92–24.79)	0.74 (0.37–1.32)
2002	13,632	73,331	16.3	1,195,295	8	0	8	10.91 (4.71–21.49)	0.67 (0.28–1.32)
2003	13,644	90,592	21.2	1,920,550	6	0	6	6.62 (2.43–14.42)	0.31 (0.11–0.68)
2004	13,662	103,337	17.7	1,829,065	7	2	9	8.71 (3.98–16.53)	0.38 (0.15–0.79)
2005	13726	86,791	20.7	1,796,574	5	0	5	5.76 (1.87–13.44)	0.28 (0.09–0.65)
2006	13,710	76,035	12.1	920,024	5	0	5	6.58 (2.14–15.35)	0.54 (0.18–1.27)
2007	16,400	69,912	24.0	1,677,888	8	1	9	12.87 (5.89–24.43)	0.54 (0.25–1.02)
2008	17,293	90,200	17.2	1,551,440	6	1	7	7.76 (3.12–15.98)	0.45 (0.18–0.93)
2009	23,031	83,313	20.3	1,682,923	5	0	5	6.00 (1.95–14.00)	0.30 (0.09–0.69)
2010	21,603	94,783	15.5	1,469,137	7	2	9	9.50 (4.34–18.02)	0.61 (0.28–1.20)
Mean	16,034	84,767	18.4	1,552,728	6.8	0.6	7.4	8.73 (6.85–10.96)	0.48 (0.37–0.59)

**Table 3**

Estimated AFRs by gender and age group based on ERASS data and recoded deaths (95% CI)

	Divers	Dives	Deaths	AFR/100K divers	AFR/100Kdives
Male	645,927	11,838,137	59	9.13 (6.95–11.78)	0.50 (0.38–0.64)
Female	201,746	3,697,476	15	7.44 (4.16–12.26)	0.41 (0.23–0.67)
<45 years	605,239	11,092,428	33	5.45 (3.75–7.66)	0.30 (0.20–0.42)
≥45 years	242,434	4,443,185	41	16.91 (12.14–22.94)	0.92 (0.66–1.2)

**Table 4**

Annual activity and fatality rates for international visitors in Queensland, 2006-13; \* data for 2014 not included as fatality numbers for that year are not finalised

	Year							
	2006	2007	2008	2009	2010	2011	2012	2013
Divers (n)	236,327	228,166	220,836	226,596	222,704	185,543	197,867	213,506
Dives (n)	874,410	844,214	817,093	838,405	824,005	686,509	732,108	789,972
Fatalities (n)	2	2	0	2	0	0	0	2
Fatalities /100,000 divers (95% CI)	0.85 (0.10–3.06)	0.88 (0.11–3.17)	0.00 (0.00–1.67)	0.88 (0.11–3.12)	0.00 (0.00–1.66)	0.00 (0.00–1.99)	0.00 (0.00–1.86)	0.94 (0.11–3.38)
Fatalities /100,000 dives (95% CI)	0.23 (0.03–0.83)	0.23 (0.03–0.86)	0.00 (0.00–0.45)	0.24 (0.03–0.86)	0.00 (0.00–0.45)	0.00 (0.00–0.54)	0.00 (0.00–0.50)	0.25 (0.03–0.91)

**Table 5**

Annual fatality rates (AFR) for SCUBA divers from the three data sources (95% CI); Qld – Queensland

Group	Period (y)	Method	Dives	Divers	AFR per 100,000 dives	AFR per 100,000 divers
Australian residents (ERASS)	2001–10	Survey	1,552,728	84,787	0.48 (0.37–0.59)	8.73 (6.85–10.96)
Qld International tourists (Tourism Australia)	2006–13	Survey	800,840	216,443	0.12 (0.05–0.25)	0.46 (0.20–0.91)
Victorian operator	2007–14	Measured	15,235	–	1.64 (0.20–5.93)	–

Table 2 includes the ERASS-derived estimates of the number of active divers and the dives conducted from 2001–2010. In addition, it shows the number of Australian residents who died while scuba diving both in Australia and while overseas as recorded on the DAN AP database. The overseas fatalities are included as the ERASS survey did not ask where the diving was conducted and many Australian residents divers do some diving overseas.

According to the ERASS data, 76% of the divers were male, and approximately 30% were aged 45 years or older. By comparison, 59 (80%) of the 74 Australians who died while diving in Australia or overseas from 2001 through 2010 were male and 41 (70%) were aged 45 years or older. These data, along with the associated AFRs are shown in Table 3.

Table 4 shows the annual activity data, annual deaths of international visitors (based on DAN AP fatality data<sup>5</sup>), and

per diver and per dive fatality rates based on the Tourism Research Australian activity data for all of Queensland from 2006 to 2013 inclusive. (Tourism Research Australia, April 2015, with permission). The mean annual scuba fatality rate among international visitors over the period was 0.46 deaths per 100,000 divers (95% CI 0.2–0.91); or 0.12 deaths per 100,000 dives (95% CI 0.05–0.25).

#### DIVE CHARTER OPERATOR, VICTORIA 2007–2014

From 2007 through 2014, an average of 15,235 scuba dives were conducted annually from this operator's vessels, during which time there were two deaths, one in 2010 and one in 2014. This gives a mean annual death rate of 1.64 deaths per 100,000 dives (95% CI 0.20–5.93).

Table 5 provides a summary of the annual fatality rate estimates derived from the three sources.

#### Discussion

The AFRs from these three sources vary more than tenfold. This is likely due to differences in diving conditions and practices, data reliability, and possibly to some differences in diver characteristics. The denominators used as baselines for the AFR estimate calculations vary in reliability. The most accurate denominator was that from the dive operator in Victoria as it was measured rather than extrapolated from surveys. The AFR from this dive operator (1.64 per 100,000 dives) is lower than one based on a one-year Victorian tank fill survey<sup>20</sup> and averaging fatalities over a five-year period (2.5 per 100,000 dives).<sup>2</sup> The difference may indicate that diving with this operator is safer than general diving in Victoria or may reflect the divers who choose to dive with this operator. However, these two estimates lie within each other's 95% confidence intervals so there may be no significant difference in the underlying risk.

The estimated scuba AFR for Victorian divers is significantly higher than that for international visitors diving in Queensland. These differences could be the result of inaccuracy of denominator data. However, other local factors may have been contributory. Waters in Victoria are colder, visibility is generally much poorer and much of the diving occurs in sites with strong currents or prone to surges. The more challenging conditions and the associated requirement for thicker suits and greater weighting can increase problems with buoyancy, breathing gas consumption, exertion and stress, thus increasing the risk of an accident.<sup>21,22</sup> In addition to the generally easier diving conditions in Queensland, diving there is highly regulated due to the existence and enforcement of a regulated Code of Practice (COP) and this may help to mitigate the risk. Although COPs exist in two other States (including Victoria), these are voluntary, not enforced by either industry or government and are likely to have little effect.

The apparent three-fold increased risk of death in divers aged 45 years or more is consistent with other reports and is often reflective of cardiac-related incidents among divers with known or occult cardiac disease.<sup>23,24</sup>

The Australian estimates generally compare favourably with those reported from other countries. For example, the AFR for DAN America members has been calculated to be 16.4 (95% CI 14.2–19.0) per 100,000 divers (based on measured data).<sup>23</sup> Similarly, British Sub-Aqua Club (BSAC) membership and fatality data indicate an AFR of 14.4 (95% CI 10.5–19.7) per 100,000 members.<sup>25–31</sup> These higher rates may be partly explained by population differences (e.g., DAN members are generally older, with an increased association of co-existing medical conditions) and diving conditions (e.g., UK conditions are often more challenging). At the lower end, measured data from an inland lake in Leicester (UK) yielded an AFR of 2.9 (95% CI 1.2–6.0) per 100,000 divers.<sup>32</sup> Despite this site being cold and potentially deep, diving there is generally well-controlled and more predictable and this may explain the relatively low death rate. Measured data from British Columbia in Canada indicated an AFR of 2.04 (95% CI 0.0–6.0) per 100,000 dives.<sup>33</sup> This is comparable to Victoria, although the water temperature is substantially colder.

#### LIMITATIONS

Comparisons between estimates from different data sources would usually be age/sex-adjusted to reduce possible confounding effects of different age/sex distributions. However, age/sex-specific data were not available from the IVS and the dive operator in Victoria so no age/sex standardisation was possible. Hence comparison of results may be influenced by different age/sex distributions in the populations.

Although commonly utilised by researchers to provide a denominator for a variety of sporting activities in Australia,<sup>34,35</sup> the ERASS, as with most surveys, has several limitations.<sup>36,37</sup> These include:

- Based on a relatively small sample, it is subject to sampling error. However, with the national diving data, the mean relative standard error was 14% (range 12–15%) indicating that the annual sample should be sufficiently reliable.
- It is retrospective and subject to recall bias. However, the participants were surveyed about activities in the previous year so the elapsed time was not substantial.
- The response rate in 2010 was 17.6% which may have introduced selection bias.
- Until 2010, the survey only included 'landlines' and not mobile phones. This raises the concern of selection bias resulting from mobile-only households being excluded from the previous years' samples, mainly associated with the likely younger age of the residents.

The proportion of Australian residents living in mobile-only households increased from 5% in 2005 to 13% in 2010.<sup>38</sup> This may have led to under-reporting of the dives conducted by younger divers who tend to only have mobile phones.

- The ERASS surveys did not include divers who were younger than 15 years old. However, these divers likely represented a small proportion of divers (< 1%)<sup>39</sup> and their exclusion should have little effect on the overall results. In addition, there were no deaths of divers younger than 15 years in Australia during that period.

Despite these limitations, the annual ERASS surveys appear to provide the best available national estimates of the scuba diving activity of Australian residents during the period of study.

As with most surveys, the results of the IVS are based on samples, rather than a census of visitors and are therefore subject to sampling error. However, the relative standard error for the number of participants was approximately 3.5%, indicating that sampling error was not a major barrier to their use. Given that most visitors would have stayed in Australia for a relatively short period, recall bias should have been small. Recall bias would have been further reduced given that many of the scuba divers had come specifically to dive. Like the ERASS survey, the Tourism Australia surveys did not include persons younger than 15 years.

Despite accurate denominator data from the operator in Victoria, over the eight-year period there were very few fatalities. This would have reduced the reliability of the estimate, as indicated by the wide confidence intervals. In addition, the results of a single operator may not be representative of the diving fatality rate throughout Victoria.

## Conclusions

It is difficult to obtain substantial and reliable data on the diving activity and, therefore, AFRs in Australia. The only measured denominator data currently available comes from a 1994 Victorian tank fill survey and the activity logs of a single dive operator in Victoria from 2007 through 2014. Other denominator data are based on surveys, with their inherent limitations. On the basis of the information currently available, the diving fatality rate in Australia appears to vary by State, with the estimated rate in Queensland being considerably lower than the estimated rate in Victoria or for Australia overall, which may be partly explained by generally more favourable conditions and/or local diving regulations. These rates are similar to or lower than comparable data from overseas, although reliability of all such estimates varies with the size and accuracy of numerator and denominator data. More research is required to further improve diving activity data collection so that risk estimates can be more accurately determined.

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# The influence of pressure changes on the retentive force and coronal microleakage of different types of posts in endodontically treated teeth during simulated dives

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## Abstract

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**Objectives:** We assessed the influence of a simulated diving environment on the interfacial microleakage and retentive forces of different post types in root-canal-filled teeth.

**Materials and methods:** One-hundred-and-twenty extracted, single-rooted teeth were endodontically treated and were randomly divided into three groups according to the post and cement used: ER Post/Harvard cement (Titanium), CeraPost/DentinBuild Evo (Zirconia), DT Light Post/Calibra (FRC). Each group was randomly divided into two equal subgroups, a control group, and an experimental group, subjected to simulated dives to 456 kPa in a diving chamber. For 10 specimens of each subgroup the pull-out strength and the coronal microleakage were measured.

**Results:** Significant differences in the linear coronal penetration were observed between the Titanium and FRC groups (experimental group  $P \leq 0.001$ ; control group  $P = 0.02$ ). Diving simulation had no significant impact on the microleakage for the three post types. The FRC groups showed significantly higher retentive strength values compared to the Titanium and Zirconia groups before and after simulated diving. The pull-out strength of the titanium experimental group was significantly less than the control group ( $P = 0.008$ ).

**Conclusions:** Following root canal treatment the combination of fibre-reinforced posts and resin cement should be preferred for patients requiring retention for tooth restorations using posts that are likely to be exposed to hyperbaric conditions.

## Key words

Dental; pressure; barotrauma; barodontalgia

## Introduction

Changes in external pressure, for example, during flying, diving or hyperbaric oxygen treatment, can cause dental pain. Clinical signs and symptoms are observed in aircrew<sup>1</sup> and divers<sup>2</sup> and the term “barodontalgia” is used to describe the pain experienced in teeth and initiated by changes in barometric pressure. The incidence of this type of tooth pain is 0.26–2.8% in aircraft personnel, air passengers and divers.<sup>3,4</sup> Barodontalgia appears to occur irrespective of the type of pressure change or, in other words, regardless of whether pressure increases or decreases and can even persist after pressure equalization.<sup>5</sup> Apart from the subjective experience of pain, pressure changes are also reported to cause fractures in dental restorations and a reduction in prosthetic device retention.<sup>6,7</sup>

The effect of barotrauma is directly related to Boyle’s Law. The pressure-related changes in volume were found to reduce the retentive strength in materials used for the cementation of full cast crowns,<sup>7,8</sup> orthodontic appliance or glass fiber posts.<sup>9</sup> Loosening or loss of fillings can lead to serious complications, especially in divers.<sup>10</sup> Problems arise when the enclosed spaces containing gases cannot expand or contract to adjust the internal pressure to correspond to the outer pressure.<sup>11</sup> It is known that trapped air can develop even after the completion of an endodontic treatment causing

microleakage to occur between the restoration and the walls of the pulp chamber.<sup>12</sup> This could explain the findings of a previous in-vitro study that focused on the pressure changes in root canal-treated teeth during simulated dives and showed that significant differences exist between the pressure inside the pulp chamber and the pressure in the diving chamber after root canal filling.<sup>13</sup>

Depending on the degree of coronal destruction, restorations for root canal-treated teeth sometimes need retention from within the root canal and this is provided by a cemented post and core. It is still unclear however, whether these pressure differences can influence the coronal microleakage and the retention of the different post systems used in post-endodontic restorations. Therefore, the objective of this study was to assess the influence of a simulated diving environment on the interfacial microleakage and retention forces of different post types in root-canal-treated teeth. The tested null hypothesis was that, regardless of the post type used, the initially measured coronal microleakage of the tested posts and the retentive strengths would not decrease after the simulated dives.

## Materials and methods

The Ethics committee of the University of Hanover Medical School approved the use of teeth extracted in the Department

for Oral and Maxillofacial Surgery. The committee decided that no written or verbal approval was required. The study was performed on 120 recently extracted human single-rooted teeth. The included teeth were with complete root formation and were free of caries, fractures and endodontic treatment prior to extraction. Only teeth with an angulation of the root lower than 45° were included in the study. Selected teeth were stored in isotonic saline solution containing 0.2% sodium azide. The coronal portions of the teeth were removed with carborundum disks at the level of the cement-enamel junction on the buccal surfaces.

#### SPECIMEN PREPARATION

The root canal of each tooth was instrumented with endodontic files (Mtwo; VDW GmbH, Munich, Germany) operated at 300 rpm resulting in a preparation with 6-degree taper and a 0.25 mm diameter at the apex. Prior to file usage, files were coated with the chelating agent File Care (VDW, Munich, Germany). After each instrument, the canals were irrigated alternately with sodium hypochlorite, sodium chloride and chlorhexidine solutions. The final irrigation (3% NaOCl) was activated ultrasonically for 30 seconds using the VDW.ULTRA™ System (VDW, Munich, Germany), and the root canals were dried with paper points (Roeko paper points, Roeko, Langenau, Germany). Each canal was then obturated using warm vertical compaction of gutta-percha with the BeeFill™ 2in1 system (VDW, Munich, Germany) in combination with a resin-based endodontic sealer (AH Plus, Dentsply De Trey, Konstanz, Germany). The length of the root fillings and the quality of the seal were assessed using radiographs, which were taken in two planes.

After endodontic treatment the teeth were stored for 72 hours in isotonic saline solution. Then 10 mm of gutta percha was removed from the coronal region and the root canals were enlarged with a slow-speed tapered drill (ISO 90) from the Komet ER post kit (Komet, Lemgo, Germany) compatible with the three different post types used in the study. A new drill was used for every 10 specimens. The preparations were acid-etched with 37% phosphoric acid (Total Etch, Ivoclar, Schaan, Liechtenstein) for 20 seconds and thoroughly rinsed and dried with paper points immediately prior to the restoration with the respective post.

The 120 prepared roots were randomly divided into three experimental groups (Table 1). The placement of the posts, the preparation of the cement and the cementation technique were all performed with strict adherence to the manufacturers' instructions. The posts were positioned, and the excess of cement was removed using a microbrush.

In Group 1, titanium posts (ER 61L16, Komet, Lemgo, Germany) were used. The posts were tried in, cleaned with alcohol and dried. A zinc-phosphate cement (Harvard cement, Richter und Hoffmann, Berlin, Germany) was mixed on a glass plate, the posts were coated with cement and then inserted in the prepared spaces using finger pressure and

**Table 1**

The three post systems and cementation methods studied;  
FRC – fiber-reinforced composite

Material	Post	Cement	Adhesive
Titanium	ER 61L16	Harvard Cement	
Zirconia	CeraPost	DentinBuild Evo	DentinBuild Evo
FRC	DT Light SL	Calibra	Prime&Bond NT

a rotation of 180 degrees. The posts were then manually fixated in this position for two minutes.

In Group 2, zirconia posts (CeraPost, Komet, Lemgo, Germany) were placed using a dual curing resin (DentinBuild Evo, Komet, Lemgo, Germany), recommended by the manufacturer, after the canals were conditioned with the corresponding DentinBuild Evo self-etching dual-curing adhesive for 30 seconds and the post surface was treated with a silane coupling agent (Monobond S, Ivoclar Vivadent, Schaan, Liechtenstein) for 20 seconds. The resin cement was mixed using a Minimix syringe and was applied to the posts directly from the mixing cartridge. The posts were then seated in the root canal; the excess resin was subsequently removed. Finally light activation was performed for 20 seconds.

For Group 3, fiber-reinforced composite (FRC) posts (DT Light SL Post, VDW, Munich, Germany) were luted with a dual-curing resin cement (Calibra, Dentsply, De Trey, Konstanz, Germany). A self-priming dental adhesive (Prime&Bond® NT, Dentsply DeTrey, Konstanz, Germany) was applied with a disposable brush to the canal surfaces for 20 seconds. After removing excess solvent by gently drying, the adhesive was cured for 10 seconds using a curing light. Mixed resin cement was spread on the post surface and posts were seated and stabilized with moderate and consistent pressure, excess was cleaned up and the posts were light-cured for 20 seconds.

For each post type, the influence of simulated dives on the coronal microleakage and the post retention were evaluated. The specimens were then randomly divided into four sub-groups of 10 teeth, in accordance with the experimental procedures outlined in the test protocol:

Group 1: Control group, pull out test;

Group 2: Control group, coronal microleakage evaluation; The specimens in the control groups underwent no pressurisation. After post placement, the teeth of the control groups were stored in saline solution.

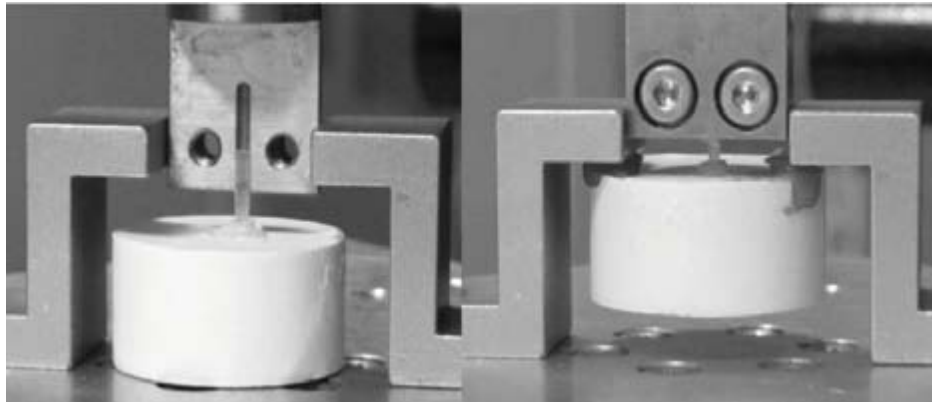
Group 3: Simulated dive, pull out test;

Group 4: Simulated dive, coronal microleakage evaluation.

The simulated dives were performed in a specially equipped diving chamber (Haux; Draegerwerk, Luebeck, Germany) using compressed air. During the dives, changes in pressure at a rate of 101.3 kPa·min<sup>-1</sup> simulated descents and ascents. For example, a descent of 50 m equivalent sea depth was simulated by increasing pressure to a maximum of 456 kPa.

**Figure 1**

Pull-out test set up; left – sample embedded in a block of acrylic resin and vertically mounted in the grip assembly; Right – sample fixed with acrylic resin to the universal testing machine before pull out testing



This pressure was maintained in the diving chamber for 5 min. Then the pressure was decreased again at a rate of 101.3 kPa·min<sup>-1</sup> to simulate the ascent.

#### CORONAL MICROLEAKAGE EVOLUTION

The samples used for evaluation of the coronal microleakage were immersed and stored for seven days in saline solution at 37°C degrees before applying a homogeneous layer of nail polish on the root surface. After the barrier layer had dried, the teeth were fixed vertically using silicone (Coltoflax Putty, Coltene/Whaledent, Altstaetten, Switzerland) and immersed for 72 hours in methylene blue dye (Löfflers methylene blue solution, Merk, Darmstadt, Germany).

A clearing technique, described previously,<sup>14</sup> was used for direct assessment of dye penetration in which the maximum depth of dye penetration could be accurately recorded. After the barrier layer was removed, the specimens were placed in a 5% sodium hypochlorite solution for 24 hours to dissolve organic debris from the root canal system and washed in running tap water for four hours. The specimens were decalcified for three days in 5% nitric acid at room temperature. The nitric acid solution was changed daily and agitated by hand three times each day. After completion of decalcification, the teeth were rinsed in running tap water for four hours. The dehydration process consisted of a series of ethyl alcohol rinses starting with 80% solution overnight, followed by a 90% solution for an hour, and three 100% ethyl alcohol rinses for an hour each.

The teeth were stored in petri dishes with methyl silicate and the depth of the penetration was measured using an optical stereomicroscope (Carl Zeiss, Oberkochen, Germany). The linear dye penetration was measured at x 20 magnification from the resected coronal root-end, calculated using a graduated measuring scale previously mounted on the microscope lens. The maximum linear leakage was recorded for each specimen.

#### PULL-OUT TEST

Macro retentions of 1 mm depth were cut with diamond burs perpendicular to their long axis, promoting retention during the pullout test. Each specimen was then embedded in a cylindrical block of chemically-cured acrylic resin (height: 25 mm, diameter: 50 mm), the acrylic resin extending to a level 1 mm below the buccal aspect of the cement enamel junction. To ensure that the posts remained vertical during testing, the lower portion of the post that protruded from the root was affixed to the grip assembly of an universal testing machine (Zwick, Ulm, Germany). Following that, the acrylic block was attached to the inferior portion of the testing machine using acrylic resin (Pattern Resin LS, GC America Inc., Alsip, USA) (Figure 1). After full polymerization of the acrylic resin a pull-out test was performed at a crosshead speed of 2 mm·min<sup>-1</sup>. The force to dislodge the posts in tension was measured in Newton (N) and the mean calculated for each test group.

#### STATISTICAL ANALYSIS

Statistical evaluation was performed with SPSS for Windows, Release 17.1 (SPSS Inc., Chicago, Ill, USA). Non-parametric tests (Mann-Whitney U test) were used to determine significant differences ( $P \leq 0.05$ ), as data were not normally distributed (Shapiro-Wilk test,  $P < 0.05$ ). Statistical significance was set at 0.05.

#### Results

##### CORONAL MICROLEAKAGE

The results of the dye penetration analysis are shown in Figure 2 and Table 2. Using x 20 stereoscopic magnification coronal leakage could be observed in the samples of all experimental groups. Significant differences in the linear coronal penetration could be observed between the Titanium and FRC groups (experimental group,  $P \leq 0.001$ ;

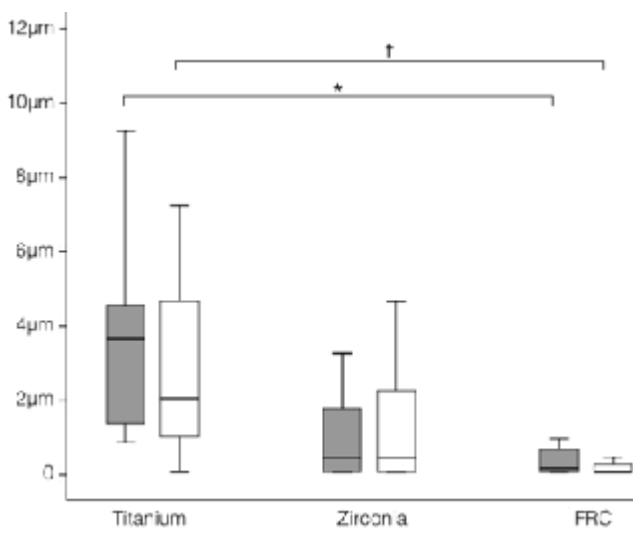
**Table 2**

Results of the microleakage evaluation; the penetration depth in mm (standard deviation); FRC – fiber-reinforced composite

Penetration depth	Titanium	Zirconia	FRC
Control group	2.66 (2.29)	1.15 (1.6)	0.16 (0.26)
Simulated dive	4.29 (3.79)	1.19 (1.6)	0.27 (0.33)

**Figure 2**

Boxplots for the linear coronal penetration of methylene blue dye in single-rooted human teeth restored, by titanium, zirconia and FRC (fiber-reinforced composite) posts: control group without simulated dives (white); after simulated dives (gray); \*  $P < 0.001$ ; †  $P = 0.02$



control group,  $P = 0.02$ ). Mann-Whitney U test showed no significant influence of the diving simulation on the microleakage for the three post types.

**PULL-OUT TEST**

The results of the pull out test are presented in Table 3 and as box plots in Figure 3. The highest pull-out forces were observed for the FRC post both for the control group (mean 260 N, median 270.1 N, interquartile range 80.1) and the specimens of the simulated dive group (mean 256 N, median 247.7 N, interquartile range 79.7) respectively. These values were significantly higher than the retentive strength values for the Titanium and Zirconia groups. The results of this study indicated that the pull-out strength of the titanium experimental group was significantly less than the control group ( $P = 0.008$ ), but that the pull-out strengths of the experimental groups with Zirconia and FRC posts were not significantly different from the controls.

**Discussion**

In the present in-vitro study, root-canal-treated teeth, restored with different types of posts were subjected to

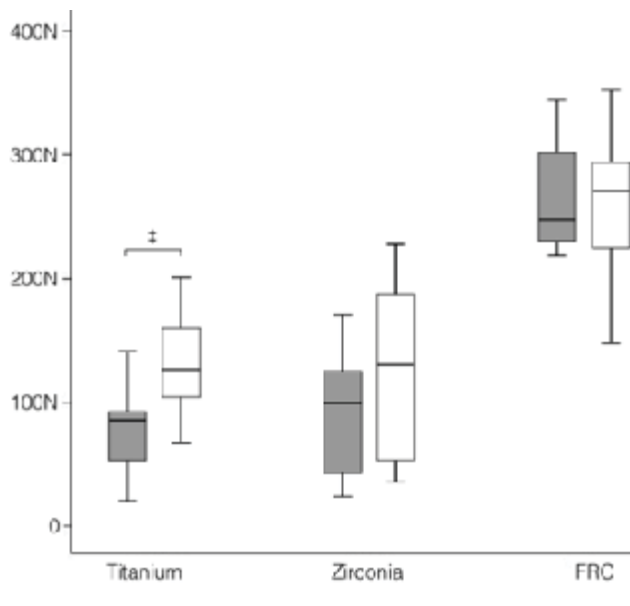
**Table 3**

Results of the pull-out tests: mean pull-out strength (standard deviation) in Newtons (N); FRC – fiber-reinforced composite

Pull-out bond strength	Titanium	Zirconia	FRC
Control group	135 (44.2)	130 (70.2)	260 (59.1)
Simulated dive	77 (34.1)	93 (48.5)	256 (66)

**Figure 3**

Boxplots for the pull-out strengths, measured on titanium, zirconia and FRC (fiber-reinforced composite) posts: control group without simulated dives (white); after simulated dives (gray); ‡  $P = 0.008$



simulated dives in a diving chamber and the influence of the hyperbaric conditions on the coronal microleakage and the pull-out retentive strength of the posts was investigated. For the teeth with titanium posts cemented with zinc phosphate cement, the tested null hypothesis could be rejected. The simulated dive groups showed significantly lower pull-out strengths and higher values of microleakage than the control groups. For the zirconia and FRC posts, cemented with adhesive resin cements, neither the pull-out strength, nor the microleakage was affected by the simulated dives. Zirconia posts showed the lowest mean in the pull-out test values among the control groups, while the Titanium groups exhibited the highest coronal microleakage.

The study confirmed previous findings on the effect of pressure cycling on the retentive force of zinc phosphate cement for full cast crowns,<sup>7,8</sup> glass fiber posts<sup>15</sup> and orthodontic bands.<sup>9</sup> With conventional cementation, the bond of the restoration is created almost entirely by static friction between the luting material and the restoration and is highly sensitive to the mechanical integrity of the cement layer. Different approaches have been used to explain the retentive force deterioration of conventionally cemented restorations.



On the one hand, it has been shown that pressure changes can lead to volume reduction of the luting material, resulting in microcracks.<sup>16</sup> On the other hand, a finite element study on crowns with different preparation geometries demonstrated that external pressure might increase the internal stress in the cement that subsequently may create cement microfractures and promote microleakage.<sup>17</sup> The estimated stress values for the different types of cement were higher (approximately 20% to 40%) for zinc phosphate cement than other cements.

In the present study, the titanium posts were cemented with a zinc phosphate cement with an average grain size of 8–10 µm. According to the manufacturer's recommendations the zinc oxide powder and phosphoric acid liquid are hand-mixed until a fixation consistency has been reached. Compared to resin cements, zinc phosphate cements pose higher open porosity and specific pore volumes.<sup>18</sup> Larger pores in the set cement can be related to air entrapment in the encapsulated cement during mixing while small pores (0.1–0.5 µm diameter) are indicative of vapourisation porosity commonly seen with exothermic reactions.<sup>19</sup>

Each porous material might have three types of pores: blind, through (open porosity) and closed pores.<sup>20</sup> The closed pores are not accessible to fluids. The blind pores terminate inside the material. The through pores are those that enable the complete passageway of fluids. Porosity that includes closed pores has a great influence on mechanical properties of a material; open porosity has its direct impact in the possibility of penetration of undesired oral fluids, bacteria and bacterial toxins. The effect of barotrauma is directly related to Boyle's Law. With closed pores, the contained gases cannot expand to any extent, corresponding to the outer pressure. The gas pressure dynamics in these pores during pressure cycling might cause microstructural changes and strength reduction of the cement layer, consequently affecting the post retention in the root canal.

A recent study on the differences between the pressure inside the pulp chamber and the pressure in a diving chamber during the various stages of root canal treatment in a simulated diving environment, showed that the lack of adhesively bonded composite sealing of the pulp chamber results in an insufficient pressure-tight seal.<sup>13</sup> In this case, the authors considered that the reason for the differences between the pressure inside the pulp chamber and the pressure in the diving chamber is the irreversible movement of trapped air along the pressure gradient. As for the titanium group, no additional adhesive sealing was performed, a phenomenon that might serve as a further explanation of the reduction of retentive force after pressure cycling.

The most common reason for failure of root canal treatment is the presence of bacteria within the root canal, either as a result of incomplete disinfection during preparation or reinfection due to a poor coronal seal. If a post and core is necessary to provide retention for a crown, the post should

provide a hermetic seal. In the present study, titanium posts, placed with zinc phosphate cement showed the highest linear coronal penetration of methylene blue dye before and after the simulated dives. In accordance with other studies,<sup>21,22</sup> this indicates that resin cements provide a far more efficient coronal seal, preventing dye penetration into the post-space region.

The present study demonstrated the superiority of FRC posts over zirconium and titanium posts. For the study, it was decided not to use the same posts for both types of tests in order to avoid a possible influence of the methylene blue dye and the clearing technique on the retention of the posts. Thus, no direct conclusions can be drawn regarding the relationship between coronal microleakage and retentive strength of posts. A comparison of the test results among all groups after pressure cycling revealed an inverse proportionality between the retentive force values and the microleakage. Further research is needed to evaluate a possible correlation of both factors under environmental pressure changes.

## Conclusions

Simulated diving, with compression to 456 kPa, decreased significantly the pull-out strength of conventionally cemented titanium posts. Under hyperbaric conditions, the combination of fibre reinforced posts and resin cement for post-endodontic treatment showed the best pull-out strength and coronal microleakage values.

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# Review article

## Increasing the probability of surviving loss of consciousness underwater when using a rebreather

Paul Haynes

### Abstract

(Haynes P. Increasing the probability of surviving loss of consciousness underwater when using a rebreather. *Diving and Hyperbaric Medicine*. 2016 December;46(4):253-259.)

Re-circulating underwater breathing apparatus (rebreathers) have become increasingly popular amongst sport divers. In comparison to open-circuit scuba, rebreathers are complex life support equipment that incorporates many inherent failure modes and potential for human error. This individually or in combination can lead to an inappropriate breathing gas. Analysis of rebreather diving incidents suggests that inappropriate breathing gas is the most prevalent disabling agent. This can result in spontaneous loss of consciousness (LoC), water aspiration and drowning. Protecting the airway by maintaining the diver/rebreather oral interface may delay water aspiration following LoC underwater; the possibility of a successful rescue is, thus, increased. One means of protecting the airway following LoC underwater is the use of a full-face mask (FFM). However, such masks are complex and expensive; therefore, they have not been widely adopted by the sport diving community. An alternative to the FFM used extensively throughout the global military diving community is the mouthpiece retaining strap (MRS). A recent study documented 54 LoC events in military rebreather diving with only three consequent drownings; all divers were reported to be using a MRS. Even allowing for the concomitant use of a tethered diving partner system in most cases, the low number of fatalities in this large series is circumstantially supportive of the efficacy of the MRS. Despite drowning featuring as a final common pathway in the vast majority of rebreather fatalities, the MRS has not been widely adopted by the sport rebreather diving community.

### Key words

Diving incidents; Drowning; Safety; Rebreathers/closed circuit; Technical diving; Unconsciousness

### Introduction

When compared to open-circuit scuba, the probability of exposure to an inappropriate breathing gas is increased when using rebreathers.<sup>1</sup> As a result, a serious or fatal incident is more likely when rebreather diving.<sup>2</sup> Inappropriate breathing gas scenarios most frequently associated with rebreather use are: (1) hypoxia, resulting from respiring an hypoxic gas; (2) hypercapnia, resulting from increased levels of inspired carbon dioxide (CO<sub>2</sub>), or hypoventilation; (3) hyperoxia, resulting from respiring an hyperoxic gas. The sport diving community frequently refers to these maladies as the rebreather “3H hazards”, all of which can lead to loss of consciousness (LoC) with little or no warning.<sup>3</sup>

The most common interface between the rebreather and the diver’s respiratory system is a mouthpiece valve assembly, frequently called a dive surface valve. This human/machine interface is referred to in this paper as a ‘mouthpiece’ and is used in conjunction with a sport diving ‘half-mask’. The mouthpiece typically requires manual operation by the diver to change from ‘surface mode’, which isolates the rebreather re-circulation system (breathing loop) from the environment, to ‘dive mode’, which allows access to the breathing loop and breathing gas.

As tone is lost from the mandibular muscles following LoC, the likely consequence is loss of airway protection as the mouthpiece/breathing loop falls from the mouth of the diver. If this occurs underwater, unless there is immediate intervention by a diving partner, the following outcomes are highly likely:

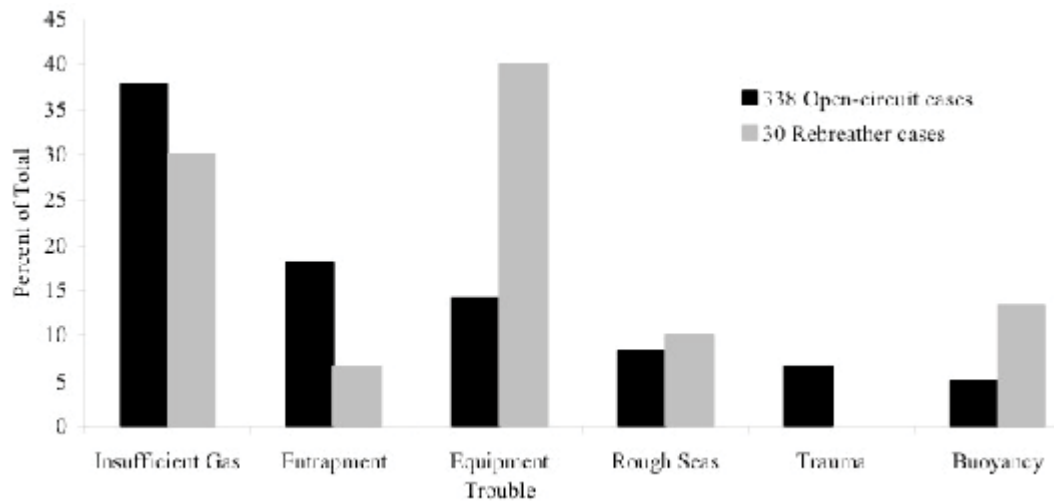
- fluid aspiration and asphyxiation;
- venting of breathing loop gas via the open mouthpiece;
- whole or partial flooding of the breathing loop;
- loss of buoyancy;
- drowning.

Although other factors (triggers) are inevitably responsible for initiating the accident, loss of airway protection and subsequent drowning is most frequently the actual cause of death (CoD). This paper examines a potential means of delaying or limiting this cycle, thus increasing the probability of surviving LoC underwater when using a rebreather.

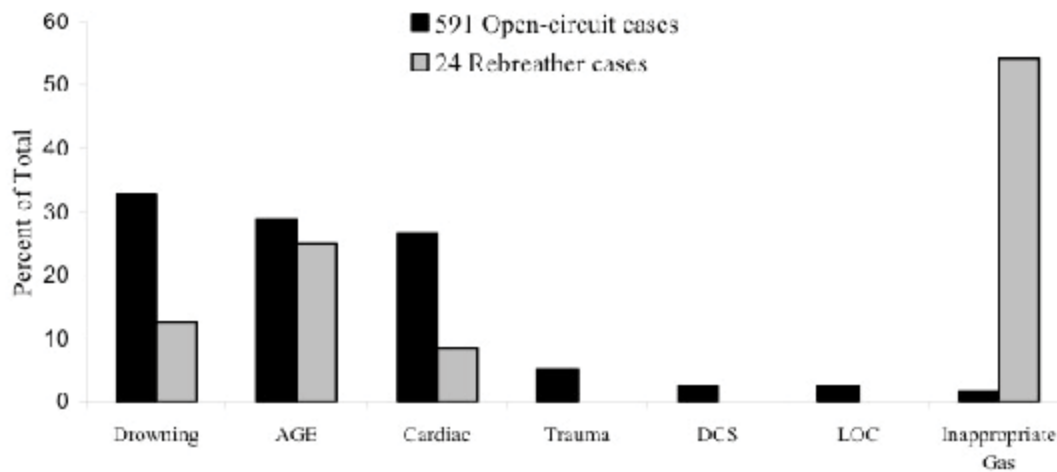
### Background

The mid-1990s saw the beginning of an upsurge in the use of rebreathers by sports divers. At that time the sport diving industry had limited rebreather experience and so, in anticipation of a growth in rebreather popularity, in 1996 the diving industry organised *Rebreather Forum Two* (RF2). The conference was organised to address the major issues

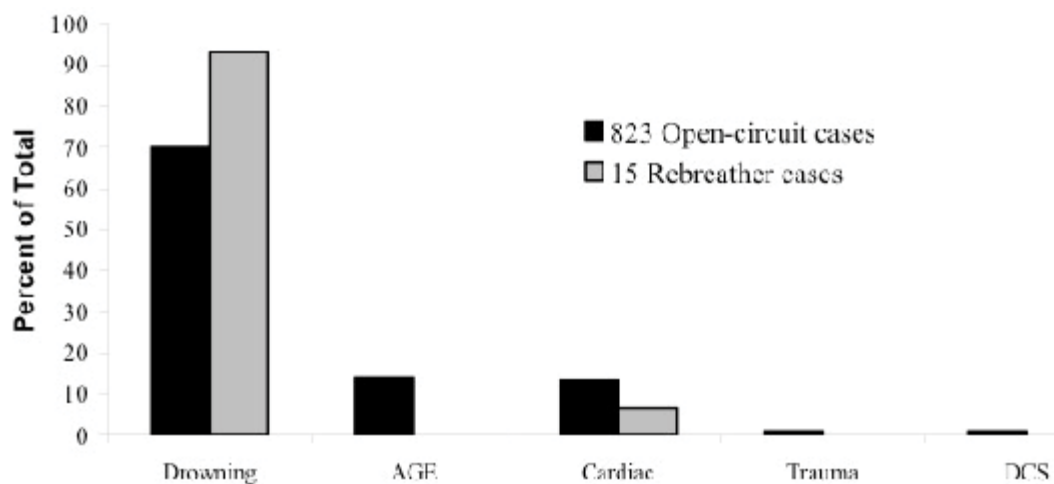
**Figure 1**  
Triggers in open circuit and rebreather diving fatalities<sup>5</sup> (with permission)



**Figure 2**  
Disabling injuries in open circuit and rebreather diving fatalities<sup>5</sup> (with permission)



**Figure 3**  
Causes of death in open circuit and rebreather fatalities<sup>5</sup> (with permission)



involved in bringing rebreather technology to the consumer market-place and was divided into working sessions to identify the key technology, safety, training and risk management issues. Drawing on the collective experience of numerous delegates from sport, military and occupational diving backgrounds, a consensus was developed in order to help shape future sport rebreather diving practice.<sup>4</sup>

**Rebreather fatality analysis**

As anticipated, sport rebreather use increased post RF2. Subsequently, with consideration of the relatively low number of rebreather sport divers, there appeared to be a disproportionately higher number of reported rebreather fatalities when compared to open-circuit scuba. As a consequence, the Divers Alert Network (DAN) conducted a study comparing sport diving open-circuit and rebreather scuba fatalities from the period 1998 to 2006.<sup>5</sup> Due to the difficulty in attaining comprehensive rebreather accident data specific to each fatality, in particular CoD as determined by a medical examiner (Coroner), the DAN study was restricted to a low number of rebreather fatalities (80 cases). However, study conclusions appeared to support the following related 1996 RF2 consensus points:

*“Rebreathers are much more complex than open circuit with insidious risk.”<sup>4</sup>*

The 2007 DAN analysis concluded that of the cases studied, equipment trouble (human error or technical failure) was the trigger (something that turns an uneventful dive into an emergency) in over 40% of rebreather fatalities compared to just over 15% of open circuit fatalities (Figure 1). In addition, inappropriate breathing gas (insidious risk) was the disabling injury (something that causes death or makes drowning likely) in over 50% of rebreather cases compared to less than 5% of open-circuit cases (Figure 2).

*“Loss of consciousness presents a significant hazard when using rebreathers, likely to result in death by drowning.”<sup>4</sup>*

The 2007 DAN analysis concluded that in 94% of cases studied, the actual CoD, as determined by a medical examiner, was drowning (Figure 3).

In an effort to quantify rebreather diving risk, in 2013, a separate rebreather fatality study concluded that of the 181 cases analysed from between 1998 and 2010, study data suggested a four- to ten-fold increased risk of death when rebreather diving compared to open-circuit scuba diving.<sup>2</sup> The study also reported that a rebreather potentially has a 25-fold increased risk of component failure compared to an open-circuit manifolded twin-cylinder scuba system. Therefore, this study appears to further support the RF2 consensus statements discussed above.

**Human error**

An incident is defined here as an unplanned event that degrades safety and culminates in equipment damage,

**Figure 4**  
Generic human error rates<sup>7</sup> (redrawn)

Mean Probability of Human Error or Failure Per Task	1	New or rarely performed task. Extreme stress, very little time. Severe distractions & impairments.
	10 <sup>-1</sup>	Highly complex task. Considerable stress, little time. Moderate distractions & impairments.
	10 <sup>-2</sup>	Complex or unfamiliar task. Moderate stress, moderate time. Little distractions & impairments.
	10 <sup>-3</sup>	Difficult but familiar task. Little stress, sufficient time. Very little distractions or impairments.
	10 <sup>-4</sup>	Simple, frequent, skilled task. No stress, no time limits. No distractions or impairments.

diver injury or death. Rebreathers are complex equipment that form one element of a broader life support system that includes:

- the diver (attitude, skill set, knowledge, experience, health and fitness to dive);
- dive partner/team (attitude, skill set, knowledge, experience, health and fitness to dive);
- surface support team (attitude, skill set, knowledge, experience, emergency response protocols, emergency medical facilities);
- diving ancillary equipment (functionality and fitness for purpose);
- environmental protection equipment (functionality and fitness for purpose);
- procedural/diving methodology (appropriateness and fitness for purpose).

Rebreather incident data suggest that a frequent contributing factor is knowingly or unknowingly violating diving and/or equipment protocols as opposed to equipment malfunction.<sup>2</sup> This is in keeping with data from the marine oil and gas industry where approximately 80% of incidents investigated were related to human unreliability and approximately 20% were related to technical causes.<sup>6</sup> These figures support a widely held perception amongst the sport rebreather community that the diver is the ‘weak link’ in the life support system ‘chain’ described above.

To assist in the estimation and qualification of human error, a generic rate from experiment and simulation in the operation of nuclear power plants was developed (Figure 4).<sup>7</sup> If we consider an experienced rebreather diver in a benign environment, the assembly, testing, pre-dive donning and functionality confirmation (pre-breathe) procedures, all of which are essential to safe rebreather use, could be considered to fall into the fourth row of Figure 4, i.e., difficult but familiar task, little stress, sufficient time, very few distractions or impairments. The mean probability of human error or failure per task for such a scenario is between one in 1,000 events to one in 10,000 events. Thus, even under relatively benign conditions, experienced divers will

occasionally make errors. It may be concluded, therefore, that to a lesser or greater extent, all levels of rebreather diver from novice to expert are prone to human error, the consequence of which could be exposure to an inappropriate breathing gas and LoC underwater.

### Rebreather incident prevention

To help prevent rebreather diving incidents the following key measures are presently implemented or recommended by sport diving training agencies and equipment manufacturers:

- Use of equipment that has been subject to independent third party testing against a recognised international standard;
- Appropriate training standards and their strict application by diving instructors;
- Appropriate dive planning;
- Analysis and clear labelling of all gas cylinders;
- Use of assembly and test checklists;
- Remaining within manufacturers' recommendations/performance guidelines;
- Remaining within training qualification parameters;
- Pre-breathe and function check prior to entering the water;
- Diving in pairs/teams;
- Frequent oxygen partial pressure display monitoring;
- Remaining within appropriate dive planning parameters;
- Application of appropriate preventive and corrective maintenance.

These incident mitigation measures are also applied within military and occupational diving environments, often to a greater level of detail and enforcement.<sup>8,9</sup> However, despite what is often the rigorous application of equipment maintenance schedules, prescriptive diver supervision and organisational management systems, in the author's experience, human error remains a common characteristic of military and occupational rebreather diving incidents. Therefore, within the sport diving environment it is reasonable to assume that, as a consequence of less formal diving equipment maintenance schedules, supervision and management practices, human error will likely continue to remain a common characteristic of sport rebreather diving incidents with the resulting potential for LoC.

### Airway protection

Aspiration of as little as 1–3 ml·kg<sup>-1</sup> body weight of water produces profound alterations in human pulmonary gas exchange.<sup>10</sup> It is also reported that average water aspiration in drowning is relatively small, rarely exceeding approximately 2.2 ml·kg<sup>-1</sup> body weight.<sup>11</sup> Therefore, preventing or limiting fluid aspiration following LoC underwater is critical to surviving such an event. Whilst it is acknowledged that the diver may eventually die as a consequence of exposure to an inappropriate breathing gas, this can take a number of minutes or longer depending upon the breathing gas composition and

ambient pressure (depth). If water aspiration is prevented or delayed following LoC, a diving partner may be able to affect a successful rescue. Alternatively it is conceivable that under certain circumstances, the distressed diver may regain consciousness, potentially enabling self-rescue.

To mitigate fluid aspiration following LoC underwater, a 1996 RF2 consensus statement endorsed the use of the full-face mask (FFM). However, a FFM adds to equipment complexity, restricts access to alternative breathing gas supply systems whilst increasing maintenance, training requirements and associated cost. These factors likely account for the sport rebreather diving community having not embraced the widespread use of FFMs despite their potential safety benefits.

One occupational diving equipment manufacturer has developed an innovative hybrid FFM/half mask design.<sup>12</sup> This mask system enables the ready separation of the lower oral section of the mask, which incorporates the rebreather mouthpiece. This design offers FFM airway protection benefits whilst also facilitating ready access to alternative breathing gas delivery systems. However, the sale of this hybrid design has generally been confined to government and occupational diving organisations. This and the relatively high cost appear to have restricted its wider use by sport rebreather divers.

In recognition of the possibility of encountering inappropriate breathing gas and the associated potential for LoC underwater, when a FFM is not used, the mouthpiece retaining strap (MRS) combined with related training has been employed by militaries worldwide for over half a century. It is a common safety design feature of the vast majority of both classic and contemporary military rebreather designs where the manufacturer has endeavoured to provide airway protection in the event of LoC underwater. In its simplest form the MRS is an elasticated adjustable strap secured to the breathing loop/mouthpiece. To optimise its effectiveness, the MRS is worn over the crown of the head and adjusted to positively hold the mouthpiece in position without causing undue discomfort. More sophisticated versions incorporate a padded flange. When retracted around the face by the distended strap, the padded flange enhances the lip seal whilst also helping to secure the mouthpiece in position (Figure 5). The MRS is a relatively low cost, simple and available alternative to the FFM.

### Mouthpiece retaining strap efficacy

A literature search has failed to identify any formal evaluation of MRS efficacy. The subject was discussed at Rebreather Forum Three (RF3), Orlando, Florida in May 2012 and a RF3 consensus statement reads: "*The forum identifies as a research question the issue of whether a mouthpiece retaining strap would provide protection of the airway in an unconscious rebreather diver.*"<sup>13</sup> However, it is unlikely



**Figure 5**

Mouthpiece retaining strap (courtesy Charles Hawks)



that a meaningful prospective experimental evaluation of the MRS could be undertaken in human subjects. In the absence of a specific formal study, the suggestion of MRS efficacy is principally based upon observational (anecdotal) evidence from military diving sources and logic.

As a measure of the perceived potential effectiveness of the oral seal achieved by a correctly worn MRS, when conducting a diver rescue, some closed-circuit oxygen rebreather military user groups are trained to break the MRS oral seal by partially inserting a finger under the unconscious diver's lip at the corner of the mouth. This is believed to help facilitate the venting of expanding gas from the distressed diver's lungs and reduce the risk of pulmonary barotrauma on ascent.<sup>14</sup> Military groups who train this technique believe that an appropriately designed MRS results in an effective seal between mouth and breathing loop mouthpiece. Anecdotal evidence from various experienced military rebreather divers/diving supervisors, including the author, suggest that the use of a MRS has on various occasions been a key contributory factor to surviving LoC underwater. It is also the author's experience as a passenger in a free-flooding combat submersible swimmer delivery vehicle, that whilst in an upright foetal position, the MRS has provided airway protection during periods of sleep lasting up to 10 minutes.

These perceptions are corroborated by one notable study that analysed 153 accidents amongst French military rebreather divers.<sup>15</sup> Fifty-four of these events led to LoC underwater; however, this resulted in drowning in only three cases. The military report states: "*gas toxicities are frequently encountered by French military divers using rebreathers, but the very low incidence of fatalities in over 30 years can be explained by the strict application of safety diving procedures*". These procedures include:

*"Systematic linking of divers in pairs, so that a diver can find his buddy regardless of diving conditions (particularly if visibility is poor) and can lend assistance in the event of rescue"*.

*"Using a strap to hold the mouthpiece in position, along with a lip guard, so that an unconscious diver can still breathe without risk of drowning. The rescuer can then concentrate on the quality of assistance and respecting the diving parameters for regaining the surface"*.<sup>15</sup>

The report gives no weighting to either of these factors so it is unclear which, if any played a larger role in preventing drowning in 51 out of the 54 LoC events. However, protecting the airway from water aspiration and effecting rescue at the earliest opportunity are cited as key factors to surviving LoC underwater. The related benefit implied by this military diving study is likely to be translatable to the sport diving setting.

### **Rebreather solo diving**

Of the 80 rebreather fatalities reviewed in the 2007 DAN study, 26 (a third) involved solo diving as a result of either deliberately diving alone or becoming separated from a diving partner. In support of this finding, whilst its accuracy cannot be readily verified, a publically available on-line collation of sport rebreather fatalities suggests that solo diving continues to remain a prominent characteristic of sport rebreather deaths that have occurred since 2007.<sup>16</sup> Due to the increased probability of respiring an inappropriate breathing gas when using a rebreather and the absence of a dive partner to witness early signs of diver distress or performance impairment and to implement rescue, solo rebreather diving appears to present additional risk.

Even a well-designed and correctly fitted MRS is unlikely to provide airway protection over an extended period following LoC. Therefore, to realise any safety benefit accruing from delaying or preventing drowning, the maintenance of close contact with a dive partner is also considered an important component to surviving LoC underwater. This proposition appears to be supported by the French military study, in which divers have survived LoC as a result of MRS use and early rescue by a dive partner.

### **Sport rebreather design and performance standards**

European standard EN14143:2013 sets minimum design and performance parameters for sport rebreathers sold within the European Union, where compliance is a mandatory aspect of consumer law.<sup>17</sup> It is also setting a broader global benchmark for rebreather design standards. However, human error and equipment failure will likely remain a characteristic of sport rebreather use. It follows that the provision of airway protection is a desirable safety design feature regardless of rebreather performance and reliability. Indeed,

**Figure 6**

Rebreather open circuit bail out valve (courtesy AP Diving)



EN14143:2013 specifies a design requirement regarding a 'face-piece', which the standard defines as: "*a mouthpiece assembly, a half mask, a full-face mask or a helmet*". The standard goes on to state: "*The face-piece shall aid ear clearing by allowing the diver's nasal passages to be occluded. It shall also minimise the ingress of water during normal use and in the event of a diver falling unconscious or having a convulsion*".<sup>17</sup> Whilst it is not specified how the minimisation of water ingress is to be implemented, EN14143:2013 states: "*The face-piece harness shall be designed so that the face-piece can be donned and removed easily. It shall be adjustable or self-adjusting and shall hold the face-piece assembly firmly and comfortably in position*".<sup>17</sup> The standard subsequently defines the design and functional requirements of a retaining strap if fitted. The European rebreather standard, therefore, recognises the potential safety benefit of protecting the airway and breathing loop in the event of LoC and as a consequence incorporated the requirement into its design specification (Anthony G, personal communication, 2014; principle author of EN14143:2013).

### Market trends

To extend the exploration parameters of self-contained sport and scientific diving, to date relatively small groups of 'technical divers' have been the most prevalent users of rebreathers. However, a considerably larger sales potential is thought to exist amongst mainstream sport divers. As a consequence, considerable resource is presently being applied by the sport diving industry to introducing rebreathers into this larger market place.<sup>18,19</sup> To help facilitate mainstream rebreather diving, the world's largest recreational diving training agency has defined a generic recreational closed-circuit rebreather (rCCR) specification and developed what it considers to be appropriate rCCR training standards. As a consequence, manufacturers are either producing dedicated rCCR models or adapting previous rebreather designs to comply with this rCCR specification.<sup>20,21</sup> Rebreather use will likely continue to increase amongst sport divers.

A mandatory rCCR specification safety feature is the bail out valve (BOV) (Figure 6). In an emergency, it enables the diver to manually access a source of open-circuit breathing gas without the need to remove the mouthpiece. However, it is worth noting that the MRS is not a mandatory rCCR safety feature. Despite the EN14143:2013 design requirement previously discussed, the reason for this remains unclear but may result from the fact that the MRS has historically not formed part of sport rebreather design. Therefore, awareness and experience of its application and potential safety benefit is limited amongst the sport rebreather community. Whereas a BOV is increasingly an integral part of sport rebreather design, it continues to remain the norm, contrary to EN14143:2013, for the vast majority of manufacturers to sell sport rebreathers without "*a means to minimise the ingress of water in the event of a diver falling unconscious*" or a means to "*hold the face-piece assembly firmly and comfortably in position*".<sup>17</sup>

### Airway protection spectrum

We may consider the upper end of the airway protection safety 'spectrum' to be an occupational diving helmet interfaced with a rebreather. An example is the Secondary Life Support saturation diving emergency bailout rebreather manufactured by Divex.<sup>22</sup> Assuming the watertight integrity of the breathing loop and helmet, water aspiration and, therefore, drowning following LoC, is highly improbable. At the low end of this 'spectrum' is the absence of any means of protecting the airway following LoC. Despite acknowledging the increased potential for exposure to an inappropriate breathing gas and LoC when rebreather diving, the sport diving community largely remains positioned at the low end of this 'spectrum'.

### Conclusions

Rebreathers incorporate a high number of inherent failure modes and the potential for human error. Individually or in combination, these can lead to inappropriate breathing gas and spontaneous LoC underwater. If the airway is unprotected, water aspiration and asphyxiation is the likely immediate outcome. Whilst FFMs are considered to offer a high level of airway protection, owing to their cost and complexity they are unlikely to be widely adopted by sport rebreather divers. Military rebreather manufacturers consider the MRS a safety-critical design feature, which is extensively employed throughout the global military rebreather diving community. Observational evidence suggests the correct use of a MRS can be an effective means of preventing or limiting water aspiration immediately following LoC. This potentially extends the window of opportunity for effective rescue or conceivably, self-rescue should consciousness be regained.



## Recommendations

In the vast majority of sport rebreather fatalities, drowning is the actual CoD. Therefore, to directly mitigate the immediate consequences of loss of airway protection following LoC underwater, an effective MRS should be a standard component of all rebreathers used by sport divers. In addition, in order to raise awareness of the potential safety benefits, its use should be mandated within sport rebreather training standards.

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# Case report

## Middle ear barotrauma causing transient facial nerve paralysis after scuba diving

Matthew Lee Carmichael and K Paul Boyev

### Abstract

(Carmichael ML, Boyev KP. Middle ear barotrauma causing transient facial nerve paralysis after scuba diving. *Diving and Hyperbaric Medicine*. 2016 September;46(4):260-261.)

Middle ear barotrauma is a well known entity with typical injury occurring when diving or ascending in a commercial jetliner. Patients often present with symptoms of acute onset otalgia, hearing loss and sometimes haemotympanum (with or without tympanic membrane perforation). On rare occasions, facial nerve paralysis can occur when the tympanic segment of the facial nerve is dehiscence within the middle ear. We present a case of spontaneously resolving facial nerve palsy associated with middle ear barotrauma following a brief, shallow dive. Prompt and astute diagnosis leads to proper management with simple myringotomy and can prevent unnecessary testing and other misguided treatments.

### Key words

Injuries; ENT; Diving incidents; Case reports

### Introduction

With the increase in recreational diving, there has been a concomitant increase in reported diving injuries.<sup>1</sup> In particular, the middle ear is a frequent site of injury. Typical injury occurs during descent when the diver fails to actively open the normally closed Eustachian tube (ET) to equalize pressure across the tympanic membrane (TM). If a diver fails to do this, the surrounding hyperbaric pressure forces blood and tissue fluid into air-filled spaces (middle ear) until ambient pressure is equalized. As most divers will report, the greatest change in pressure is within the first 10 metres and if equalization of middle ear pressure does not occur within this depth, injury is likely to occur. In general, middle ear barotrauma (MEBt) presents as acute onset otalgia, subjective hearing loss and at times haemotympanum (with or without TM perforation). This typically resolves spontaneously and without sequelae. However, facial nerve paralysis has been reported as a rare complication of MEBt. Herein, we report a case of transient facial nerve paralysis following a brief, shallow dive.

### Case report

A physically fit, 37-year-old, male commercial diver presented to the emergency room (ER) with right facial droop and oral incompetence. Approximately 45 minutes prior to presenting, the patient reported diving to a depth of 3–4 metres' sea water for five minutes. He reported onset of right ear pain on decent; however, he continued the dive. Upon exiting the water, symptoms of right-sided otalgia, tinnitus, decreased hearing and a "tin" taste began abruptly. On reaching the dive shop, his wife noticed he had developed right facial droop and brought him immediately to the ER.

At presentation, he had complete right-sided facial paralysis and right haemotympanum with a bulging TM. He denied ever having previous difficulty equalizing pressure during dives, but could not remember if he had adequately cleared his ears on this dive. A CT head was obtained to rule out any acute cerebral events. Whilst being placed onto the scanner table, he reported "finally able to clear my ears" and immediately noted his symptoms abating. Subsequent examination revealed complete resolution of right facial paralysis and of the right-sided haemotympanum with an intact TM. The CT showed no evidence of acute hemorrhagic stroke and no middle ear effusion but showed a thin to absent bony covering of the tympanic segment of the facial nerve on the right as compared to the left (Figure 1). MRI was subsequently performed and was without evidence of acute cerebral infarction. Total time of onset to resolution of symptoms was within two hours.

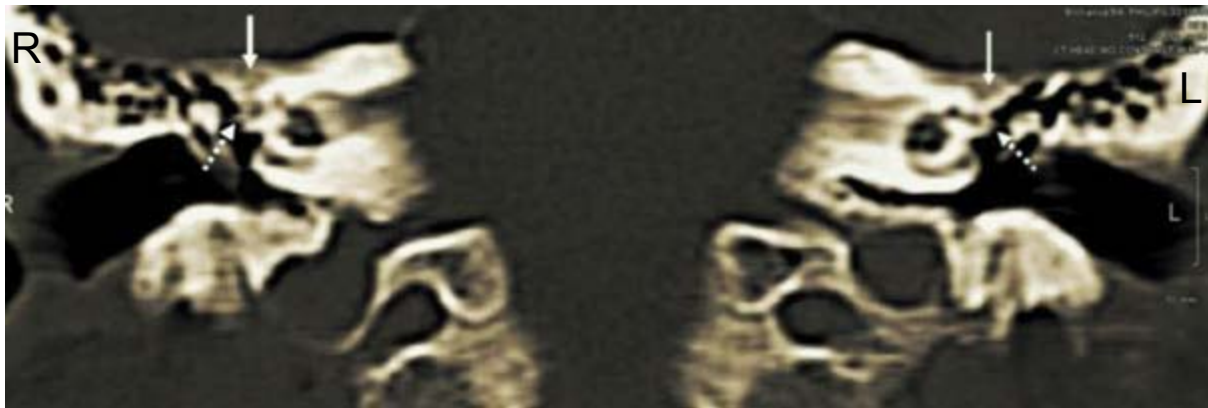
Despite multiple attempts to obtain permission to report his case, the diver was lost to follow-up.

### Discussion

Transient facial nerve paralysis is a recognized but rare complication of MEBt. It manifests as a lower motor neuron lesion with corresponding complete loss of ipsilateral facial tone, as compared to an upper motor neuron lesion causing forehead-sparing facial paralysis, as seen in cerebral vascular accidents. Barotrauma in scuba diving results from the interaction between the internal physiologic pressure of the middle ear and the pressure levels exerted by water surrounding the diver.<sup>2</sup> The ability to ventilate the middle ear space via the ET is essential, and, if not done early and frequently enough upon diving, the ET becomes ineffective because it irreversibly blocks at pressure differentials of

**Figure 1**

CT head without contrast; solid arrows indicate the geniculate ganglion of the facial nerve; dashed arrows identify the anterior tympanic segment of the facial nerve as it begins its course within the middle ear space; note the thin bony covering of the anterior tympanic segment of the facial nerve on the left as compared to the right where only soft tissue (facial nerve) is identifiable



approximately 90 mm Hg; equivalent to 1.5 metres' depth.<sup>2</sup>

For MEBt to cause facial nerve paralysis, the facial nerve must be compromised within the middle ear. During its course through the temporal bone, the tympanic segment of the facial nerve is found within the middle ear space typically covered by a very thin bony wall called the fallopian canal. However, increasing evidence suggests a large portion of the adult population has a dehiscence within this canal, exposing the facial nerve to middle ear pathology. In a 1971 anatomical study, 55% of normal adult temporal bones showed dehiscence of the facial nerve canal.<sup>3</sup> In a 2004 study, 29.3% of adult temporal bones revealed facial nerve canal dehiscence; a much higher incidence than intraoperative findings suggest.<sup>4</sup> The theory of ischaemic compression of the facial nerve resulting in neuropraxia was confirmed in a study using guinea pigs.<sup>5</sup> As middle ear pressure was increased, blood pressure to the TM and dehiscent facial nerve decreased as compared to monitored blood pressure within the femoral artery. When middle ear pressure exceeds the capillary blood pressure, blood flow to the facial nerve will decrease and induce ischaemic neuropraxia when facial nerve canal dehiscence is present.<sup>5</sup>

Although an experienced commercial diver, we believe this man neglected to equalize adequately the pressure within his middle ears. In doing so, he developed significant MEBt of the right ear. The subsequent middle ear pressure was sufficient to overcome the capillary blood pressure to the facial nerve causing neuropraxia. Once the patient was able to equalize the pressure in his right ear (approximately one to two hours after onset of facial paralysis), his symptoms and facial paralysis resolved.

In conclusion, the tympanic segment of the facial nerve is vulnerable to injury when a dehiscence occurs within the fallopian canal. As such, middle ear pathology has the potential for injury to the nerve. Our case represents the rare occasion when middle ear pathology can lead to potentially serious symptoms. When confronted with this

rare phenomenon, careful history and physical examination of the TM is of utmost importance as patients can endure unnecessary diagnostic testing and misguided treatments. Recognition of the conglomeration of symptoms, physical exam findings and historical facts will lead to this astute diagnosis. By and large, treatment is focused on relieving middle ear overpressure. If the patient is unable to equalize pressure through opening of the ET (as was eventually done by our patient) then simple myringotomy and evacuation of the middle ear space is performed with curative intent.<sup>6</sup>

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**Submitted:** 22 June 2016; revised 02 August and 15 October 2016

**Accepted:** 15 October 2016

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## Partial retraction

Partial retraction of Lawrence CHD, Chen IYD. The effect of scuba diving on airflow obstruction in divers with asthma. *Diving and Hyperbaric Medicine*. 2016 March;46(1):11-14.

Consistent with the Committee on Publication Ethics guidelines, we the above authors are initiating a partial retraction of our paper: Lawrence CHD, Chen IYD. The effect of scuba diving on airflow obstruction in divers with asthma. *Diving and Hyperbaric Medicine*. 2016 March;46(1):11-14.

We wish to make the following statement:

*“Following independent statistical review of our paper we would like to withdraw the following: all subgroup statistical analysis including Table 1 and the statement “\*P < 0.05, non-asthmatic controls vs Group A3 asthmatics” in the legend of Figure 2; the discussion statement: “We hope that these data will provide practitioners assessing and risk stratifying people with asthma prior to diving with a modest evidence basis on which to advise them of their relative risk of airflow obstruction compared to the normal population.”*

*The reason for this is that, following publication, it was identified that the scientific method for comparing between groups was inappropriate for the study design. We are extremely disappointed that our statistical method for calculating significance when comparing groups was inadequate but equally grateful to the journal editors and readers for their input in rectifying this and maintaining*

*scientific integrity. We would like to make absolutely clear that at no point did we seek to mislead or misguide the journal or any other group. We have learnt a valuable lesson in study design and the limitations of statistics.*

*The observational data as published looking at airflow obstruction in divers with asthma in real-world conditions remain valid and in the context of diving and asthma still have value in addition to what is already in the scientific domain. We hope that this can serve as a foundation for future studies in this field”.*

**Submitted:** 15 September 2016

**Accepted:** 18 September 2016

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## Editor-in-Chief, *Diving and Hyperbaric Medicine* Journal

Call for expressions of interest (closing date 28 February 2017)

*Diving and Hyperbaric Medicine* is published jointly by the South Pacific Underwater Medicine Society (SPUMS) and the European Underwater and Baromedical Society (EUBS). The journal is indexed on Medline, SciSearch and Embase/Scopus.

Expressions of interest are called for the position of Editor-in-Chief from 01 January 2018. This is a contracted position for five (5) years, and attracts a modest honorarium. There is funding for up to six months' overlap with the current Editor-in-Chief, prior to 01 January 2018, to allow smooth transition and handover.

Applicants must have an established academic track record in medicine with strong publication history, and extensive experience in the process of peer review. Experience in editing and publishing a peer-reviewed journal would be an advantage, but not absolutely essential provided other

criteria are strong. Preference will be given to medically qualified applicants, given the journal's track record as a leading publication in diving medicine. The *Diving and Hyperbaric Medicine* journal is published in English and the Editor is expected to either have English as their primary language, or mastery of English as a second language.

The Editor of the journal is a prominent position for both societies, and the successful applicant is expected to have highly developed interpersonal skills, given the multicultural, multilingual and intercontinental origins of the two societies.

Please forward all inquiries and curriculum vitae to both the SPUMS President, Clinical Professor David Smart at <president@spums.org.au> and EUBS President, Professor Jacek Kot at <president@eubs.org>.

# Book review

## The Leading Edge

Innovation, technology and people in  
Australia's Royal Flying Doctor Service  
Stephen Langford

Paperback, 380 pages

ISBN 978174288148

UWA Publishing, February 2016

**Available from:** <http://uwap.uwa.edu.au/>

**Price:** AUD 29.99

As a former aviation medical doctor who spent ten great years working with the emergency aeromedical retrieval service in New South Wales, I was delighted to receive a copy of Stephen Langford's account of his 33 years spent in the Royal Flying Doctor Service (RFDS) in Western Australia (WA). It is a fascinating insider's account of an evolving and sophisticated medical service to the WA community that is globally recognised as uniquely Australian in concept and execution.

I met Stephen on a number of occasions in the 1990s when we were both closely engaged in the local branch of the medical craft group *The International Society of Aeromedical Services (Australasia)*. It was clear at the time Stephen was a dedicated enthusiast full of wonderful and poignant stories about the Service, its characters and its patients. He was also full of technological concepts and grand designs to ensure the RFDS remained a leader in its highly specialised field. I am very pleased to say this book conveys a great sense of what it was like to talk to Stephen in person about his work and one of the great loves of his life.

The book is a relatively light read – it is conversational and avoids lengthy accounts of technology and medical details in order to keep the subject matter both human and relevant to the general reader. It can be recommended to both the specialist with a specific interest in remote medical support and the general reader who wants to get a real feel for what it is like to be part of this unique medical organisation.

At 380 pages in all, the 60 short chapters are divided into six major sections covering the 'pre-Langford' history (Retrospective), Aviation, Medical (the longest by some margin), Chests and Clinics (how *does* one ensure a comprehensive range of medicines is available, locatable and able to be administered when doctor and patient may be 2,000 km apart?), Evaluation and Education. This is useful, because the reader interested in (for example) the history and rationale for aircraft types in use over the years can get straight to this discussion without being distracted by the other subjects. Each section allows Stephen to use his uncomplicated approach to written communication in order to convey some highly specialised ideas in an understandable way. The whole is peppered with anecdotes from Stephen's

casebook which vividly highlight the special problems (and solutions) the nurses, doctors and pilots need to face in a remote, harsh and unforgiving physical environment. These stories are very welcome illustrations relevant to the particular chapter in which they appear. There are also excellent colour plates in this well-presented paperback.

There are many personal highlights for me – and while I appreciate the discussion of aircraft type, capacity, range and the statistics on activity appearing in the relevant sections – it is the interactions of environment, clinical necessity and operational requirements that are most easily recalled. The account of Stephen's 'Dash under the ash' to retrieve a neonate to tertiary cardiothoracic care (p. 184-6) is particularly fascinating and instructive, as is (in a very different way) 'A bite on the backside' on p. 246-8.

One reaches the conclusion by the end that the RFDS in WA is very lucky to have found Stephen. Over 33 years he has emerged with his common sense, energy and humour intact. He learnt his business from the ground up and while more recently he has been in an executive position, forming policy and arranging the pieces on his vast board, he knows this game inside out. This book makes it clear his efforts remain focussed on the patients that are so reliant on the Service, as well as the men and women who are out there in the remote areas of the state trying to deliver effective health programmes and timely emergency treatment under some of the most difficult conditions on the planet. For his insight, effectiveness and unwavering commitment, Stephen is a very worthy recipient of the WA Local Hero Award in the 2016 Australian of the Year Awards.

By the same token, one gets the strong impression that Stephen is equally fortunate to have found the RFDS. For a young doctor in 1982, unsure of what he was going to do with his life and somewhat (by his own admission) 'restless' for excitement, Stephen stumbled into his first job for the RFDS in Port Hedland in 1983. There he found an organisation and a group of people he seems to have enthusiastically and almost instantly embraced. We should all be so lucky as to find such a worthy organisation to which we can make a career commitment – safe in the knowledge that our efforts are worth making.

I commend this book to anyone interested in retrieval medicine, tales of the outback or simply a lover of Australian 'can do' philosophy. It has been added to the reading list for our trainees in Sydney, both anaesthetic and DHM!

*Michael Bennett*

*Conjoint Professor in the Prince of Wales Clinical School,  
Faculty of Medicine, University of New South Wales,  
Australia*

### Key words

Aviation; Book reviews; General interest



## Notices and news

EUBS notices and news and all other society information is now to be found mainly on the new society website: <[www.eubs.org](http://www.eubs.org)>

### 43rd EUBS Annual Scientific Meeting 2017

#### Preliminary Announcement

**Dates:** 13–17 September

**Venue:** Ravenna, Italy

**Organising Committee:** Paolo Pelaia (Ancona), Monica Rocco (Roma) and Pasquale Longobardi (Ravenna)

The EUBS Executive Committee and the local organising committee welcome you to Ravenna for the 43rd Annual Scientific Meeting of EUBS.

The dedicated conference website <[www.eubs2017.org](http://www.eubs2017.org)> is now active and provides practical information and registration for the conference. Early registration ends on 31 March 2017.

#### Zetterström Award

The Zetterström Committee, composed of P Lafère, M Coulange and O Hyldegaard, have presented the 2016 Zetterström Award for best poster presentation to:

F Tillmans, T Noy, R Lüddecke, I Rohde, B Lohrie, S Klapa, S Sebens, H Werr, A Koch, W Kähler. *Increase in T-cells after hyperoxic exposure of healthy humans in vivo without relevant induction in apoptosis* Poster #27

#### Patrick Musimu Award

The Patrick Musimu Award for best contribution, either oral or poster presentation, in the area of breathhold diving, was instituted in 2011 by the Belgian Society for Diving and Hyperbaric Medicine. The 2016 award was presented to:

D Cialoni, M Pieri, G Giunchi, AM Lanzone, N Sponsiello, A Marroni. *Detection of venous gas emboli after repetitive breath hold dives in a Taravana case* Oral #55

#### EUBS Executive Committee

Bengusu Oroglu, from Istanbul, Turkey has been elected as the new Member-at-Large to replace Pierre Lafère after serving his three-year term. The Executive Committee wish to express their gratitude for Pierre's contributions to the ExCom activities during his term of office.

Our Membership Secretary Tricia Wooding has announced her intention to retire after 13 years of faithful service to the EUBS. During the EUBS 2016 meeting and in the months thereafter, ExCom has been working hard to select and appoint a new Membership and Financial Secretary. Tricia will be happy to remain available during a transition period to guarantee a smooth handover.

#### The Science of Diving

Support EUBS by buying the PHYPODE book “*The science of diving*”.

PHYPODE research fellows <[www.phypode.org](http://www.phypode.org)> have written a book for anyone with a keen interest in the latest research trends and results in diving physiology and pathology. Edited by Tino Balestra and Peter Germonpré, the royalties from this book are being donated to the EUBS. Need more reason to buy? TB and PG don't think so!

**Available from:** Morebooks <<https://www.morebooks.de/store/gb/book/the-science-of-diving/isbn/978-3-659-66233-1>>

#### The



website is at  
<[www.eubs.org](http://www.eubs.org)>

Members are encouraged to log in and keep their personal details up to date.

The new, revamped EUBS website <[www.eubs.org](http://www.eubs.org)> will be online by December 31st. Its layout has been drastically modified for viewing on smartphones, tablets and computers, while offering the same functionality as before. Check it out!



## Notices and news

SPUMS notices and news and all other society information is now to be found mainly on the new society website: <[www.spums.org.au](http://www.spums.org.au)>

### SPUMS Annual Scientific Meeting 2017

Main Theme: Medical Support of Commercial Diving

**Dates:** 21–27 May 2017

**Venue:** Exclusive use of Rama Candidasa Resort and Spa, Bali, Indonesia

**Keynote speakers:** Dr Debbie Pestell, President, Canadian Undersea and Hyperbaric Medical Association

Dr Jurg Wendling: National Director, Dan Europe Suisse

**Additional speakers:** Neal Pollock, Ian Gawthrop, David Smart, Sarah Lockley

**Workshop:** Hands-on diver-focused echocardiography with Neal Pollock, Ian Gawthrop and Jurg Wendling

**Conveners:** Katherine Commons and Clinton Gibbs <[asm2017@spums.org.au](mailto:asm2017@spums.org.au)>

**Scientific Convener:** Denise Blake <[scientific.convener@spums.org.au](mailto:scientific.convener@spums.org.au)>

**Abstract** submissions are now open via the registration site.

**Registration:** via the CVENT link at <<http://spums.org.au/content/2017-spums-asm>>

**Facebook:** [facebook.com/spums2017](https://facebook.com/spums2017)

#### Associate Professor Neal W Pollock, PhD

Neal Pollock has been appointed to the Research Chair in Hyperbaric and Diving Medicine in the Department of Kinesiology, Faculty of Medicine, Laval University, Quebec City, Canada. This position is linked to the Service de médecine hyperbare, Centre de médecine de plongée du Québec, Hôtel-Dieu de Lévis. He takes up his new position toward the end of the year.

Neal is a valued member of the DHM Editorial Board and Interim Editor-in-Chief for the journal *Wilderness and Environmental Medicine*. He was Director of Research for DAN America and a Research Associate at Duke University, North Carolina. He has been Guest Speaker at two SPUMS ASMs and will also be well-known to many EUBS members. SPUMS and EUBS wish him every success in his new role.

The



website is at

<[www.spums.org.au](http://www.spums.org.au)>

The new website has now been launched. Members are encouraged to log in and update their personal details.

#### Education Officer's Report, October, 2016

Since my report to the AGM in May, I can congratulate the following SPUMS member who has been awarded the Diploma of Diving and Hyperbaric Medicine:

Dr Tobias Trinks (Royal Brisbane and Women's Hospital)  
*Transcutaneous oximetry measurements of the leg: comparing different measuring equipment*

To date, 2016 has also seen four new projects registered, several under current review and many more enquiries. The SPUMS Diploma is a unique qualification, administered by our society but with a formal status by being referenced in the Medicare Benefits Schedule book as the qualification required to work and bill for patient treatments in hyperbaric facilities in Australia.

I thank the support of Denise Blake and Simon Mitchell on the Academic Board and also the many others who have contributed when asked. Finally, good luck to all SPUMS Diploma candidates.

David Wilkinson

Education Officer

[david.wilkinson@health.sa.gov.au](mailto:david.wilkinson@health.sa.gov.au)

The full report will be available on the SPUMS website.



## SPUMS Diploma in Diving and Hyperbaric Medicine

### Requirements for candidates (May 2014)

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 (S)he must be medically qualified, and remain a current financial member of the Society at least until they have completed all requirements of the Diploma.
- 2 (S)he must supply evidence of satisfactory completion of an examined two-week full-time course in diving and hyperbaric medicine at an approved facility. The list of such approved facilities may be found on the SPUMS website.
- 3 (S)he 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 (S)he must submit a written proposal for research in a relevant area of underwater or hyperbaric medicine, in a standard format, for approval before commencing the research project.
- 5 (S)he must produce, to the satisfaction of the Academic Board, a written report on the approved research project, in the form of a scientific paper suitable for publication. Accompanying this report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–4 above.

In the absence of other documentation, it will be assumed that the paper is to be submitted for publication in *Diving and Hyperbaric Medicine*. As such, the structure of the paper needs to broadly comply with the 'Instructions to authors' available on the SPUMS website <[www.spums.org.au](http://www.spums.org.au)> or at <[www.dhmjournal.com](http://www.dhmjournal.com)>.

The paper may be submitted to journals other than *Diving and Hyperbaric Medicine*; however, even if published in another journal, the completed paper must be submitted to the Education Officer (EO) for assessment as a diploma paper. If the paper has been accepted for publication or published in another journal, then evidence of this should be provided.

The diploma paper will be assessed, and changes may be requested, before it is regarded to be of the standard required for award of the Diploma. Once completed to the reviewers' satisfaction, papers not already submitted to, or accepted by, other journals should be forwarded to the Editor of *Diving and Hyperbaric Medicine* for consideration. At this point the Diploma will be awarded, provided all other requirements are satisfied. Diploma projects submitted to *Diving and Hyperbaric Medicine* for consideration of publication will be subject to the Journal's own peer review process.

#### **Additional information – prospective approval of projects is required**

The candidate must contact the EO in writing (or email) to advise of their intended candidacy and to discuss the proposed topic of their research. A written research proposal must be submitted before commencement of the research project.

All research reports must clearly test a hypothesis. Original basic and clinical research are acceptable. Case series reports may be acceptable if thoroughly documented, subject to quantitative analysis and if the subject is extensively researched 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 the research project and the written report will be primarily the work of the candidate, and that the candidate is the first author where there are more than one.

It is expected that all research will be conducted in accordance with the joint NHMRC/AVCC statement and guidelines on research practice, available at: <[www.nhmrc.gov.au/\\_files\\_nhmrc/publications/attachments/r39.pdf](http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/r39.pdf)>, or the equivalent requirement of the country in which the research is conducted. All research involving humans, including case series, or animals must be accompanied by documentary evidence of approval by an appropriate research ethics committee. Human studies must comply with the Declaration of Helsinki (1975, revised 2013). Clinical trials commenced after 2011 must have been registered at a recognised trial registry site such as the Australia and New Zealand Clinical Trials Registry <<http://www.anzctr.org.au/>> and details of the registration provided in the accompanying letter. Studies using animals must comply with National Health and Medical Research Council Guidelines or their equivalent in the country in which the work was conducted.

The SPUMS Diploma will not be awarded until all requirements are completed. The individual components do not necessarily need to be completed in the order outlined above. However, it is mandatory that the research proposal is approved prior to commencing research.

Projects will be deemed to have lapsed if:

- the project is inactive for a period of three years, or
- the candidate fails to renew SPUMS Membership in any year after their Diploma project is registered (but not completed).

For unforeseen delays where the project will exceed three years, candidates must explain to the EO by email why they wish their diploma project to remain active, and a three-year extension may be approved. If there are extenuating circumstances why a candidate is unable to maintain financial membership, then these must be advised by email to the EO for consideration by the SPUMS Executive. If a project has lapsed, and the candidate wishes to continue with their DipDHM, then they must submit a new application as per these guidelines.

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

As of January 2016, the SPUMS Academic Board consists of:

- Dr David Wilkinson, Education Officer, Adelaide;
- Associate Professor Simon Mitchell, Auckland;
- Dr Denise Blake, Townsville.

#### **All enquiries and applications should be addressed to:**

David Wilkinson  
**Fax:** +61-(0)8-8232-4207  
**E-mail:** <[education@spums.org.au](mailto:education@spums.org.au)>

#### **Key words**

Qualifications; Underwater medicine; Hyperbaric oxygen; Research; Medical society



Capita Selecta Diving Medicine  
Academic Medical Centre,  
University of Amsterdam, The Netherlands  
**Course calendar 2016/2017**

CSD offers advanced courses (content conforms to ECHM-EDTC Level 1, 2D).

**18 March 2017:** *Non-DCI-related diving disorders* (6 cp)  
**Venue:** AMC, Amsterdam

**6–13 May 2017:** *Mini-congress Diving Medicine* (14 cp)  
**Venue:** Marsa Shagra Eco-diving village, Marsa Alam, Egypt

Detailed information and registration form will be available soon.

**For further information:** <[www.diverresearch.org](http://www.diverresearch.org)> or  
**e-mail:** <[n.a.schellart@amc.uva.nl](mailto:n.a.schellart@amc.uva.nl)>

**International Congress on Hyperbaric  
Medicine (ICHM) 2017**

**Date:** 11–14 May  
**Venue:** The Sava Centre, Belgrade, Serbia

The ICHM President, Miodrag Zaric, and the organising committee invite you to participate in the 19th ICHM, hosted by the Centre for Hyperbaric Medicine and the University of Belgrade School of Medicine. The ICHM is the only worldwide association in this field, with meetings held every third year across the globe.

The scientific programme will include invited speakers, oral and poster presentations. Key topics include discussions on research pathways in hyperbaric medicine, controversial and new/promising indications, pathogenesis of DCI, cost effectiveness and basic research. A practical, problem-orientated pre-congress workshop, as well as post-congress courses are also planned for physicians, nurses and technicians.

**Preliminary timetable:**  
10 January 2017 – deadline for submission of abstracts  
10 February 2017 – notification of accepted abstracts  
15 February 2017 – early-bird registration deadline

**Website:** <[www.ichm2017.com](http://www.ichm2017.com)>  
**E-mail:** <[office@ichm2017.com](mailto:office@ichm2017.com)> or <[chm@chm.rs](mailto:chm@chm.rs)>  
**Phone:** (+381)-(0)11-3670-158  
**Fax:** (+381)-(0)11-2650-823

**Scott Haldane Foundation**

The Scott Haldane Foundation (SHF) is celebrating its 40th anniversary. Initially serving Dutch diving medics, Scott Haldane International has now become one of the world's leading institutions in the field of Diving Medicine Education.



To recognise this, a 'celebratory' International Symposium on Diving Medicine has been organised for Saturday 21 January 2017 in Eindhoven in the southern part of the Netherlands, which has its own international airport close to the Belgian border. A panel of experts, including Alessandro Marroni, Rob Van Hulst, Wouter Sterk, Tino Ballestra and Lourens Prins will present topics related to dive safety.

**Registration is open at:** <[www.scotthaldane.org](http://www.scotthaldane.org)>.

The courses Medical Examiner of Diver (part I and II) and SHF in-depth courses, as modules of the level 2d Diving Medicine Physician course, fully comply with the ECHM/EDTC curriculum for Level 1 and 2d respectively and are accredited by the European College of Baromedicine.

**SHF courses for 2017**

**21 January:** Scott Haldane 40th Anniversary Diving Medicine Conference; Eindhoven, The Netherlands  
**11 February:** Refresher course Diving Accidents; Nijverdal, NL  
**24–25 March:** Basic course Diving Medicine (level 1 part I); Zeist, NL  
**01, 07, 08 April:** Basic Course Diving Medicine (level 1 part II), AMC Amsterdam, NL

More courses will be published soon on our website.

**For further information:** <[www.scotthaldane.nl/en/](http://www.scotthaldane.nl/en/)>

**DAN Europe**

DAN Europe has a fresh, multilingual selection of recent news, articles and events featuring DAN and its staff.

**Go to the website:** <<http://www.daneurope.org/web/guest/>>

**Undersea and Hyperbaric Medical Society  
50th Annual Scientific Meeting 2017**

**Dates:** 29 June–01 July  
**Venue:** Naples Grande Beach Resort  
Naples, Florida



**For further information:**  
<[https://www.uhms.org/index.php?option=com\\_civicrm&task=civicrm/event/info&reset=1&id=135](https://www.uhms.org/index.php?option=com_civicrm&task=civicrm/event/info&reset=1&id=135)>

## ANZ Hyperbaric Medicine Group Introductory Course in Diving and Hyperbaric Medicine

**Dates:** 20 February–03 March 2017

**Venue:** The Prince of Wales Hospital, Randwick, Sydney

**Cost:** AUD 2,400.00 (inclusive of GST)

**Course Conveners:** Associate Professor David Smart (Hobart), Dr John Orton (Townsville)

The Course content includes:

- History of diving medicine and hyperbaric oxygen treatment
- Physics and physiology of diving and compressed gases
- Presentation, diagnosis and management of diving injuries
- Assessment of fitness to dive
- Accepted indications for hyperbaric oxygen treatment
- Wound management and transcutaneous oximetry
- In water rescue and simulated management of a seriously ill diver
- Visit to HMAS Penguin
- Practical workshops
- Marine Envenomation

Approved as a CPD learning project by ANZCA: (knowledge and skills category): 56 hours for attendance at lectures and presentations for one credit per hour; 24 hours for workshops/PBLDs/small group discussions for two credits per hour

### Contact for information:

Ms Gabrielle Janik, Course Administrator

**Phone:** +61-(0)2-9382-3880

**Fax:** +61-(0)2-9382-3882

**E-mail:** <gabrielle.janik@sesiahs.health.nsw.gov.au>

## German Society for Diving and Hyperbaric Medicine

An overview of basic and refresher courses in diving and hyperbaric medicine, accredited by the German Society for Diving and Hyperbaric Medicine (GTÜeM) according to EDTC/ECHM curricula, can be found on the website: <[http://www.gtuem.org/212/Kurse/\\_Termin/Kurse.html](http://www.gtuem.org/212/Kurse/_Termin/Kurse.html)>



### DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

P O Box 347, Dingley Village  
Victoria, 3172, Australia

**E-mail:** <hdsaustraliapacific@hotmail.com.au>

**Website:**  
<[www.classicdiver.org](http://www.classicdiver.org)>

## Instructions to authors

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### For further information contact:

**E-mail:** <[folke.lind@karolinska.se](mailto:folke.lind@karolinska.se)>

**Website:** <[www.hyperbaricoxygen.se](http://www.hyperbaricoxygen.se)>

## DIVER EMERGENCY SERVICES PHONE NUMBERS

### AUSTRALIA

1800-088200 (in Australia, toll-free)  
+61-8-8212-9242 (International)

### SOUTHERN AFRICA

0800-020111 (in South Africa, toll-free)  
+27-828-106010 (International, call collect)

### NEW ZEALAND

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

### EUROPE

+39-6-4211-8685 (24-hour hotline)

### ASIA

+81-3-3812-4999 (Japan)

### UNITED KINGDOM

+44-7740-251-635

### USA

+1-919-684-9111

**The DES numbers (except UK) are generously supported by DAN**

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### DAN ASIA-PACIFIC DIVE ACCIDENT REPORTING PROJECT

This project is an ongoing investigation seeking to document all types and severities of diving-related incidents. All information is treated confidentially with regard to identifying details when utilised in reports on fatal and non-fatal cases. Such reports may be used by interested parties to increase diving safety through better awareness of critical factors.

Information may be sent (in confidence unless otherwise agreed) to:

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

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### DAN Asia-Pacific NON-FATAL DIVING INCIDENTS REPORTING (NFDIR)

NFDIR is an ongoing study of diving incidents, formerly known as the Diving Incident Monitoring Study (DIMS). 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.

**The NFDIR reporting form can be accessed on line at the DAN AP website:**  
<[www.danasiapacific.org/main/accident/nfdir.php](http://www.danasiapacific.org/main/accident/nfdir.php)>

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