Lower risk of decompression sickness after recommendation of conservative decompression practices in divers with and without vascular right-to-left shunt

Christoph Klingmann, Nils Rathmann, Daniel Hausmann, Thomas Bruckner and Rolf Kern

Abstract

(Klingmann C, Rathmann N, Hausmann D, Bruckner T, Kern R. Lower risk of decompression sickness after recommendation of conservative decompression practices in divers with and without vascular right-to-left shunt. *Diving and Hyperbaric Medicine*. 2012;42(3):146-150.)

Introduction: A vascular right-to-left shunt (r/l shunt) is a well-known risk factor for the development of decompression sickness (DCS). No studies to date have examined whether divers with a history of DCS with or without a r/l shunt have a reduced risk of suffering recurrent DCS when diving more conservative dive profiles (CDP).

Methods: Twenty-seven divers with a history of DCS recommended previously to dive more conservatively were included in this study and retrospectively interviewed by phone to determine the incidence of DCS recurrence.

Results: Twenty-seven divers performed 17,851 dives before examination in our department and 9,236 after recommendations for conservative diving. Mean follow up was 5.3 years (range 0–11 years). Thirty-eight events of DCS occurred in total, 34 before and four after recommendation of CDP. Four divers had a closure of their patent foramen ovale (PFO). A highly significant reduction of DCS risk was observed after recommendation of CDP for the whole group as well as for the sub-groups with or without a r/l shunt. A significant reduction of DCS risk in respect to r/l shunt size was also observed.

Discussion: This study indicates that recommendations to reduce nitrogen load after DCS appear to reduce the risk of developing subsequent DCS. This finding is independent of whether the divers have a r/l shunt or of shunt size. The risk of suffering recurrent DCS after recommendation for CDP is less than or equal to an unselected cohort of divers.

Conclusion: Recommendation for CDP seems to significantly reduce the risk of recurrent DCS.

Key words

Decompression sickness, decompression illness, patent foramen ovale (PFO), risk, risk management

Introduction

A right-to-left shunt (r/l shunt), caused predominantly by a patent foramen ovale (PFO), is a well-known risk factor for the development of decompression sickness (DCS). First described more than two decades ago, many studies have been published subsequently confirming an increased risk of DCS for divers who have a r/l shunt.[1–9] A 1998 meta-analysis calculated that the risk of developing severe DCS in the presence of a PFO increased by a factor of 2.52 and for any DCS by a factor of 1.93.[10] The risk of a major episode of DCS is directly related to the size of the septal defect.[9]

The presence of a PFO has been accepted as a risk factor for the occurrence of stroke and transient ischaemic attacks (TIA) in young patients, particularly if associated with an atrial septal aneurysm.[11] PFO closure is increasingly performed for the prevention of recurrent stroke or TIA as well as for the prevention of recurrent DCS in divers' on an individual basis.[12–18] However, a recent randomised controlled trial failed to show superiority of PFO closure over best medical treatment for preventing recurrent stroke or TIA.[19] On the other hand, a Swiss working group has recently published good evidence that PFO closure significantly reduces the risk of developing DCS, even though one diver with PFO closure still suffered neurologic DCS.[20] However, there are no consensus guidelines to support this indication in divers.[3]

To our knowledge, no studies have evaluated the influence of reduced inert gas load during diving in divers with or without a r/l shunt and with a history of DCS. For this reason we performed follow up on divers examined in our department for the presence of a r/l shunt with a history of DCS to assess their risk of recurrent DCS after we had provided advice and education on how to reduce nitrogen load when diving.

Methods

The Ethics Committee at Ruprecht-Karls University in Heidelberg, Germany approved this study (Project Number S-030/2008) and all participants gave their written consent. Forty-nine divers with a history of physician-confirmed DCS from previous studies and from our diving medical clinic were contacted.[7,21–23] Having received written consent, a structured telephone interview was conducted using a purpose-designed questionnaire which included health and general diving-related questions and specific questions about history of DCS, recurrent DCS, and whether PFO closure was performed.* DCS was classified as being either 'minor' or 'major'. Minor DCS symptoms included 'bends', cutaneous lymphoedema and cutaneous erythema with or without extreme fatigue, headache and nonspecific

* The questionnaire may be obtained from the authors: <info@tauchersprechstunde.de>

dizziness. Major DCS events were defined by one or more of the following symptoms: severe vertigo; limb weakness; cutaneous sensory level; impaired bowel or bladder control; paresis or paraplegia; blurred vision; dysarthria; amnesia for the event, hemiplegia or loss of consciousness after a dive. To reduce the risk of false-positive diagnosis of DCS, symptoms must have persisted for at least 30 minutes and have occurred within 24 hours of the dive. Number of logged dives, symptoms of DCS, number of DCS events and PFO status (i.e., closure procedure) were recorded.

All divers had received either a transcranial or carotid Doppler sonography to screen for a vascular right-to-left shunt (r/l shunt), either as a participant of one of our previous studies or as a patient in our clinic. A r/l shunt was diagnosed as small when five or more air microbubble signals occurred in the Doppler spectra of either middle cerebral artery or carotid artery after the Valsalva manoeuvre. The r/l shunt was classified as large if more than 20 signals were detected, in accordance with our previously published classification system.[7,24] After confirmation of DCS and confirmation of PFO status, all divers were educated to perform any future diving using 'conservative' dive profiles (CDP). At the time of examination of the divers who took part in our earlier studies, there had not been a formal recommendation for divers to practice CDP, as exists today.[25,26]

Recommendations for CDP included: use of nitrox, but with decompression times calculated on air tables; no dives deeper than 25 metres' sea water (msw); no repetitive dives; minimising Valsalva manoeuvres, no decompression dives and a 5-minute safety stop at 3 msw. These recommendations were not obligatory and divers were free to choose their individual nitrogen-reducing methods. Even though we recommended all divers with a history of DCS at the time of presentation to dive conservatively in the future, we cannot be sure whether the divers adopted this advice or not.

STATISTICS

The 'risk of DCS' was calculated by division of DCS events by the number of logged dives multiplied by a factor of 10,000 for easier presentation of the otherwise very small values. Statistical analysis was performed with SAS Version 9.1® (Cary, USA). A Wilcoxon signed-rank test was performed for the comparison of the median of two related samples (risk of DCS before and after recommendation for CDP). The significance level was defined as $P \leq 0.05$ and highly significant when P was ≤ 0.01. The absolute risk for DCS before and after recommendation for CDP was compared using confidence intervals. Risk of DCS per diver before and after recommendation for CDP was compared using a McNemar test. Box-and-whiskers plots were generated for graphical presentation of the results of both groups according to the definition of Tukey: the box represents the upper and lower quartile, the centre line represents the median and the vertical lines represent the whiskers.[27]

Results

Of 49 divers who were examined after DCS for presence of a r/l shunt and whom we tried to contact, 32 divers (65%) gave their written consent to take part in this study. Telephone interview revealed that five divers had stopped diving after their examination in our institution, leaving 27 divers in this survey. Twenty male divers and seven female divers with an average age of 47 years (range 31–65 years) performed in total 27,087 dives, 17,851 before examination in our department (median 400, range 60–2,600), and 9,236 after recommendation for CDP (median 200, range 60–2,400) respectively. Time between examination in Heidelberg and the telephone interview varied between 0 and 11 years (mean 5.3 years). Thirty-eight incidents of DCS occurred in total, 34 before recommendation for CDP and four in three divers after recommendation for CDP. Twenty major and seven minor DCS events occurred in the first group and three major DCS events in the second group. After receiving a recommendation to dive using CDP, 17 divers used enriched air nitrox as a breathing gas, three divers used trimix and seven divers used air as their breathing gas.

R/L SHUNT

On examination, nine of the 27 divers had no demonstrable shunt, nine had a small and nine a large r/l shunt.

After examination in our department and before telephone interview, four divers, two with a small and two with a large shunt, had undergone closure of their PFO. Three divers had PFO closure immediately after examination in our institute and one diver had PFO closure after she had two episodes of neurological DCS. After PFO closure, no further DCS events occurred in any of the four divers. Owing to the small sample size no statistical analyses were performed on this group. Further, all four divers who had PFO closure were excluded from statistical evaluation of DCS risk before and after recommendation for CDP as, after PFO closure, they no longer met the inclusion criteria for a r/l shunt.

DCS RISK BEFORE AND AFTER RECOMMENDATION FOR CDP

The absolute risk of suffering DCS before examination in our department for the remaining 23 divers was 0.002 or 20/10,000 (events of DCS / dive). After examination in our department and recommendation for CDP the absolute risk of suffering DCS was 0.0003 or 3/10,000 (events of DCS/ dive). The absolute risk difference for DCS before and after examination was 0.0017 or 17/10,000 (95% confidence intervals, 0.0009 to 0.0025). As the confidence interval does not include zero the risk reduction is significant with a relative risk reduction of 85%.

It is also appropriate to consider the risk per diver of suffering DCS. Before examination in our department, 23 divers had one or more DCS events. After recommendation for

Figure 1
Box plots of DCS risk before and after advice on reducing nitrogen loading during diving with respect to the presence or absence of a patent foramen ovale; DCS risk – DCS events per 10,000 dives multiplied by 10,000

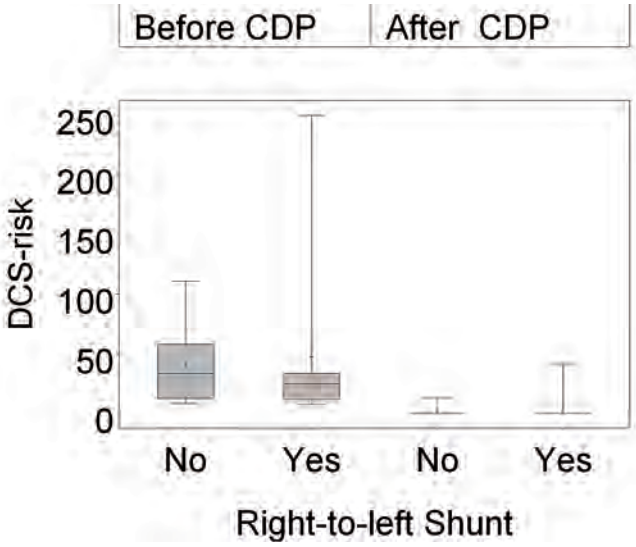
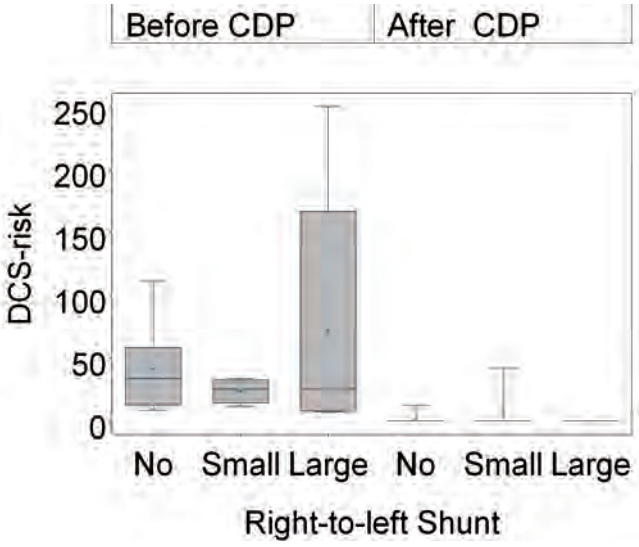


Figure 2
Box plots of DCS risk before and after advice on reducing nitrogen loading during diving with respect to right-to-left shunt size; DCS risk – DCS per 10,000 dives multiplied by 10,000



CDP, only two divers suffered one episode of DCS. Using the McNemar test, this difference is highly statistically significant ($P < 0.001$).

R/L SHUNT

Of the 23 divers who did not have a PFO closure, fourteen divers had a r/l shunt (seven small and seven large r/l shunts) and nine divers had no shunt. The mean DCS risk (multiplied by a factor of 10,000) for divers without a shunt was 41.3 (range 8.0–111) compared to 47.6 (range 7.4–250) for divers with a shunt. After the recommendation of CDP the risk lowered to 1.4 (range 0–12.5) for divers without a shunt and 3.0 (range 0–41.7) for divers with a shunt. This difference was highly significant in both groups ($P = 0.008$ and $P < 0.001$ respectively (Figure 1).

R/L SHUNT SIZE

The mean DCS risk for divers without a shunt was 41.3 (range 8.0 to 111) compared to 23.5 (range 11.8–33.3) for divers with a small shunt and 71.6 (range 7.4–250) for divers with a large shunt. After recommendation of CDP the risk reduced to 1.4 (range 0–12.5) in divers without a shunt, 6.0 (range 0–41.7) in divers with a small shunt and zero in divers with a large shunt. The DCS risk decreased in a highly significant manner after recommendation of CDP in divers with no shunt ($P = 0.008$) and significantly in divers with small or large r/l shunt ($P = 0.031$ and $P = 0.016$ respectively, Figure 2).

Discussion

Although many institutions recommend reduction of nitrogen load or decompression stress to prevent recurrent DCS it is surprising that no studies have been performed to substantiate the success of these recommendations.[25,26] The same applies for recommendations for divers with a r/l shunt. In the 1990s, when a r/l shunt was identified to be a risk factor for DCS, many diving medical specialists promoted a routine examination of divers in order to exclude a shunt. As a result of further studies, it became clear that even though the risk for DCS is increased with a r/l shunt, it remains quite small and the recommendations to screen for a r/l shunt have vanished.[10]

When DCS has occurred, especially after so called 'undeserved' cases of DCS, divers are encouraged to seek screening for a shunt. If a shunt is revealed in a diver who had 'undeserved' neurological DCS, some diving medical societies classify these divers as ineligible to scuba dive.[26] There are also several diving medical specialists who recommend divers with a history of DCS and a positive r/l shunt to undergo closure if it turns out to be a PFO, even though there is no clear evidence to indicate that this intervention reduces the risk of DCS or neurologic events.[16–19]

However, in a 2011 study of 83 scuba divers with a history of DCS and a follow up of 5.3 years, 28 divers had no PFO, 25 had a PFO closure and 30 continued diving with a PFO without closure.[20] At the beginning of the study there were no significant differences between the groups in the number of dives, dive profiles, diving depth or cumulative dives to more than 40 msw. After follow up, whilst there were no differences between the groups in respect to minor DCS events, the risk for major DCS was significantly higher in the divers with PFO and no closure than in divers with PFO

closure or divers without PFO. Although this offers new evidence that PFO closure reduces the risk for major DCS, the authors do not recommend closure in all divers with a history of DCS but rather recommend further studies to confirm these results.

In our study, only four divers underwent PFO closure and these remained free of DCS events thereafter in 1,436 dives. The group size and number of logged dives are insufficient to draw any conclusions about this intervention. In the 14 divers with a PFO but no closure, advice on reducing nitrogen loading simply resulted in an significant absolute risk reduction in DCS incidents. A similar, highly significant reduction in risk was also seen in the nine divers without a shunt. Even when the data were stratified by shunt size, and despite smaller group sizes, the differences remained significant. These data strongly suggest that recommendations for CDP, or possibly simply having had a previous DCS event, results in highly reduced risks of suffering recurrent DCS. Interestingly, the DCS risk after recommendation for CDP in both divers with or without a PFO was less than or equal to the risk of unselected cohorts of divers.[28,29] This outcome requires further study.

Our study has several limitations. Firstly, this is a small retrospective study of divers who were recruited from previous studies conducted at various times. The response rate (32 of 49) from divers whom we attempted to contact was satisfactory, given the extensive time period covered, and only five of these divers had ceased diving. Secondly, although the diagnosis of DCS was confirmed by a diving medical specialist, the divers were not examined by us at the time of their acute presentation with DCS and reporting bias is possible. Thirdly, examination for a r/l shunt was performed by more than one examiner and two techniques were used. Therefore, it is possible that the prevalence of r/l shunt may differ between groups as well as the r/l shunt size. Fourthly, there was no control group that continued to dive without any recommendations to change their diving habits. Finally, it is not possible to be certain that the divers from this study applied CDP.

Whether the risk reduction was as a result of our recommendation or the divers changed their diving habits independently of our recommendations after their first incident of DCS, it remains compelling that there are impressive risk reductions for DCS following the initial incident and counselling. A causal relationship has not been established in this study in the absence of a control group that continued diving without changed diving habits. Despite the limitations of our study, we would encourage hyperbaric units that treat diving accidents on a regular basis to commence a prospective study to address this issue. Given the large risk differences we observed, the study groups could be relatively small and it should be feasible to perform a controlled randomised study, with results from our study being used to inform the relevant power calculation.

Conclusion

We observed a highly significant reduction of DCS risk after providing divers with recommendations for conservative dive profiles (CDP), whether or not they had a r/l shunt. After recommendations for CDP, the risk of suffering recurrence of DCS was smaller than or equal to that of an unselected cohort of divers. Nevertheless, because of the heterogeneity of our small study population we cannot make general recommendations. A prospective, randomised study is needed to confirm our preliminary observations and to provide further information towards the reduction of risk for recurrent DCS.

References

1 Moon RE, Camporesi EM, Kisslo JA. Patent foramen ovale and decompression sickness in divers. *Lancet*. 1989;1:513-4.
2 Wilmshurst P. Right-to-left shunt and neurological decompression sickness in divers. *Lancet*. 1990;336:1071-2.
3 Germonpre P. Patent foramen ovale and diving. *Cardiol Clin*. 2005;23:97-104.
4 Germonpre P, Dendale P, Unger P, Balestra C. Patent foramen ovale and decompression sickness in sports divers. *J Appl Physiol*. 1998;84:1622-6.
5 Kerut EK, Norfleet WT, Plotnick GD, Giles TD. Patent foramen ovale: a review of associated conditions and the impact of physiological size. *J Am Coll Cardiol*. 2001;38:613-23.
6 Saary MJ, Gray GW. A review of the relationship between patent foramen ovale and type II decompression sickness. *Aviat Space Environ Med*. 2001;72:1113-20.
7 Klingmann C, Benton PJ, Ringleb PA, Knauth M. Embolic inner ear decompression illness: correlation with a right-to-left shunt. *Laryngoscope*. 2003;113:1356-61.
8 Cantais E, Louge P, Suppini A, Foster PP, Palmier B. Right-to-left shunt and risk of decompression illness with cochleovestibular and cerebral symptoms in divers: case control study in 101 consecutive dive accidents. *Crit Care Med*. 2003;31:84-8.
9 Torti SR, Billinger M, Schwerzmann M, Vogel R, Zbinden R, Windecker S, et al. Risk of decompression illness among 230 divers in relation to the presence and size of patent foramen ovale. *Eur Heart J*. 2004;25:1014-20.
10 Bove AA. Risk of decompression sickness with patent foramen ovale. *Undersea Hyperb Med*. 1998;25:175-8.
11 Mas JL, Arquizan C, Lamy C, Zuber M, Cabanes L, Derumeaux G, et al. Recurrent cerebrovascular events associated with patent foramen ovale, atrial septal aneurysm, or both. *N Engl J Med*. 2001;345:1740-6.
12 Bridges ND, Hellenbrand W, Latson L, Filiano J, Newburger JW, Lock JE. Transcatheter closure of patent foramen ovale after presumed paradoxical embolism. *Circulation*. 1992;86:1902-8.
13 Hung J, Landzberg MJ, Jenkins KJ, King ME, Lock JE, Palacios IF, et al. Closure of patent foramen ovale for paradoxical emboli: intermediate-term risk of recurrent neurological events following transcatheter device placement. *J Am Coll Cardiol*. 2000;35:1311-6.
14 Wahl A, Meier B, Haxel B, Nedeltchev K, Arnold M, Eicher E, et al. Prognosis after percutaneous closure of patent foramen

ovale for paradoxical embolism. *Neurology*. 2001;57:1330-2.
15 Martin F, Sanchez PL, Doherty E, Colon-Hernandez PJ, Delgado G, Inglessis I, et al. Percutaneous transcatheter closure of patent foramen ovale in patients with paradoxical embolism. *Circulation*. 2002;106:1121-6.
16 Scott P, Wilson N, Veldtman G. Fracture of a GORE HELEX septal occluder following PFO closure in a diver. *Catheter Cardiovasc Interv*. 2009;73:828-31.
17 Wahl A, Praz F, Stinimann J, Windecker S, Seiler C, Nedeltchev K, et al. Safety and feasibility of percutaneous closure of patent foramen ovale without intra-procedural echocardiography in 825 patients. *Swiss Med Wkly*. 2008;138:567-72.
18 Saguner AM, Wahl A, Praz F, de Marchi SF, Mattle HP, Cook S, et al. Figulla PFO occluder versus Amplatzer PFO occluder for percutaneous closure of patent foramen ovale. *Catheter Cardiovasc Interv*. 2011;77:709-14.
19 Furlan AJ, Reisman M, Massaro J, Mauri L, Adams H, Albers GW, et al. Closure or medical therapy for cryptogenic stroke with patent foramen ovale. *N Engl J Med*. 2012;366:991-9.
20 Billinger M, Zbinden R, Mordasini R, Windecker S, Schwerzmann M, Meier B, et al. Patent foramen ovale closure in recreational divers: effect on decompression illness and ischaemic brain lesions during long-term follow-up. *Heart*. 2011;97:1932-7.
21 Klingmann C, Knauth M, Ries S, Tasman AJ. Hearing threshold in sport divers: is diving really a hazard for inner ear function? *Arch Otolaryngol Head Neck Surg*. 2004;130:221-5.
22 Klingmann C, Praetorius M, Baumann I, Plinkert PK. Barotrauma and decompression illness of the inner ear: 46 cases during treatment and follow-up. *Otol Neurotol*. 2007;28:447-54.
23 Klingmann C, Praetorius M, Baumann I, Plinkert PK. Otorhinolaryngologic disorders and diving accidents: an analysis of 306 divers. *Eur Arch Otorhinolaryngol*. 2007;264:1243-51.
24 Ries S, Knauth M, Kern R, Klingmann C, Daffertshofer M, Sartor K, et al. Arterial gas embolism after decompression: correlation with right-to-left shunting. *Neurology*. 1999;52:401-4.
25 [Tetzlaff K, Klingmann C, Muth CM, Piepho T, Welslau W. *Checkliste Tauchtauglichkeit*. Stuttgart: Gentner-Verlag; 2009.] (German)
26 [Swiss Underwater and Hyperbaric Medical Society. Empfehlungen 2007. *Der Schweizerischen Gesellschaft Für Unterwasser- und Hyperbarmedizin Zum Tauchen Mit Einem Offenen Foramen Ovale*] [cited 2012 June 11]. Available from: <http://www.suhms.org/downloads/SUHMS%20PFO%20Flyer%20d.pdf>. (German)
27 Tukey JW. Box-and-Whisker Plots. In: Tukey JW, editor. *Exporative Data Analysis*. London: Addisson-Wesley, Reading Menlo Park; 1977. p. 39-43.
28 Vann RD, Freiberger JJ, Caruso JL, Denaoble PJ, Pollock NW, Uguccioni DM, et al. *Annual Diving Report 2006 edition*. Durham NC: Divers Alert Network; 2006. [cited 2012 June 11]. Available from: <http://www.diversalertnetwork.org/medical/report/2006DANDivingReport.pdf>.
29 Klingmann C, Gonnermann A, Dreyhaupt J, Vent J, Praetorius M, Plinkert PK. Decompression illness reported in a survey of 429 recreational divers. *Aviat Space Environ Med*. 2008;79:123-8.

Acknowledgements

We thank Gary Smerdon, DDRC, Plymouth, UK for assistance with preparing the manuscript and helping us with the language. The results of this study were presented at the 2nd tri-national scientific meeting of the Austrian (ÖGTH), German (GTÜM) and Swiss (SUHMS) diving medical societies in Regensburg, March 2011.

Submitted: 31 July 2011
Accepted: 17 June 2012

Christoph Klingmann[1], Nils Rathmann[2], Daniel Hausmann[2], Thomas Bruckner[3], Rolf Kern[4]

[1] HNO-Praxis am Odeonsplatz, Brienner Strasse 13, 80333 München, Germany.
[2] Department of Clinical Radiology and Nuclear Medicine, Faculty of Medicine Mannheim, University of Heidelberg, Germany.
[3] Institute for Medical Biometrics and Informatics, University of Heidelberg, Germany.
[4] Department of Neurology, Faculty of Medicine Mannheim, University of Heidelberg, Germany.

Address for correspondence:
Priv Doz Dr med Christoph Klingmann
HNO-Praxis am Odeonsplatz
Brienner Strasse 13
80333 München
Germany
Phone: *+49 (0)89-290-4585*
Fax: *+49 (0)89-290-4584*
E-mail: *<info@tauchersprechstunde.de>*

Provisional report on diving-related fatalities in Australian waters 2007

John Lippmann, Douglas Walker, Christopher L Lawrence, Andrew Fock, Thomas Wodak and Scott Jamieson

Abstract

(Lippmann J, Walker D, Lawrence CL, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2007. *Diving and Hyperbaric Medicine*. 2012;42(3):151-170.)

Introduction: An individual case review of diving-related deaths reported as occurring in Australia in 2007 was conducted as part of the on-going Divers Alert Network (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 details from the post-mortem examination, where available, are provided.

Results: In total, there were 19 reported fatalities, comprising three females and 16 males. Nine of the deaths occurred while snorkelling and/or breath-hold diving, eight while open-circuit scuba diving, one while using a closed-circuit rebreather, and one while using surface-supply breathing apparatus. Cardiac-related issues were thought to have contributed to the deaths of at least three but possibly up to six snorkel divers and possibly two scuba divers. One diver is believed to have died as a result of immersion pulmonary oedema of diving. Six of the compressed-gas divers were very inexperienced, three being certified within 14 days prior and dying while under the guidance of an instructor.

Conclusions: Inexperience, pre-existing medical conditions and buoyancy issues were highlighted in several deaths in this series.

Key words

Diving deaths, scuba, breath-hold diving, surface-supply breathing apparatus (SSBA), closed-circuit rebreather, diving accidents, case reports

Introduction

Although some diving-related fatalities are almost certainly unavoidable, many deaths might have been avoided through better education, greater experience, good medical screening and advice, better equipment choice or design and common sense. The aim of the Divers Alert Network (DAN) Dive Fatality Reporting Project (incorporating Project Stickybeak) is to educate divers and the diving industry and to inform diving physicians on the causes of fatal dive accidents in the hope of reducing the incidence of similar accidents 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 2007 that are recorded on the DAN Asia-Pacific (AP) database. When a fatal accident is unwitnessed, it is often difficult to determine exactly what has occurred. In such cases, 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 and Government of Victoria, Australia to access and report on data included in the Australian National Coronial Information System (NCIS). The methodology used for this report is identical to that described previously for the 2004 Australian diving-related fatalities.[1]

Snorkelling and breath-hold fatalities

BH 07/01

This 39-year-old, overseas male tourist was in a group tour of the Great Barrier Reef (GBR). He had no history of medical problems, was not taking any medications and was believed to be healthy and a reasonable swimmer. He had not snorkelled before, and during the trip to the reef the group was given a talk on snorkelling, followed by a DVD presentation. Although he apparently spoke some English, the victim appeared not to pay attention. There was also a brochure available in the victim's native language.

The victim was provided with a Lycra suit, mask, snorkel and fins, and offered a life jacket to wear, which he accepted. However, he had difficulty getting into the life jacket as it appeared to be too small, so the tour guide/snorkel instructor helped him to zip up the jacket – the victim needed to exhale in order to do so. The weather was reported to be fine and the water relatively calm. After a short swim in the shallow water, during which the group appeared to manage well, they were allowed to join others in the patrolled swimming area with deeper water, overseen by a lifeguard. There were reported to be about 70 swimmers in the area under the watch of a single lifeguard.

Table 1
Summary of snorkelling and breath-hold diving-related
BMI – body mass index; BNS – buddy not separated; BSB – buddy separated before problem;

ID	Age	Gender	Height (cm)	Weight (kg)	BMI (kg m^{-2})	Training	Experience	Dive group
BH 07/01	39	M	182	96	29.0	nil	nil	GSB
BH 07/02	15	M	173	95	31.7	nil	some	BSD
BH 07/03	33	M	174	142	46.9	n/s	n/s	BSB
BH 07/04	44	M	170	87	30.1	n/s	some	GSB
BH 07/05	51	M	169	81	28.4	nil	nil	GSB
BH 07/06	37	M	178	60	18.9	nil	nil	solo
BH 07/07	63	M	166	68	24.7	nil	some	BSB
BH 07/08	70	F	150	56	24.9	n/s	n/s	GSB
BH 07/09	38	M	180	87	26.9	n/s	n/s	BNS

After an estimated five minutes since the group entered the area, the lifeguard noticed the victim floating face-down and motionless approximately 30 metres from shore and away from the other swimmers and being carried out with the current. When he paddled to him on his rescue board, he found the victim to be unconscious and apnoeic, still wearing snorkelling equipment and floating face-down supported by the life jacket. The lifeguard delivered two rescue breaths before dragging the victim to shore where he again gave some rescue breaths. Basic life support (BLS) was commenced with ventilations delivered using a bag-valve-mask. An automated external defibrillator (AED) was attached but no shock was advised, indicating that the victim was likely to have been in asystole. Advanced life support (ALS) was later implemented by a helicopter rescue paramedic but the victim failed to respond and was pronounced dead at the site.

Autopsy: The body had early decompositional changes. The victim was obese (body mass index (BMI) 29 kg m^{-2}). The right and left lungs weighed 705 g and 702 g respectively and were described as congested. The heart weighed 436 g and was described as normal. The report is light on detail – there is no description of pulmonary oedema nor whether the lungs appeared over-expanded and histology was obscured by autolysis. Toxicology revealed a blood alcohol of 0.72 g L^{-1}. The cause of death was given as drowning. The elevation of blood alcohol was believed to have contributed to the drowning.

Comments: Given this was an unwitnessed and apparently silent death the exact mechanism of the accident is unknown. However, it appears that the victim's life jacket was far too small for him and this, combined with his obesity, would have restricted his chest compliance and breathing and hampered his ability to snorkel safely. It would certainly have been more difficult for him to clear the snorkel if he was unable to take a deep breath. The blood alcohol level detected would have been consistent with impaired judgment and may have slowed his response to inhalation of water.

Others in the group later complained that their instruction and supervision was inadequate, and this could well have been the case as the supervisor had several distractions. The victim's apparent lack of attention to the initial briefing could have been, among other things, an indication of poor comprehension. Although it is appreciated that other supervisors were in the vicinity, the ratio of one lifeguard to directly oversee around 70 snorkellers seems inadequate. Although the life jacket provided buoyancy, it failed to support the unconscious victim with his face out of the water. This is an important function of a life jacket (and arguably of a scuba diver's buoyancy compensator, BCD).

Summary: Apparently healthy overseas tourist; reasonable swimmer; first use of snorkel; constrictive life jacket; water too deep to stand; blood alcohol level 0.72 g L^{-1}; among large crowd in supervised swimming area; drowning

BH 07/02

This obese but otherwise healthy, 15-year-old male was spearfishing for octopus with two friends as they had done on many previous occasions. After about two hours, one swam back to shore with some of their equipment while the other two continued to snorkel 30 to 50 metres from the shore. The

Table 1 (cont)
fatalities in Australian waters in 2007
BSD – buddy separated during problem; GSB – group separated before; n/s – not stated

Dive purpose	Depth (msw)	Incident (msw)	Weight belt	Weights (kg)	BCD	Disabling injury
recreation	n/s	surface	n/s	n/s	worn	asphyxia
spearfishing	4	n/s	n/s	n/s	n/s	asphyxia
spearfishing	n/s	surface	n/s	n/s	n/s	cardiac
recreation	n/s	surface	n/s	n/s	n/s	asphyxia?cardiac?
recreation	n/s	surface	n/s	n/s	nil	cardiac
recreation	n/s	surface	n/s	n/s	n/s	asphyxia
recreation	n/s	n/s	n/s	n/s	n/s	asphyxia?cardiac?
recreation	n/s	surface	n/s	n/s	n/s	ashpyxia?cardiac?
recreation	n/s	surface	n/s	n/s	n/s	cardiac

victim fired his spear at an octopus and found the spear had become embedded under a rock and would not come free. He then used the thin line attached to the spear to get extra leverage by wrapping it round his right hand. His buddy saw him struggling under the water, kicking his legs. Neither the victim nor buddy in the water had a knife with them as the only knife the group had was with the third diver who had returned to shore. The buddy attempted without success to release the line and pull the spear free, then called for help to people on the beach, swimming closer to shore in order to be able to guide them. It took them a short time to find the victim, who was about two metres underwater. They cut him free from the line which had entangled him and took him ashore where ambulance officers provided ALS, without success. He had been submerged for approximately 10–15 minutes.

Autopsy: There were bruises and abrasions on the right hand and fourth and fifth fingers consistent with entanglement with the spear-gun line. The right and left lungs weighed 605 g and 740 g respectively and were partially collapsed. There was frothy fluid and diluted blood in the trachea and bronchi, and pulmonary oedema and congestion in the lungs. The findings were consistent with drowning, modified by extensive resuscitation efforts (collapse, not overexpansion). The cause of death was given as drowning due to entanglement by speargun line while snorkelling.

Comments: This tragic accident indicates the potential dangers of entanglement when snorkelling or diving and the importance of having a knife readily available. The buddy tried valiantly to free his friend but was unable to because he had no knife to cut the line.

Summary: Healthy teenager; spearfishing for octopus; spear fouled, so wrapped line around hand to free it and became entangled; buddy unable to release him as no knife available; drowning

BH 07/03

This 33-year-old, morbidly obese male had suffered a mild CVA eight years earlier, although there were no further details of his medical history other than that he had suffered from a dry cough for several weeks before the incident. He was not currently taking any medications and had appeared to be well and in good spirits. His previous snorkelling experience was not reported. He was with a group of relatives on an unpatrolled beach of a small bay. Shortly after lunch, he and two others decided to go snorkelling to spearfish and entered the water from a rock ledge. The victim was dressed in board shorts and was carrying a speargun and wearing mask, snorkel and fins. There was a moderate swell.

After a very short time his companions heard some yelling and saw their friend standing in the water, supported by two men. He looked unwell and was heard to say "*my time is up*" shortly before he became cyanotic and collapsed. He was brought to shore where BLS was commenced by one of his rescuers. The victim regurgitated some stomach contents, including his recent lunch. The ambulance arrived a few minutes later and found the victim to be apnoeic and pulseless. A defibrillator was attached and indicated that he was in asystole. ALS was implemented but was unsuccessful.

Autopsy: The pathologist described him as obese (BMI 46.9). The heart weighed 410 g with left ventricular hypertrophy of

16 mm (normal < 15 mm). The coronary circulation showed left dominance with a small right coronary artery, greater than 80% luminal narrowing of left main coronary artery and up to 70% narrowing of the left circumflex coronary artery. The aorta showed patchy atheromatous changes. The histology of the heart muscle showed equivocal early ischaemic changes but no old scarring. The lungs weighed 330 g and 390 g respectively, and were described as congested and a little heavy. There was a little frothy fluid in the trachea. The cause of death was given as cardiac arrhythmia due to ischaemic heart disease. Other contributing factors included terminal drowning and obesity.

Comments: The victim was at a high risk of cardiac-related death whether or not he went snorkelling. However, the combination of the exercise of swimming soon after having eaten appears to have triggered a cardiac event. Compared to the previous cases reviewed in this paper, the lungs are not particularly heavy and it is likely that heart disease is more significant than the drowning.

Summary: Previous CVA; morbidly obese; unknown snorkelling experience; separated from buddies; distress soon after entering water; severe cardiovascular disease; cardiac arrhythmia

BH 07/04

This 44-year-old, male tourist was with three friends on a charter boat on the GBR. His medical history was unknown but he stated that he was a strong swimmer and had some previous snorkelling experience. He appeared to be healthy and reported that he had no medical problems.

About 20–25 minutes after breakfast, which included a shot of 'jagermeister' (an alcoholic beverage), the victim took a ginger-based seasickness tablet (Travelcalm®), and with two friends and a snorkel supervisor donned mask, snorkel and fins and entered the water. The depth was about 4 msw, the sea had a small surface chop and there was negligible current. The group was snorkelling approximately 30 m from the boat when the skipper entered the water shortly afterwards to join the group. One of the tourists remained on board as a surface watch. The victim was then seen to be snorkelling back towards the boat, occasionally lifting his head to see where the boat was. He did not appear to be distressed. However, when he tried to board the boat he fell back into the water and the friend on board held out a fishing rod for him to hold onto, which he initially did. The skipper observed this and quickly swam to the victim but found him face-down in the water, unconscious and cyanotic.

When he was brought aboard, the victim was apnoeic. When the skipper rolled him into the recovery position, some stomach contents were drained, together with a small amount of water. The skipper then began BLS, assisted by the victim's friend, while alerting the others. BLS was continued for 10–15 minutes until staff from a nearby dive vessel arrived with oxygen equipment and an AED. The latter was attached and reported that no shock was advised. BLS was continued without response for another 17 minutes until a doctor advised by telephone that it be ceased.

Autopsy: The autopsy revealed bilateral aspiration pneumonitis with gastric contents in the upper airways and lungs which showed an early neutrophil reaction (suggesting that the aspiration occurred sufficiently long before death for the body to mount a vital reaction). The right and left lungs weighed 522 g and 533 g respectively. The heart weighed 352 g (normal) with coronary arteries showing less than 20% narrowing by atherosclerosis. The liver weighed 1,917 g and showed fatty changes. Toxicology returned a negative reading for alcohol. It was suggested that the victim possibly aspirated water through his snorkel and this could have resulted in arrhythmia. The cause of death was given as aspiration pneumonitis with fatty liver as a contributing factor.

Comments: Drowning should be considered as a possible alternative cause of death. Aspiration pneumonitis with a vital reaction is most uncommon where a diver has died at the scene although aspiration during resuscitation efforts is relatively common. A vital reaction usually takes minutes to hours to develop. What caused the aspiration in this case is unclear. Heavy recent alcohol consumption is associated both with fatty liver and paroxysmal arrhythmias (so-called 'holiday heart'). The latter are usually atrial in origin, although sometimes ventricular and associated with increased dispersion of QT intervals.[2] However, in this case, toxicology for alcohol was negative despite the recent reported consumption, although the presence of a fatty liver may well be a marker of long-term high alcohol consumption. It would seem unlikely that the victim could have suffered a significant aspiration prior to becoming unconscious but not appeared distressed before attempting to board the boat. Therefore, this would appear to support the hypothesis of aspiration-induced arrhythmia as the most likely primary event.

Summary: Apparently healthy; strong swimmer; no prior signs of distress; collapsed when trying to board boat; minimal cardiovascular disease; arrhythmia?, drowning?

BH 07/05

This 51-year-old, overseas, male tourist was an experienced swimmer but had never snorkelled before. He was described by his wife as fit and active, exercised daily and had seen his doctor recently. He had a history of oral cancer 3–4 years prior, gout, hypertension, and hyperlipidaemia. He was taking lisinopril 10 mg, allopurinol 100 mg, and simvastatin 40 mg daily. On the night before the accident, he had consumed a number of alcoholic drinks including a bottle of wine, two vodkas and a Cointreau.

The victim was on a day trip to the GBR on a large vessel. During the outward trip passengers were given a talk on snorkelling and its potential risks, told there would be some current at their destination, and offered floatation aids. The site was a moored pontoon with a roped area which was under constant watch. Because of the current, it was decided to have a tender outside the roped area to ensure rapid response to any problems. This was in addition to the lookout on the pontoon. The sea was described as calm and clear but there was a current moving away from the pontoon.

The victim donned a Lycra suit, mask, snorkel and fins and entered the water with a fellow passenger but then swam away from him. After about 30 minutes, the lifeguard in the tender watching the crowd of snorkellers from outside the roped area initially saw the victim about 10 metres away swimming easily in the direction of the current before changing direction back towards the pontoon. After he had swum about six strokes, later described as wild and ineffective, the victim saw the tender and raised a hand as if requesting assistance. When the tender reached him, he was asked to hold onto it. His head then tilted to one side and he became unconscious. The tender driver grabbed the victim's arm but was unable to pull him into the tender until he was assisted by several of the snorkellers. The victim was rapidly brought back to the pontoon where he was apnoeic and pulseless, so BLS was commenced. Supplemental oxygen (O_2) was provided, and when an AED was attached, four shocks were advised and given as ventricular fibrillation was detected. After consulting the Royal Flying Doctor Service, the trained crew, assisted by a passenger who was a nurse, administered four 1 mg ampoules of adrenaline down an oropharyngeal airway after attempts to establish an intravenous line were unsuccessful. Resuscitation was discontinued after 65 minutes, on radio advice by a doctor.

Autopsy: The autopsy revealed an overweight man (BMI 28.4) with extensive rib fractures and a perforation of the right ventricle, the result of resuscitation attempts. The heart weighed 390 g and showed 90% stenosis of the right and left coronary arteries and patchy interstitial fibrosis, but no description of acute ischaemia on histology. There was severe coronary arterial atherosclerosis, with almost complete loss of lumen in the anterior interventricular and right coronary arteries. Cardiac arrhythmia due to ischaemic heart disease was given as the cause of death. There was no history of heart disease but there was a history of hypertension and hypercholesterolaemia. The right and left lungs weighed 903 g and 1,004 g respectively, and were oedematous and congested consistent with terminal drowning.

Comments: This case highlights the reality that snorkelling deaths due to pre-existing health problems can be unavoidable despite well-controlled snorkelling situations and with rapid and appropriate first aid. This victim appears to have got into difficulties when he exerted himself trying to swim against the current. The combination of exertion, facial immersion and probable salt water aspiration (common with inexperienced snorkellers) are likely to have precipitated a cardiac arrhythmia in a heart predisposed to this. The dive operator's vigilance and preparedness are to be commended. Cardiac perforation is an uncommon complication of resuscitation and suggests over-vigorous resuscitation.

Summary: Apparently fit; being treated for hypertension and hyperlipidaemia; first snorkel experience; current; signalled for help; sudden death; unrecognised severe ischaemic heart disease with identified risk factors; cardiac-related death

BH 07/06

The victim was a 37-year-old, overseas, male tourist visiting the GBR. There is no record of his medical history but he appeared to be healthy. He was described as a poor swimmer and it appears unlikely that he had snorkelled before. He and his girlfriend hired mask, snorkel and fins and went snorkelling off an unpatrolled island beach. The weather was clear, the water relatively calm and there was a slight breeze. The couple snorkelled together for a while until the girlfriend returned to shore, leaving the victim to snorkel alone. About 15 minutes later, he was noticed floating unconscious in the water and eventually brought to shore by a nearby boat. The rescue took around 15 minutes, during which no BLS was provided, but it was commenced once he had reached the beach. The victim was then brought aboard a ferry and BLS was continued during the 45-minute journey to the mainland where an ambulance was waiting. When assessed, he was unconscious, apnoeic and in asystole. He was intubated and adrenaline was administered, briefly precipitating ventricular fibrillation which, after defibrillation, converted to a pulseless electrical activity. BLS was given during the transfer to hospital where he eventually died from the delayed effects of inhalation of seawater.

Autopsy: The right and left lungs weighed 1,269 g and 1,293 g respectively, and appeared congested. There was copious fluid on sectioning with large amounts of pulmonary oedema fluid in the trachea and bronchi consistent with drowning. The heart weighed 340 g and was normal. The cause of death was given as drowning.

Comments: This case once again highlights the importance of snorkellers being capable of swimming and of the need for close supervision of inexperienced snorkellers.

Summary: Apparently healthy; poor swimmer; probable first use of snorkel; separation; found unconscious 15 minutes later; delay to BLS; drowning

BH 07/07

The 63-year-old, male victim was described as "*fit as a fiddle*" by his daughter. He was an experienced snorkeller although "*not a strong swimmer*". He was with a friend who

was making her first snorkel swim. They entered shallow water together and he showed her how to snorkel, returning to the shore twice while she was getting used to it. On the third occasion, after a short time he ceased holding her hand to allow her to snorkel unassisted. She intended to remain close to the shore but when she found herself further out than she felt comfortable with, she looked around for him before returning to shore. She was alarmed by her failure to see him and notified the police. When the police and ambulance searchers found him, he was wedged between two rocks 'near shallow water' and was estimated to have been submerged for 30–40 minutes. He was unconscious, very cold and had no palpable pulse. It appears that the attending paramedics did not attempt resuscitation before/while transferring him to hospital, where he was pronounced dead.

Autopsy: The autopsy report notes abrasions over both hips and the top of his head (which could have occurred post mortem), but there were no signs of scalp bruising or significant trauma. The heart weighed 310 g, with widely patent coronary arteries. The only abnormality was a degree of mitral valve prolapse. Occasional small foci of ischaemic fibrosis were identified in the heart on histology, suggesting some form of heart disease, although this is not typically associated with mitral valve prolapse. The right and left lungs, weighing 780 g and 690 g respectively, were over-expanded and contained pulmonary oedema fluid. The upper airway contained foamy fluid, consistent with drowning. The cause of death was given as drowning with a possible contribution from mitral valve prolapse.

Comments: The coroner 'found' the cause of death to be drowning but omitted to make any comment on why this fatality occurred. Unfortunately, it was not stated whether any equipment had been lost, at what depth the victim's body was found or how his body was wedged in the rocks. There was also no mention of the sea conditions or water temperature: all factors that can be useful when investigating a dive fatality. It is noted that the victim was a weak swimmer. It is unclear whether he came into contact with the rocks before or after becoming unconscious. One could speculate that he lost equipment when washed against rocks or became trapped in the rocks and was unable to surface for air. It is also possible that he suffered from a cardiac arrhythmia related to the mitral valve prolapse, drowned and then became trapped. However, it is equally possible that the mitral valve prolapse was irrelevant.

Summary: Apparently fit; weak swimmer with some snorkel experience; separation; found wedged under rocks; mitral valve prolapse of unknown significance; drowning (cardiac-related?)

BH 07/08

This 70-year-old, overseas, female tourist had no significant medical history and was said to have been a strong swimmer. It is not known if she had snorkelled before. She took an unknown seasickness medication an hour before setting off by boat to a nearby island on the GBR. She and some family members decided to go snorkelling from the beach in a supervised area, despite her complaining of feeling dizzy. The weather was clear with a light wind and the sea was relatively calm. After a few minutes, the victim's companions noticed that she was missing and notified the lifeguard. Approximately 15 minutes later, an island staff member found the victim's body partly submerged and removed her from the water. BLS was commenced by the lifeguard and continued for 20–30 minutes, without success.

Autopsy: The upper airways showed foamy material. The right and left lungs weighed 525 g and 508 g respectively. The lungs showed peripheral displacement of air by central fluid, the appearances being typical of 'wet' drowning. The heart weighed 232 g and revealed a 60% concentric narrowing in the left anterior descending coronary artery (LAD). Histology revealed some haemorrhage into the plaque, as well as microscopic foci of ischaemic fibrosis. The cause of death was given as drowning with possible contribution from 60% stenosis of the LAD.

Comments: The scenario of this silent death is suggestive of a cardiac-related episode. Typically a 75% stenosis is usually required to cause death. However, consideration should be given to cardiac dysrhythmias when an unstable atheromatous plaque with haemorrhage in it and microscopic scarring due to ischaemia are present during exercise. The victim was feeling dizzy before entering the water and the effects of immersion and salt-water aspiration through her snorkel could have magnified the problem and caused her to become unconscious and drown.

Summary: Apparently healthy; strong swimmer; unknown snorkelling experience; seasickness medication; felt dizzy before snorkelling; silent death; moderate CVD; drowning (possibly cardiac-related)

BH 07/09

The victim, a 38-year-old male, was an overseas national working on an island in the north-west of Australia. Before being employed in Australia, he passed a medical check with no evidence of adverse health factors apart from being a pack-a-day smoker. His BP was 128/76 and he was moderately overweight (BMI 26.9). It is unknown if he had snorkelled before. The victim and three workmates decided to snorkel on a reef in a cove. He was wearing shorts, a mask, snorkel and fins. The water conditions were choppy, with a one-metre swell and a slight current. They entered the water from shore and, after only a few minutes, the victim indicated to his nearest buddy that he was having trouble breathing and coping with the sea conditions. He began to panic, lifted his mask onto his forehead and appeared to have difficulty swimming. The buddy swam to him and began to

assist him to swim towards shore, about 40 metres distant. The victim became increasingly panicky and lost his mask, snorkel, and one fin. The other workmates came over and assisted but, shortly before reaching shore, the group was briefly submerged by a large swell. On reaching shore, they found the victim to be unconscious, apnoeic and pulseless. A bystander began BLS, which was only continued for five minutes before being abandoned because of lack of response.

Autopsy: The autopsy revealed an unstable plaque in the LAD with a 90% stenosis and 50% stenosis of the right coronary artery. The heart weighed 430 g and showed no macroscopic scarring. The right and left lungs weighed 1,002 g and 854 g respectively, and were congested and oedematous. There was pulmonary oedema in the upper airways consistent with terminal drowning. The cause of death was given as ischaemic heart disease due to unstable plaque in the LAD.

Comments: It is likely that exertion triggered a cardiac arrhythmia in a man with an unrecognised critical stenosis of a coronary artery. Panic, loss of mask and snorkel and probable aspiration of seawater probably all contributed to the cardiac problem and resulted in terminal drowning, which would make resuscitation more difficult.

Summary: Heavy smoker; no history of ill-health; unknown snorkelling experience; difficulty with sea conditions; substantial atheroschlerosis; drowning (likely cardiac-related)

Scuba diving fatalities

SC 07/01

This 45-year-old woman had an undeclared history of attention deficit disorder for which she was prescribed dexamphetamine. She was apparently healthy and had become certified as an open-water diver one week earlier. She was now participating in an advanced open-water course and had completed three uneventful dives on the previous day to a maximum depth of 7 msw.

On this day, the weather was overcast; the water was calm and clear with visibility of 10–15 metres, and the dive was at slack water. The victim was with a group of six students, accompanied by an instructor and a divemaster. They descended to a depth of 26 msw and knelt on the seabed while writing their names backwards on a slate. The victim then gave a 'low air' hand signal. The instructor saw that her contents gauge read 120 bar and gave her his 'octopus' regulator to breathe on briefly while he breathed on her demand valve to check that it was OK, which it appeared to be. She then took back her own regulator. However, a short time later, she again signalled 'low air' before starting to ascend. The instructor immediately signalled for the others to remain on the seabed with the divemaster and caught hold of the victim by her BCD. They then ascended together while using his buoyancy to control their ascent rate. He noticed she seemed to be having some difficulty with her breathing, taking short, shallow breaths. However, she refused the offer of his secondary regulator. The ascent was described as controlled and at a rate of around 15 msw min^{-1}.

On surfacing, the instructor asked if she was OK to which she replied "*No, I don't feel good*" before rolling onto her side unconscious. Shortly afterwards, white froth began to flow from her mouth. The instructor then towed the victim to shore, some 30 metres distant, intermittently providing rescue breaths, despite the continued flow of frothy sputum. Another diver assisted the victim onto the shore where she was assessed as unconscious and apnoeic. A rescuer initially thought a weak radial pulse, described as a weak "*flutter*", could be felt. BLS was commenced, complicated by vomitus, water, bile and froth coming from the airway. After 10 minutes, another diver arrived with an AED which when attached indicated that no shock be given. At this time the victim had fixed, dilated pupils. Paramedics arrived soon after and commenced ALS. A 'shockable' cardiac rhythm was briefly created although subsequent defibrillation failed to restore sinus rhythm. There was continued difficulty ventilating the victim as the airway appeared to be obstructed by fluid and a "*gurgling sound*" was heard.

An equipment check on the beach showed remaining air as 90 bar. When the equipment was tested later it functioned correctly. Although the primary air supply hose was noted to be kinked at the first stage regulator, and seemed to have been so for some time, causing the air flow to the primary regulator to be restricted, there was no breathing problem encountered during a test dive by the police later so this was not thought to have been an adverse factor in this fatality.

Autopsy: Before commencing the autopsy (two days after death) X-rays of the head, neck, and trunk showed gas within the chambers of the heart and major vessels, including the cerebral arteries. The appearances were those of arterial gas embolism. The heart weighed 360 g and was normal with up to 20% narrowing of the coronary arteries. There was fine patchy replacement fibrosis in the heart on histology, which is not explained. The right and left lungs weighed 915 g and 740 g respectively and were well-expanded. There were gastric contents in the upper airways. The cause of death was given as CAGE.

Comments: The victim had passed a dive medical but had omitted to mention that she was taking dexamphetamine (25–30 mg daily) for adult-onset attention deficit hyperactivity disorder and also suffered from migraine. While her husband stated that she was taking medication daily for the former, no trace was found at autopsy. She was not taking any medication for migraine. The date of the X-ray examination is not recorded but probably preceded the autopsy. Given the two-day delay and brief description of the gas, the gas could

Table 2
Summary of scuba and surface-supply diving-related
BNS – buddy not separated; BSB – buddy separated before problem; BSD – buddy separated during problem; GSB – group separated before problem; n/a – not applicable; n/i – not inflated; n/s – not stated; BCD – buoyancy compensator;

ID	Age	Gender	Height (m)	Weight (kg)	BMI (kg m^{-2})	Training	Experience	Dive group
Scuba								
SC 07/01	45	F	176	84	27.1	just trained	none beyond training	GNS
SC 07/02	57	M	172	84	28.4	trained	experienced	GNS
SC 07/03	45	M	170	68	23.5	trained	some	GSB
SC 07/04	29	M	190	90	24.9	just trained	none beyond training	GSB
SC 07/05	62	F	165	75	27.5	nil	nil	BSD
SC 07/06	24	F	n/s	n/s	n/s	trained	some	BSB
SC 07/07	60	M	184	88	26.0	trained	some	BSB
SC 07/08	62	M	180	90	27.6	just trained	none beyond training	BNS
Rebreather								
RB 07/01	42	M	n/s	n/s	n/s	trained	experienced	BNS
Surface supply								
SS 07/01	38	M	181	101	30.7	trained	some	BSB

be the result of CAGE, decomposition, post-mortem off-gassing, or resuscitation. A number of features are consistent with CAGE, including the relative inexperience and loss of consciousness after surfacing. However, the description of her apparent distress underwater and breathlessness while ascending does not fit with typical CAGE. Given the evidence of pulmonary oedema at autopsy one might consider a diagnosis of scuba divers' pulmonary oedema (SDPE).[3] However, it is not possible for a pathologist to make this diagnosis in the absence of a history of previous episodes of shortness of breath while diving.

The victim reported being low or out of air at depth despite her contents gauge indicating more than half her air remaining. Examination of her equipment subsequently showed that the hose to her primary regulator was kinked (long standing) and that this kink restricted the airflow; however, a subsequent test dive with the equipment failed to show this to be a problem. Whether her feeling of being 'out of air' was down to this must remain a matter of conjecture. However, it is interesting to speculate that such a restriction to flow may have been a trigger to developing SDPE.

Summary: History of adult-onset attention deficit disorder; newly trained, inexperienced diver doing 26 msw dive on an advanced diver course; difficulty breathing at depth; controlled, assisted ascent with instructor; vomited and unconscious on surfacing; rescue breaths while towed to shore; CAGE?/SDPE?

SC 07/02

This 57-year-old male was an experienced diver who had qualified four years earlier and reportedly dived on most weekends. He had once been an alcoholic, but had abstained for 20 years. He had had a thyroidectomy, a high resection for Duke's 'B' bowel cancer and a left shoulder operation, and had a history of petit mal epilepsy, bipolar disease, and chronic obstructive airways disease (COAD). Medications included sodium valproate, dextropropoxyphene, vardenafil, naproxen slow release, tiotropium inhaler, oxycodone hydrochloride, paracetamol, olanzapine, lithium carbonate, and salbutamol. However, it was suggested that none of these conditions appeared to be causing him any problems at the time and it was not known which, if any, of the prescribed medications he was actually taking. It was reported that he was so keen to scuba dive that he sent a substitute to have a 'diving medical' in his name. He was also overweight and had reported to his doctor that he felt anxious when it came time to ascend at the end of a dive.

On the day before the incident, a witness who knew him reported seeing him break the surface rapidly after a dive and then lie motionless until the boat picked him up.

Table 2 (cont)
fatalities in Australian waters in 2007
+ sufficient air (to surface safely); ++ 1/4–1/2 full tank; +++ >50% full; nad – nothing abnormal discovered;
CAGE – cerebral arterial gas embolism; PBT – pulmonary barotrauma; SD – sub-dural; SDPE – scuba divers' pulmonary oedema

Dive purpose	Depth (msw)	Incident (msw)	Weight belt	Wts (kg)	BCD	Remaining air	Equip test	Disabling injury
training	26	bottom	off	8	inflated	++	nad	CAGE?/SDPE?
recreation	22	10	n/s	n/s	n/i	+++	nad	PBT/CAGE
recreation	6	surface	n/s	n/s	inflated	+	nad	asphyxia? cardiac?
recreation	19	surface	on	n/s	n/s	+	nad	CAGE
training	11	1.5	nil	0	nil	+	nad	asphyxia
recreation	12	n/s	on	n/s	n/i	n/s	n/s	asphyxia? SD haematoma?
recreation	25	surface	on	14	inflated	++	nad	PBT/CAGE
training	21	surface	on	n/s	inflated	+++	n/a	cardiac?
recreation	125	100	n/s	n/s	inflated	+++	n/a	asphyxia?
crayfishing	4	4	on	21	nil	+++	nad	PBT/CAGE

Apparently, the victim cancelled his next planned dive that day. Although a person who shared a room with the victim that night reported that he was "*in good spirits*", he was reported to have looked very "*unwell*" the next morning prior to the fatal dive.

This dive was a transit of a passage cave, starting at its deeper entrance at 22 msw and exiting at its shallower end at 10 msw, a distance of 125 metres. The victim had reportedly dived this cave about 12 times over four years. His buddy on this occasion was a very experienced diver who had also dived the cave before. They had no problems until they were nearing the exit where the victim rested on a rock, holding his chest and patting it. The buddy gave him an 'OK' signal several times and there was a delay before he responded. He took the victim by the arm and towed him to complete their exit into open water, at which point he rested again before ascending. When they reached about 10 msw, they both grabbed the dive boat's mooring rope. The victim then spat out his regulator, which the buddy replaced with his own secondary regulator before prising the victim's fingers off the rope and assisting him to the surface. During this ascent the victim became unconscious. On reaching the surface, the victim was pulled into another operator's dive boat and was found to be unconscious and apnoeic, and "*looked very grey*". BLS was commenced and continued after he was transferred to his original dive boat and taken to shore. There was no oxygen available on the boat during this 20-minute period. Paramedics were waiting at the jetty but there is no record of whether or not any ALS was implemented.

Examination of the equipment by the police showed 115 bar of enriched air nitrox (EAN) 31.5 remained in the cylinder. No faults were found in either the equipment or the quality of the gas. The victim's computer recorded that the ascent rate was greater than 18 msw min^{-1}.

Autopsy: The autopsy was carried out three days after death. X-rays were taken before autopsy but it is unclear how soon after death. These showed subcutaneous emphysema of the neck, chest and abdomen, a pneumoperitoneum and large gas bubbles within the great vessels of the chest and abdomen. There were rib fractures consistent with vigorous external cardiac massage. Autopsy revealed extensive subcutaneous emphysema, gas bubbles in the arteries at the base of the brain and in the lungs, and gas in the subepicardial veins and in the peritoneum. The right and left lungs weighed 675 g and 610 g respectively, and were distended and voluminous with subpleural blebs and some emphysema with apical adhesions. Histology showed multiple intra-alveolar and parenchymal haemorrhages and the blood vessels, including those of the alveoli, contained a significant number of spaces consistent with gas bubbles. The heart weighed 400 g and was normal with no coronary atheroma. The cause of death was given as decompression sickness.

Comments: The cause of death was given as "*decompression sickness*" but this is a highly unlikely diagnosis given the relatively mild exposure. With three days between death and autopsy, the gas seen could have been from post-mortem off-gassing, decomposition or resuscitation, rather than decompression sickness. There appears to be an event on the bottom before ascent where the victim rested on a rock, holding his chest. Whether he was feeling breathless or experienced anginal discomfort cannot be known. He may have sustained a CAGE during the ascent, especially given the presence of emphysematous blebs. Alternatively, it is possible that the rapid ascent on the day before could have caused pulmonary barotrauma (PBT) that precipitated the problem on this apparently uneventful dive. The description given by the buddy of events late in the dive indicates the victim lacked an alert response to his situation so could well have not been breathing correctly during the ascent, certainly so after he let his regulator fall out of his mouth.

The connection between epilepsy, cardiac arrhythmias and sudden death remains unclear but could be one explanation for the event on the bottom. His multiple medical problems including his COAD meant that this man was unfit to dive. That he was concerned about his ascents, and that he sent another person to undertake his diving medical, indicates that this diver was aware that diving with his medical conditions could have consequences and that they should have precluded him from diving.

Summary: History of emphysema, petit mal epilepsy, bipolar disorder, bowel cancer; experienced diver; familiar dive site; rested at cave passage exit with possible chest discomfort and/or breathlessness; unconscious during ascent; pulmonary barotrauma and CAGE

SC 07/03

This 45-year-old, apparently healthy male had completed approximately 15 dives prior to becoming certified, before which he had been medically assessed and been declared fit to dive. He then completed a further four dives over the following six months. He and three friends entered the ocean from a rocky shoreline. The victim's buddy was an experienced diver and they had dived together several times before. The water's surface was calm, but there was a powerful swell of up to one metre and the visibility was poor, often less than one metre. The depth of the site varied from 3 to 6 msw. They had agreed that each diver would surface once their air reached 80 bar.

Shortly after entering the water and submerging, the victim surfaced and requested more weights from his son, who remained on the rocks as an observer. After adding 2 kg to his integrated weights system, he re-submerged. The victim and his buddy had only sporadic contact owing to the poor visibility. The surge was strong and, at one time, the buddy saw the victim thrown upside down and into a rock by the surge, after which he lost contact with the victim and surfaced shortly afterwards when he reached the agreed air cylinder ascent pressure. The remaining divers returned to shore and, together with the victim's son, scanned the water for the victim. After about 20 minutes, a bystander reported seeing the victim floating some 300 metres from shore some 400 metres along the coast. She also reported that she thought she had seen him thrown into a rock by a wave. The son and one of the other divers swam to the victim who was found to be unresponsive and apnoeic. His BCD was partly inflated, his weights had been dropped and his mask, snorkel, one bootee and fin were missing. Rescue breathing was attempted as he was towed to shore, where ALS was provided by waiting paramedics without success.

When checked, the victim's pressure gauge read 40 bar and his dive computer indicated an underwater time of 23 minutes. When his equipment was tested later by police, no faults were found.

Autopsy: At the time of admission to the mortuary there was a film of frothy fluid around the mouth. A CT scan prior to autopsy showed no air embolism or pneumothorax. The pathologist described a 10 x 8 cm abrasion on the forehead, a 2-cm laceration on right hairline, left periorbital bruising, bruising and abrasion of his chin but no intracranial pathology. The right and left lungs, weighing 785 g and 660 g respectively, were over-expanded and showed 'emphysema aquosum', denoting drowning. The heart weighed 325 g and there was a 40–50% narrowing of the LAD macroscopically. Histology indicated a 70% narrowing of the LAD, but no ischaemic damage to the myocardium. The cause of death was given as drowning. The pathologist commented that it was possible that the diver suffered an arrhythmia while diving.

Comments: It was apparent from witness reports and the head injury that the diver was thrown against rocks at some point but it is unclear if this occurred before or after he became unconscious. In either case, such trauma could have resulted in subsequent drowning. The condition of his LAD coronary artery raises the possibility of a cardiac factor, as suggested by the pathologist. These challenging sea conditions were likely to have been beyond the capabilities of this relatively inexperienced diver with significant, although possibly unknown, cardiovascular disease.

Summary: Apparently healthy; trained; limited experience; poor visibility; buddy separation; strong surge; head trauma; inflated BCD and ditched weights; severe atheroschlerosis; drowning (with possible cardiac involvement)

SC 07/04

This 29-year-old male was a foreign national working in Australia. His workmates described him as fit and athletic and he ran regularly. However, it was also reported that

he had been suffering on and off from a cold/flu over the previous two months and a variety of medications were later found in his hotel room causing the coroner to state that the victim had "*suffered from a number of respiratory tract infections of uncertain severity*". He had completed dive certification two weeks earlier for which he had successfully undergone a dive medical examination by a doctor with relevant training. He completed four dives as part of training and one post-certification dive.

On the day of the fatal dive, the victim and three other certified divers went diving under the supervision of an instructor. The conditions were described as perfect, being sunny with a light wind, calm sea and minimal current. The dive, to a maximum depth of 19 msw, appeared to be problem-free and, when the victim indicated that his gauge read 60 bar, the instructor escorted him to the safety stop before re-descending to join the others, still keeping the victim in sight. The dive time to this point was 32 minutes. After a safety stop of three minutes at 5 msw, the victim was seen to ascend, apparently normally. On reaching the surface, he gave an 'OK' signal to an observer on the boat, then changed to his snorkel and snorkelled to the boat. However, when trying to climb the ladder he collapsed back into the water. When the victim was brought aboard the boat he was unconscious although initially he appeared to be breathing spontaneously and so was placed in the recovery position. However, soon afterwards he was found to be apnoeic and BLS was commenced, with rescue breathing enhanced by supplemental O_2. A rescue helicopter brought paramedics who attempted ALS before confirming his death.

When his equipment was later examined by police, no likely adverse factors were found. His dive computer indicated that he had exceeded the recommended ascent rate of 10 msw min^{-1} although the actual rate was not shown. The remaining air pressure in the cylinder was 20 bar.

Autopsy: The autopsy was informed by a knowledge of underwater medicine, a CT examination of the head and chest being performed before commencing the autopsy, and the neck vessels being clamped before the skull was opened. The small vessels over the brain contained small gas bubbles but these were ascribed to decomposition changes. However, brain histology revealed numerous petechial haemorrhages throughout the white matter of both cerebral cortices, pons and mid brain, consistent with air embolism. Gas was present in the basal artery and Circle of Willis. The right and left lungs were very heavy, weighing 1,240 g and 1,160 g respectively, and both lungs showed numerous air bullae up to 15 mm in diameter over their surfaces. Cavitation was seen within the lungs, maximal on the left side, and both lungs showed gross oedema and congestion.

The pulmonary trunk, aorta, inferior and superior vena cavae and pulmonary veins were clamped or ligated before removing the heart, which was opened under water. Bubbles of gas escaped from the right atrium and ventricle and to a lesser extent from the left atrium but not from the left ventricle. Visible gas was present in the anterior descending and circumflex branches of the left coronary artery. No atheroma was present. The heart weighed 450 g and showed a moderate degree of concentric thickening but no evidence of any myocardial fibrosis or infarction, or of hypertrophic cardiomyopathy. Examination of the victim's medications suggests that he had respiratory symptoms. The cause of death was given as air embolism (CAGE).

Comments: According to witness reports, this diver appeared to have conducted a well-controlled and problem-free dive. While the dive computer indicated his ascent rate had exceeded 10 msw per minute, no witness reported that his ascent rate appeared to have been excessive. It is possible that the victim's previous respiratory conditions could have contributed to his death through air-trapping during ascent. It is also possible that this inexperienced diver was not exhaling adequately during ascent. However, this is speculation.

Summary: Apparently fit; respiratory infections over previous months; certified two weeks prior; recent dive medical; second post-certification dive; good conditions; dive appeared problem-free; collapsed shortly after ascent; CAGE

SC 07/05

This 62-year-old female was described as healthy and physically fit and was keen to learn to scuba dive so that she could do so with her new partner, who was a diver. Although not a qualified instructor, her partner had begun to teach the victim some basic skills in a neighbour's pool. On this occasion, the two planned to practise skills in the shallows of a river. The victim was wearing a bathing costume and mask, as well as a scuba tank with harness and regulator. Neither she, nor her partner wore a BCD or fins. They entered the water and waded to a depth that was neck-deep for the victim and intended to kneel on the bottom and practise skills. The visibility was about 0.4 m and the victim's cylinder was one quarter full. The water temperature was approximately 26°C.

Unfortunately, they were unaware that recent floods had scoured an 11-metre-deep channel near the sandy bank and the victim inadvertently stepped into this channel. The partner heard her call "*Help!*" before she began to sink. Although she was a strong swimmer, without fins or a BCD she could not ascend. The partner realised the problem and tried to unbuckle the harness, but only managed to release the strap securing the tank, believing that this would cause the tank to fall away and so enable the victim to swim to the surface. He was unable to release the other straps partly because she had accidentally knocked off his mask in the ensuing panic. He then tried to support her and assist her to the surface but was unable to do so. He could no longer see the victim because of the low visibility so he exited the water to seek help, which was not readily available.

Police divers found the victim's body the next day. The 11.6 litre steel scuba tank was found first, with the belt undone. The contents gauge showed less than 50 bar remaining air. The equipment was later examined and found to function correctly. A test dive showed that a person without fins would be unable to swim back to the surface using arms and legs from 11 metres' depth, and that the weight of the tank made it difficult to maintain an upright position in the absence of fins and other buoyancy and pulled the wearer down backwards when not trying to swim to the surface. The police concluded that there were no suspicious circumstances surrounding this death.

Autopsy: The heart weighed 314 g and showed only mild coronary atheroma with a healthy myocardium. The right and left lungs weighed 622 g and 594 g respectively and were well-inflated. There was no pulmonary oedema fluid in the upper airways and only mild to moderate pulmonary oedema on the cut surface. The cause of death was given as drowning.

Comments: Although this stretch of the river was well known to the victim and her partner (being on his property) they were tragically unaware that what was previously shallow water, where it might have been relatively safe to practice certain skills, had recently changed. However, it is seldom appropriate not to wear fins with scuba. The wearing of a BCD and ability to inflate it might have averted this accident. It is likely that the victim removed her regulator when calling for help and failed to replace it effectively, causing her to aspirate water and lose consciousness as she sank to the bottom. Autopsy findings in fresh-water drowning are more subtle than those of salt-water drowning and with early decompositional changes (two days between death and autopsy) pulmonary oedema fluid in the upper airways may be absent.

Summary: Apparently fit and healthy; minimal scuba training by non-instructor; not wearing fins or BCD as planned to be in shallow water only; inadvertently stepped into deeper water and sank; poor visibility; buddy unable to rescue; drowning

SC 07/06

This diver was a 24-year-old, female, overseas tourist who was visiting an island off the south-west coast of Australia with her boyfriend. She had been certified six months earlier and this was her eighth dive. The couple were diving from a commercial dive boat with other certified divers. The conditions were described as calm, with a swell of less than 2 m, a light wind and visibility of up to 5 m. After the briefing, the victim and her boyfriend asked the divemaster/instructor if he would accompany them on this dive due to their inexperience. He agreed and they set off together. After descending, the divemaster initially helped the victim adjust her buoyancy and held her hand as they swam. After a few minutes, she signalled that she was 'OK' so the instructor swam ahead of the victim and her buddy, looking back to check on them periodically. At one point, the divemaster looked back and could not see the pair so swam back to look for them. He soon found the buddy but the victim was not with him. The buddy indicated that the victim was 'OK' but had returned to the surface and signalled for the divemaster to continue the dive with him. However, after about a further five minutes, the divemaster found the victim floating near to the bottom, unconscious and with her regulator out of her mouth. He quickly ditched her weight belt, brought her to the surface and towed her to the nearby boat, providing two rescue breaths on the way.

The victim was soon dragged onto the boat and assessed as unconscious, apnoeic and pulseless. BLS was commenced but was complicated by large amounts of water and white frothy sputum in the airway. In response to a distress call, a doctor on a nearby boat and two nurses from the island arrived and implemented ALS after which a pulse was palpable and the victim began to breathe spontaneously. She was transferred by boat to the island and then evacuated by aircraft to the nearest hospital for initial assessment and stabilisation, and from there to a tertiary hospital where neurological services were available. Investigations at the initial hospital revealed a small right subdural haematoma and marked right mass effect throughout the right cerebral hemisphere. No fractures or right scalp haematoma were observed. Neurosurgical opinion was that the subdural haematoma was too small to warrant evacuation and EEG data were consistent with a severe hypoxic brain injury. She remained in a coma and was eventually repatriated to her home country, still on a ventilator, where she remained hospitalised without improvement. It is reported she eventually died there as a result of severe hypoxic injuries.

The dive master's dive computer indicated that the maximum depth of the dive was 12 msw with a dive time of 15 minutes.

Comments: This diver eventually died in her home country and the death should have been referred to the coroner there. Coronial investigations become much more complicated and often unsatisfactory when the event occurs in one jurisdiction and the death occurs in another jurisdiction. There was evidence of aspiration of salt water and a right-sided subdural haematoma. The haematoma could have been the result of blunt trauma occurring prior to the dive (with a latent period), during water entry, or during the dive, or maybe contact with the boat hull in the swell when surfacing near the boat. It is also possible that the subdural haematoma occurred during diver recovery and was not directly relevant to the death.

Less commonly a subdural haematoma may occur with subarachnoid haemorrhage associated with a berry aneurysm, or AV malformation (not seen on angiogram), coagulopathy (normal coagulation studies make this unlikely), or malignancy or associated with cerebral atrophy. Spontaneous non-traumatic subdural haemorrhage is rare but described. The CT scan was performed without contrast,

which probably limits its diagnostic accuracy. The absence of a skull fracture probably says little about the mechanism of the subdural haematoma, and subcutaneous bruising from blunt trauma could have been concealed by the scalp hair.

The possible causes of death are hypoxic brain damage due to drowning following head injury, or hypoxic brain damage due to drowning. This case demonstrates that an autopsy is a useful part of a gold standard investigation of a diving death. It is unfortunate that the buddy did not accompany the victim to the surface as this might have saved valuable underwater recovery time.

Summary: Apparently healthy; inexperienced diver; accompanied by buddy and divemaster; separation; found unconscious near to the bottom; small subdural haematoma on CT scan; ALS successful; remained comatose; repatriated; reported to have died

SC 07/07

This victim was a 60-year-old male who was described as healthy and very fit. He had learned to dive in the Philippines approximately two years earlier and had reportedly done 16 dives, almost all in the Philippines prior to enrolling to dive with a dive club in southern Australia. He had purchased his own second-hand diving equipment which had reportedly been serviced prior to sale. Two days prior to the day of the fatal dive he conducted two 10–15 msw drift dives in an area prone to currents. His buddy was a very experienced diver who guided him on these dives to familiarise him with use of the drift line. The victim was described as looking uncomfortable and was having trouble maintaining correct buoyancy and horizontal orientation. He was wearing dentures and, on the second dive, bit too hard on these, causing them to fracture. This was possibly an indication of his level of anxiety.

On the day of the accident, the victim, now wearing an old set of dentures, dived with the same buddy from the dive club boat, driven by another club member. On the first dive, a drift dive to around 20 msw, the victim continued to struggle with buoyancy control and orientation and used his air supply quite quickly. After a surface interval of approximately four hours, the divers prepared to dive again. The conditions were described as calm, with visibility of around 4–5 metres. The current was variously reported to be between 1 and 3 knots. The divers were using a 100-metre buoyed drift line fitted with two 10-metre lengths at the bottom. The victim was instructed to hold onto the end of one of these. The depth ranged from 16–25 msw.

During the first 10–12 minutes, the buddy occasionally sighted the victim but then did not see him for the remainder of the dive. Approximately 15 minutes after the divers descended, the boat driver saw the victim surface 300 metres away. He was face-up with a partially inflated BCD and was not moving. The boat driver was unable to bring him aboard and so radioed for assistance. Others arrived and brought the victim on board. He was unconscious and apnoeic and there was froth in his mask. It appears that BLS was not commenced for approximately 15 minutes. Eventually, a policeman and an off-duty paramedic arrived and took over resuscitation efforts. A bag-valve-mask with supplemental O_2 was used for some of the time. After approximately 30 minutes of BLS without response the paramedic declared the victim to be deceased. He was not wearing any dentures and none were later found.

His equipment was found to be functional and no significant defects were indicated. There was 70 bar of air remaining in his cylinder.

Autopsy: A CT examination was made before commencing the autopsy and was reported by an experienced forensic radiologist. This showed there was widespread intravascular gas collection predominantly in the left side of the heart and arterial structures highly suggestive of pulmonary barotrauma/CAGE and not typical for decomposition or post-mortem off-gassing (post-mortem decompression). At the autopsy, the pericardial sac was opened and filled with water, then each ventricle was pierced in turn. About 15–20 ml of gas escaped from the left ventricle, and a small amount of gas was released from the right ventricle. The heart weighed 366 g and appeared to be healthy. The coronary arteries showed no significant stenoses. There was a copious escape of blood and gas when the carotid artery was opened. There was little if any gas noted outside the vascular system. Gas was noted in the hepatic and portal veins. Before removing the brain, the internal carotids and basilar arteries were ligated. Copious amounts of gas were noted within the entrapped Circle of Willis, and copious amounts escaped from all arterial outlets when cut.

The lungs were hyper-inflated and entirely covered the anterior heart contour. The right and left lungs weighed 820 g and 685 g respectively. There was a small amount of lightly blood-stained pulmonary oedema fluid in the trachea. All the lobes elicited considerable crepitus on compression. Histology of the lungs showed evidence of widespread alveolar rupture and also a subpleural gas collection was identified. In some areas, the pleura was separated from adjacent parenchyma. No pre-existing, significant, naturally-occurring disease was noted. The brain showed mild congestion and oedema. Numerous intraparenchymal blood vessels showed gas dissection of the wall and separation of the wall from adjacent parenchyma. There was a firm diagnosis of pulmonary barotrauma and CAGE.

Comments: This diver had relatively little experience in cooler waters and strong currents. The drift line being used enabled the divers to be up to 20 m apart. This was not appropriate with a relatively inexperienced diver in low visibility and what could have been a strong current. Evidence from a dental expert advised that it was likely that an old pair of dentures would be ill-fitting and probably

loose, making it reasonably easy for them to fall out while diving. If so, it is probable that a diver would be unable to grip his regulator effectively. The victim might have had difficulty with his dentures, aspirated some water, inflated his BCD and surfaced with inadequate exhalation. This is a well-documented example of pulmonary barotrauma and CAGE.

Summary: Few dives since trained in tropics; little experience in drift diving; using old and likely ill-fitting dentures; poor buddy contact leading to separation; possible aspiration; panic and uncontrolled buoyant ascent; CAGE

SC 07/08

This 62-year-old male was described as a heavy drinker with a recent history of hypertension and hyperlipidaemia. He had completed his open-water diver training the day before and had very recently been assessed as fit to dive. On this occasion, he and another diver were to dive with an instructor, leaving two other staff on the boat. Surface conditions were described as choppy but not rough, but during the snorkel to the anchor line the other diver aborted the dive. The instructor asked the victim if he was ready to continue to which the victim replied that he needed a minute to catch his breath. When he felt ready, the victim signalled to the instructor to descend. He then signalled 'OK' to the instructor at approximately 13 msw as they passed through a thermocline (of 12^{O}C). On the bottom, at about 20 msw, the victim wrote "*breathing fast*" on the instructor's slate but after relaxing for a minute he signalled that he was 'OK' to proceed. During the tour portion of the dive, the victim appeared to be relaxed, in control and having a good time.

After a circuit of the site, the pair returned to the anchor and the instructor, noting that they had plenty of air remaining, signalled to the victim asking if he wanted to continue the dive. The victim almost illegibly wrote "*tired*" on the slate and then signalled to ascend. At the 5-msw safety stop the victim returned an 'OK' signal and showed no signs of distress, his breathing and body positioning appearing to be normal. However, after only about one minute, the victim started to ascend and did not respond to the instructor's signals to return to the safety stop. The instructor surfaced to find the victim unconscious face-down in the water. His eyes were glassy and open and, although the regulator was still in his mouth, he did not appear to be breathing.

The instructor and another person who had been on the boat as deckhand responded quickly and gave some rescue breaths while ditching the victim's equipment. Once on the boat, BLS was commenced and after a couple of minutes one of the rescuers noticed what appeared to be a fluttering in the victim's neck and thought that he could feel a pulse. He also noticed that the victim appeared to take an unaided breath so he was placed in the recovery position and given supplemental oxygen. However, it was soon apparent that he was apnoeic and BLS was re-commenced and continued until reaching shore where waiting paramedics initiated ALS, without success.

Most of the victim's equipment was lost after being ditched but his cylinder was examined and found to be serviceable. There was no mention in the police report as to whether the regulator was still on the cylinder.

Autopsy: The coroner recorded the cause of death as undetermined as there was no convincing anatomical cause of death. Post-mortem X-rays showed no accumulation of gas in the chest. There was no evidence of pneumothorax or embolism. The heart weight was at the upper range of normal (442 g) and there was moderate diffuse atheroma of the coronary arteries with up to 50% narrowing of the LAD macroscopically. There was no evidence of recent or old myocardial infarction. The right and left lungs weighed 942 g and 818 g respectively, and were well-expanded. No pulmonary oedema was described in the upper airways. Toxicology detected pseudoephedrine. The pathologist gave the cause of death as undetermined.

Comments: There was a history of hypercholesterolaemia, hypertension and heavy alcohol use. While no clear cause of death was found at autopsy, the history, the borderline cardiac weight and the moderate coronary atheroma all suggest a cardiac arrhythmia (an event that cannot be demonstrated at autopsy). As was shown in case BH 07/08, histological examination of the coronary arteries may demonstrate a greater degree of stenosis and the presence of an unstable plaque that might not be appreciated on macroscopic examination. Histology of such lesions is probably desirable. A combination of exertion, cold, pseudoephedrine and other possible dive-related factors likely caused this diver to suffer from a cardiac arrhythmia which rendered him unconscious. What was thought to be a return of spontaneous respiration was probably agonal breathing.

Summary: History of heavy drinking, hypertension, hyperlipidaemia; recently passed dive medical; first dive immediately after training; breathless and tired during dive; unconscious on surface; possible arrhythmia?

Rebreather fatality

RB 07/01

This victim was a 42-year-old male who was reportedly fit and healthy, although a heavy smoker. He was an experienced technical and wreck diver and part of a group dedicated to finding and diving deep wrecks. He was experienced in the use of his Inspiration Classic closed-circuit rebreather (CCR). As well as his rebreather, he was carrying two 12-L bail-out cylinders for emergency open-circuit use in the event of a rebreather failure. The gas composition in these cylinders was unknown. On this occasion, the victim was among a group of eight divers whose objective was to make a positive identification of a wreck thought to be an ore

carrier torpedoed during World War II, lying at a depth of 125 msw. All those present had made careful calculations of their dive profiles, a multi-hour decompression schedule and extensive 'bail-out' open-circuit planning.

The divers entered the water and descended to 5 msw depth where they made a final check of each other's equipment. They then descended together down the shotline. At around 70 msw, the buddy heard the audio alarm of an Inspiration. He checked his own equipment and found nothing wrong, but was unsure if the victim checked his. At approximately 90 msw on the shotline, the victim stopped and signalled that he needed assistance to connect a hose from his bail-out cylinder to his manual diluent connection. The buddy assisted with this and, after it had been connected, the victim signalled with a 'thumbs up' which was taken to mean that all was 'OK'. The descent was resumed but with the alarms still sounding. At approximately 100 msw, the victim stopped on the shotline and he failed to respond when his buddy tapped on his rebreather. When the buddy swam in front of the victim he noticed that the dive surface valve (mouthpiece, DSV) of the rebreather was out of his mouth, his eyes were shut and one hand was holding the shotline. The buddy tried in vain to replace the victim's DSV and inflate his drysuit but was unable to do so in the strong mid-water current.

At this point another diver, who had noticed there was a problem, came to assist. He also attempted to inflate both the victim's drysuit and BCD without apparent success. The three continued to descend and reached the bottom of the shotline. The second diver released the victim's weight belt but he remained negatively buoyant. Both divers tried to hold onto the victim but lost their one-handed grip on him as the shotline was dragged by the current across the seabed. There was no current on the seabed itself and the victim's heavy body was left behind as they were swept onwards. The divers realised that they already had a decompression obligation of approximately 3.5 hours so made a decision to begin their long and slow ascent. When closer to the surface, one of the divers sent up a message by a marker buoy reporting what had happened and asking for the police to be informed. Decompression risk prohibited any search being made by the other divers, and the police divers are neither trained nor permitted to dive to this depth.

It was thought the victim's heavy body would remain where it was but a later police search using side scan sonar failed to locate it, though there was some doubt as to whether the correct dive location was identified by the dive boat's skipper. Although the divers had left the shotline buoyed at the dive location, it was not there when the police search was made. The victim's body has not been found.

Comments: Deep mixed-gas diving using rebreathers is a hazardous undertaking at the best of times. Conducting such dives off-shore and in a strong current adds substantially to these risks. In this case, the dive group had set up systems that they believed would minimise risk, including having a dive supervisor who remained on the surface and various check lists to ensure that all divers had suitable plans and had performed pre-dive checks. However, the utility of such systems is severely compromised where there is substantial variation and modification of equipment such that the supervisor is unable to ascertain or independently verify that the various divers are entering the water with their gear configured correctly.

The Inspiration Classic is a CCR rated for use to 100 msw using trimix (O_2/He/N_2) diluent. The unit has been tested to 150 msw using heliox diluent. It consists of a breathing loop with a set of one-way valves and a chemical carbon dioxide (CO_2) scrubber. Two 3-L (water volume) cylinders, one with O_2 and the other a diluent gas, supply breathing gas to the unit. Exhaled gas passes through the scrubber material where CO_2 is removed. O_2 sensors then detect the partial pressure of O_2 (PPO_2) in the residual gas and O_2 is added by an electronic solenoid controlled by computers to maintain a constant inhaled PPO_2 (usually 131 kPa, 1.3 ATA). As the diver descends, the loop would be crushed unless additional gas is added. This gas, known as the diluent gas, is usually either trimix or air depending on the planned depth. During ascent, gas must be vented from the unit. Because the diver must drive the gas around the unit through the action of breathing, issues such as gas density and work of breathing become critical at depths such as were planned in this case, and correct gas choice is vital.

With the Inspiration Classic, the standard set up is that the on-board diluent cylinder provides gas for the breathing loop, and BCD. However, in this case, it is believed that the victim had planned to use diluent from his off-board 'bail-out' cylinder for breathing and the on-board cylinder for drysuit and BCD inflation (and hence which contained air rather than trimix). Photographs taken just before the victim dived appeared to show that the 'bail-out' cylinder was not connected and that the automatic diluent addition valve (ADV) was still connected to his on-board cylinder (i.e., air).

The victim had done considerable research into this wreck and was keen to be the person to positively identify it. Thus, there was substantial pressure to do the dive, which may have added to stress and acted as a distracter. It would seem most likely that the victim entered the water and descended with the unit running with air as its diluent. At 70 msw, the PPO_2 of the breathing loop would reach 163 kPa (1.6 ATA) causing the alarms that were heard by the buddy. By 90 msw, the PPO_2 would have been 183 kPa (1.8 ATA) and at this depth the victim would almost certainly have been suffering from considerable nitrogen narcosis, perhaps explaining his inability to 'plug in' the off-board diluent hose.

The victim's buddy mentions that the victim then did some checks after the cylinder was plugged in and signalled to proceed. This statement seems inconsistent in that:

- the signal for 'OK' is not the 'thumbs up';

- correct procedure for checking the presence of an incorrect diluent would involve flushing and venting the breathing loop with a considerable quantity of gas, an event that one would have expected the buddy to comment on had it occurred;
- the descent was recommenced with the victim's alarms still sounding.

If the victim did not flush the breathing loop, then the majority of the gas present would have continued to have been air, leading to nitrogen narcosis and elevated CO_2 levels from a high work of breathing, both of which would seriously impair the victim's judgment. It is possible that the victim may have planned to 'breath down' the high PPO_2 if he was indeed aware of it. In this scenario, the high N_2 or CO_2 would have been enough to render the victim unconscious as would a high PPO_2 if the victim convulsed; the latter being a strong possibility given the probable circumstances. That the buddy did not stop the dive with the alarms sounding, or consider the implications of plugging in the off-board cylinder under these circumstances, seems very surprising given the level of diving being conducted. It is even more concerning that he allowed the descent to recommence at 90 msw with alarms still going. Once the victim was unconscious with the DSV out of his mouth, his chances of recovery from this depth were negligible. The inability of the rescuers to inflate the wing and dry suit is unsurprising. The diluent cylinder on the Inspiration rebreather has a 3-litre water volume. At 200 bar this equates to 600 litres of available gas. When the victim became unconscious and the DSV fell from his mouth, the CCR would have flooded, making the victim substantially negatively buoyant. The 16 kg lift BCD that is standard with this unit would take 210 litres of gas alone to inflate fully at this depth. If gas from this cylinder had been used for diluent as well as dry-suit inflation during the descent, this would have left insufficient gas to fully inflate the wing or dry suit at depth to counter the loss of buoyancy, especially if any gas had been used to purge the loop during rescue attempts.

Summary: Apparently healthy; trained and experienced technical diver; using closed-circuit rebreather; deep wreck at 125 msw; became unconscious at 100 msw; strong current and depth made body recovery hazardous; probable oxygen toxicity; probable drowning; body not recovered

Surface-supplied breathing apparatus

SS 07/01

This victim was a 38-year-old male who had been certified to dive six months earlier at which time, although obese, he had been assessed as fit to dive. He had done five or six dives since. He and a friend were diving for crayfish using a surface-supply system with two hoses. It is unknown if the victim had used this equipment before. He wore a wetsuit, mask and fins but no BCD or harness for the air hose. He also wore two weight belts, one with 17 kg and the other with 4 kg. The dive site was shallow at 3–4 msw but there was thick kelp in one area. The sea conditions were described as calm with a swell of less than two metres.

The divers had been in the water for around 30 minutes when the victim surfaced with his regulator out and signalled to be pulled to the boat by the hose, shouting "*Quick*". Pulling on his airline the friend in the boat determined that it was snagged in kelp and a line was thrown to the victim. He was pulled to within 6 m of the boat but was unable to be retrieved any further and, upon releasing the rope, sank from sight. The boat driver jumped into the water to try to support the victim but was unable to do so as he was too heavy. He then re-boarded the boat and tried to get the boat to the victim but the engine stalled. These actions brought the buddy to the surface and he was directed to where the victim was last seen. He found the victim tangled in kelp, unconscious and with the regulator out of his mouth.

On the surface, the victim was still entangled in both kelp and his airline and he needed to be cut free before the buddy and others could get him out of the water. When eventually he was brought aboard the boat, BLS was commenced and continued for over 45 minutes while the arrival of police and paramedics was awaited. On arrival, they took over resuscitation efforts, without success. When the victim's airline was cut, air spilled into the water showing that the compressor was still delivering air to that line. It was later determined that, although old, all the equipment was in working order and did not contribute to this death.

Autopsy: Unfortunately the pathologist was not notified of this death until many hours later and as a result, a CT scan was not performed. There was significant gas in the right ventricle and a lesser amount in the left ventricle and the aorta. There were also some small bubbles in the arteries at the base of the brain. The heart was heavy (496 g) with minimal atherosclerosis. There appeared to be some intimal/medial thickening of the small vessels surrounding the AV node. The pathologist noted that the significance of this was not clear although it had previously been described as a possible cause of cardiac arrhythmia during exercise.[4] The right and left lungs, weighing 1,258 g and 1,078 g respectively, were over-expanded and there was severe pulmonary oedema in the lungs and upper airways consistent with drowning. Two possible causes of death were given:

- PBT/CAGE followed by drowning due to loss of consciousness.
- Drowning due to loss of the regulator probably owing to snagging on kelp.

The pathologist favoured the former diagnosis.

Comments: This inexperienced diver was grossly over-weighted with two weight belts, and it was likely that it would have been difficult to release one or both of these in an emergency. He had no other options as he was not wearing a BCD. It is likely that he and/or his hose became entangled in kelp, his regulator dislodged and he made a panicked ascent with inadequate exhalation, resulting in

Table 3
Root cause analysis of diving-related fatalities in Australian waters in 2007
BCD – buoyancy compensator; CAGE – cerebral arterial gas embolism; CVD – cardiovascular disease; SD – subdural haemorrhage; PBT – pulmonary barotrauma; SDPE – scuba divers' pulmonary oedema

Case	Trigger	Disabling agent	Disabling injury	Cause of death
BH07/01	Tight jacket, alcohol?	Aspiration of water	Asphyxia	Drowning
BH07/02	Tangled in speargun cord	Entrapment	Asphyxia	Drowning
BH07/03	Water inhalation via snorkel?	Cardiovascular disease	Cardiac incident	Cardiac-related
BH07/04	Nausea? Alcohol?	Aspiration of vomit	Asphyxia? Cardiac incident?	Aspiration pneumonitis
BH07/05	Exertion	Cardiovascular disease	Cardiac incident	Cardiac-related
BH07/06	Unknown (poor swimmer)	Aspiration of water	Asphyxia	Drowning
BH07/07	Unknown (poor swimmer)	Entrapment? Mitral valve prolapse?	Asphyxia? Cardiac incident?	Drowning
BH07/08	Unknown	Cardiovascular disease?	Asphyxia? Cardiac incident?	Drowning
BH07/09	Exertion	Cardiovascular disease	Cardiac incident?	Drowning
SC07/01	Breathing difficulty? SDPE?	Ascent related? SDPE?	CAGE? SDPE?	CAGE. (SPDE?)
SC07/02	Medical condition?	Ascwent related	PBT/CAGE	CAGE
SC07/03	Rough conditions, exertion	CVD? Blow to head?	Asphyxia, cardiac incident?	Drowning
SC07/04	Unknown	Ascent-related. Medical condition?	CAGE	CAGE
SC07/05	Stepped into deep water	Buoyancy-related (no BCD)	Asphyxia	Drowning
SC07/06	Subdural haemorrhage	Medical condition (SD haem)	Asphyxia	Drowning (delayed)
SC07/07	Loose denture?	Aspiration of water	PBT/CAGE	CAGE
SC07/08	Exertion, cold? Pseudoephedrine?	Cardiac-related	Cardiac incident?	Cardiac-related?
RB07/01	Incorrect gas mix	Oxygen toxicity	Asphyxia	Drowning?
SS07/01	Entanglement/loss of air supply/over weighted	Ascent-related? Buoyancy-related?	Asphyxia? CAGE?	Drowning

pulmonary barotrauma and CAGE. Unable to stay on the surface, he sank and drowned.

Summary: Apparently healthy but overweight; inexperienced; using surface-supplied air; thick kelp; entangled in hose and kelp; loss of regulator; over-weighted and with no BCD; drowning (possibly partly owing to CAGE)

Discussion

As stated previously, the main purpose of these reports is to highlight problems so that similar events can be minimised in the future. As well as describing each event and drawing conclusions from the facts, including autopsy findings, we use a sequence of four events – trigger, disabling agent, disabling injury and cause of death – to provide a simple root cause analysis of each fatality (Table 3).

In this series, there were no cases of breath-hold divers who were believed to have died as a result of apnoeic hypoxia; we hope that this continues in future reports. At least two of the breath-hold divers were reported to have been poor swimmers, which is not uncommon, especially among visitors to the GBR. Life vests can provide valuable

additional buoyancy for snorkellers. However, these need to fit comfortably and provide effective buoyancy. Unfortunately, many life jackets and BCDs do not prevent an unconscious wearer from floating face-down and, in these circumstances, will not prevent a drowning.

Two of the compressed gas victims (SC 07/05 and SS 07/01) were not wearing BCDs and found themselves in situations where a BCD may have provided the required buoyancy to enable survival. All compressed gas divers should wear BCDs and fins in any situation where they may not be able to stand with their head clear of the water.

The incident BH 07/01 raises the concern of the challenges of providing a thorough briefing prior to diving-related activities, especially when different languages are involved. We strongly advise that intending snorkellers be competent swimmers and sufficiently fit and healthy. Snorkelling operators should pay careful attention to pre-screening participants for apparent health and fitness, anxiety, swimming ability and snorkelling experience to identify those who will need better orientation to the use of snorkelling equipment (especially effective clearing of water from the mask and snorkel), and closer supervision. Careful attention should also be paid to ensuring that the equipment is functional and a good fit.

Data from DAN America have identified cardiovascular disease as a possible contributing factor in 26% of scuba diving-related fatalities.[5] In this 2007 Australian case series, cardiac-related factors were thought likely to have been the disabling injury in three of the snorkelling deaths (BH 07/03, BH07/05 and BH 07/09) and may have contributed to another five deaths (BH 07/04, BH 07/07, BH 07/08, SC 07/03 and SC 07/08). There is currently debate about the necessity of a fitness-to-dive assessment by a doctor prior to open-water certification.[6,7] Although such a medical is still required under the current Australian Standards for recreational scuba diving (AS 4005.1), the major recreational training agencies operating in Australia no longer encourage this and many dive operators have consequently abandoned the practice in order to minimise barriers to course enrolments. However, with an ageing diving population, there is an increased potential for known or occult disease, and DAN America data indicate that increased age is associated with a higher dive-related mortality from cardiac as well as other causes.[5] It will be interesting to observe over time whether or not the abandonment of the mandatory medical in Australia is associated with an increase in morbidity and mortality, although this may be difficult to determine epidemiologically.

Fitness-to-dive assessments are fallible and have some inherent limitations as relatively few tests are usually performed. The assessment also relies on the candidate to be thorough and honest about their medical history. Although most divers who undergo diving medicals are assessed to be low risk, a dive medical, especially one performed by a doctor with appropriate training, will sometimes determine that an individual has an unacceptable risk of an accident while diving.

In this case series, although several divers had recently been assessed as fit to dive, pre-existing health conditions may have contributed to their deaths. The victim in SC 07/02 with a history of emphysema and petit mal epilepsy, among other conditions, would have undoubtedly been counselled not to dive by most dive physicians. However, it appears that he gained the required medical by using a substitute for the examination. The victim in SC 07/04, with a recent history of recurrent chest infections, was determined to be fit to dive, and this raises questions on the level of investigation required when such a history is provided. The victim in SC 07/01 failed to declare that she was suffering from attention deficit disorder, possibly through fear that she would be advised not to dive. However, had she declared her condition, she would likely have been assessed as fit to dive by many diving physicians. We believe cardiac arrhythmias could have been the disabling injury with SC 07/03 and SC 07/08, both of whom had recently undergone medical assessments.

It is worth noting that the (lay) rescuers in SC 07/08 ceased BLS after several minutes in the belief that a spontaneous pulse and respirations had returned. There is evidence that pulse checks are often performed poorly by laypersons, and even by some medical professionals, with false positives and false negatives common.[8–11] There are also data that suggest lay rescuers have difficulty in accurately assessing breathing and are often unable to recognise agonal gasps, which are common after cardiac arrest and which do not provide effective ventilation.[12–14] For this reason, lay rescuers are now advised to begin BLS if the victim is unresponsive and not breathing 'normally' (i.e., breathing regularly and not gasping), and to continue until responsiveness or normal breathing returns, unless it is impossible to continue (e.g., exhaustion), and until health-care professionals arrive and direct that BLS be ceased.[15] The rescuers in BH 07/09 abandoned BLS after only five minutes, seemingly without any of the suggested cessation triggers. AEDs were available in four of these events although, by the time they were attached, no shock was advised in three of these cases, probably because of the delays associated with the rescues. In one case where there was a very rapid response, several shocks were advised but the victim failed to recover.

Six of the ten compressed gas divers were inexperienced, having completed ten or fewer dives. Indeed, three had completed their open-water training within the previous 1–14 days. Inexperience and medical factors appeared to have contributed to the demise of these new divers.

Case RB 07/01 reflects the fact that divers conducting high-risk diving activities must have clearly defined criteria for aborting the dive if things are not going well. In this particular case, there seems to have been a complete failure of both the victim and the buddy to grasp the implications of

continuing such a deep and dangerous dive with the unit's alarms sounding. Whether this was a matter of complacency or a lack of knowledge is difficult to determine from the reports received. Buddies conducting such dives have a responsibility to understand the functioning of each other's equipment and the meaning and implications of alarms and to 'call the dive' if things are not progressing correctly. From our experience, we have seen a progressive increase in acceptance of risk within such groups as they have successfully carried out dives without incidents. While this team did have a 'dive supervisor' and dive plans, these are of little consequence if the supervisor is unable to vet the diver's equipment is correct and fit for the task. Some agencies have advocated commonality of equipment and gas to overcome this problem. Furthermore, divers who operate far offshore in slow boats, distant from retrieval services must realise that in the event of a serious accident there is little hope of timely medical support being available. Accepting such risk is a matter of personal choice, providing that everyone involved is actually aware of the risks and the consequences of an accident.

The problem of distinguishing CAGE and post-mortem off-gassing continues to make interpretation of autopsy findings difficult. CT scan offers great promise; however, correct interpretation depends on accurate reporting of the location (arterial, venous, soft tissue and joint) and rough volume of the gas. Gas in joints and tissues suggests off-gassing or later decomposition. Gas due to decomposition tends to start in the liver. The CT scan should be performed within eight hours of death.

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

- Incomplete case data. Fatalities were sometimes unwitnessed, and reports provided by any witnesses and by police varied in their likely reliability, as did their content and depth, and the expertise of the investigators.
- Unreliability of some autopsy reports because 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 injury.
- Classification of cases into a sequence of four events (trigger, disabling agent, disabling injury, cause of death) requires a single choice for each event which may omit important factors in some cases.
- Limited annual case data; 19 deaths is too small a number to determine reliable trends.
- In some coronial jurisdictions, this research team has been unable to access witness reports and this limits our ability to examine cases in as much detail as we believe is necessary.

Conclusions

There were 19 reported diving-related fatalities during 2007, including nine deaths while snorkelling and/or breath-hold diving, eight while scuba diving, one while using a closed-circuit rebreather and one while using surface-supply breathing apparatus.

Causal factors associated with these deaths included: inexperience; diving in adverse conditions; cardiac disease or other co-existing illnesses and diver error. With snorkellers, the likely disabling injuries were asphyxia and cardiac causes. In scuba divers, the disabling injuries appear to have been asphyxia, CAGE, cardiac causes and immersion pulmonary oedema.

Factors that may reduce mortality in the future include better supervision of inexperienced and older snorkellers; improved medical screening of older divers; better education of prospective and active divers about potential health risks; careful buddy monitoring and the wearing of suitable buoyancy vests.

References

1 Walker D, Lippmann J, Lawrence C, Houston J, Fock A. Provisional report on diving-related fatalities in Australian waters 2004. *Diving Hyperb Med*. 2009;39:138-61.

2 Schuckit MA. Alcohol-use disorders. *Lancet.* 2009;373:492-501.

3 Edmonds C, Lippmann J, Lockley S, Wolfers D. Scuba divers' pulmonary oedema – Recurrences and fatalities. *Diving Hyperb Med*. 2012;42:40-4.

4 James TN. The spectrum of disease of small coronary arteries and their physiologic consequences. *J Am Coll Cardiol.* 1990;15:763-74.

5 Denoble PJ, Caruso JL, Dear G, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med,* 2008;35:393-406.

6 Meehan CA, Bennett MH. Medical assessment of fitness to dive – comparing a questionnaire and a medical-based interview approach. *Diving Hyperb Med*. 2010;40:119-24.

7 Glen S. Three year follow up of a self certification system for the assessment of fitness to dive in Scotland. *Br J Sports Med*. 2004;38:754-7.

8 Bahr J, Klingler H, Panzer W, Rode H, Kettler D. Skills of lay people in checking the carotid pulse. *Resuscitation*. 1997;35:23-6.

9 Brennan RT, Braslow A. Skill mastery in public CPR classes. *Am J Emerg Med*. 1998;16:653-7.

10 Eberle B, Dick WF, Schneider T, Wisser G, Doetsch S, Tzanova I. Checking the carotid pulse check: Diagnostic accuracy of first responders in patients with and without a pulse. *Resuscitation*. 1996;33:107-16.

11 Nyman J, Sihvonen M. Cardiopulmonary resuscitation skills in nurses and nursing students. *Resuscitation*. 2000;47:179-84.

12 Perkins GD, Stephenson B, Hulme J, Monsieurs KG. Birmingham assessment of breathing study (BABS). *Resuscitation*. 2005;64:109-13.

13 Ruppert M, Reith MW, Widmann JH, Lackner CK, Kerkmann R, Schweiberer L, et al. Checking for breathing: Evaluation

of the diagnostic capability of emergency medical services personnel, physicians, medical students, and medical laypersons. *Ann Emerg Med*. 1999;34:720-9.
14 Bang A, Herlitz J, Martinell S. Interaction between emergency medical dispatcher and caller in suspected out-of-hospital cardiac arrest calls with focus on agonal breathing: A review of 100 tape recordings of true cardiac arrest cases. *Resuscitation*. 2003;56:25-34.
15 Sayre MR, Koster RW, Botha M, Cave DM, Cudnik MT, Handley AJ, et al. Part 5: Adult Basic Life Support: 2010 International Consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. *Circulation*. 2010;122:S298-324.

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

Funding: This study was funded by DAN Asia-Pacific.

Acknowledgements

We acknowledge Monash University National Centre for Coronial Information for providing access to the National Coronial Information System (NCIS), State and Territory Coronial Offices, various police officers, dive operators and divers who provided information on these fatalities.

Submitted: 06 December 2011
Accepted:15 June 2012

John Lippmann, OAM, BSc, Dip Ed, MAppSc, is the Executive Director of Divers Alert Network (DAN) Asia-Pacific, and is a PhD candidate at James Cook University.
Douglas Walker, MB, ChB, MM, is a retired general practitioner, former Editor of the SPUMS Journal and Project Stickybeak researcher.
Chris Lawrence, MB, BS, FRCPA, is Director, Statewide Forensic Medical Services, Royal Hobart Hospital, Tasmania.
Andrew Fock, MB, BS, FANZCA, Dip DHM, is a senior specialist for the Hyperbaric Service, The Alfred Hospital, Melbourne.
Thomas Wodak, LLB, is a retired County Court judge with an interest in litigation involving medical matters, and a past dive instructor.
Scott Jamieson is a researcher for DAN Asia-Pacific.

Address for correspondence:
John Lippmann
P.O. Box 384 Ashburton
VIC 3147, Australia
Phone: *+61-(0)3-9886-9166*
Fax: *+61-(0)3-9886-9155*
E-mail: *<johnl@danasiapacific.org>*