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

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Abstract

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

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

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

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

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

Key words

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

Introduction

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

Methods

As part of its on-going research into and reporting of diving fatalities in Australia and elsewhere in the Asia-Pacific region, DAN AP has obtained ethics approval from the Human Research Ethics Committee, Department of Justice, Government of Victoria, Australia to access and report on data included in the Australian National Coronial Information System (NCIS). In addition, ethics approvals have been sought and obtained from various coronial offices in certain Australian States and Territories. The methodology used for this report was identical to that described in this journal previously for the 2004 Australian diving-related fatalities.[1]

Breath-hold and snorkelling fatalities (Table 1)

BH 11/01

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

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

Table 1

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

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

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

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

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

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

BH 11/02

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

After an unknown time (but less than 30 min) the friend nearby indicated that he was returning to shore and she responded that she was fine. However, about two minutes later when the friend looked back, he could no longer see the victim snorkelling and was surprised to see her lying motionless on the shoreline. When he went to her, he found her to be unconscious with water oozing from her mouth and nose. He began BLS and was soon assisted by some of the others. However, this was soon abandoned. The reason for this was variously given as "*she had coughed up a lot of water and blood on the beach and took a couple of breaths and appeared to be wheezing slightly*", and she "*looked like she was gone*".

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

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

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

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

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

BH 11/03

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

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

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

Autopsy: This was conducted six days post mortem. BMI was 26 $kg{\cdot}m^{-2}$. The heart weighed 440 g (n.r. 331–469 g). There was severe atherosclerosis of the coronary arteries with greater than 75% narrowing of the right and left anterior descending (LAD) coronary arteries and a 20 x 10 x 10 mm scar of the postero-lateral left ventricle. There was fusion of the right and non-coronary cusps of the aortic valve with calcification and sclerosis but no left ventricular hypertrophy. There was gastric aspirate in the upper airways. The right and left lungs weighed 674 g (n.r. 446–880 g) and 548 g (n.r. 348–790 g) respectively. They showed anthracosis and bullous emphysema of the upper lobes, with marked pulmonary oedema and congestion. There was 100 ml of straw-coloured fluid in both pleural cavities. The cause of death was given as cardiac arrhythmia in a man with ischaemic and valvular heart disease following immersion. Toxicology: nil

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

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

BH 11/04

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

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

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

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

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

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

BH 11/05

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

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

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

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

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

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

BH 11/06

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

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

Autopsy: This was conducted four days post mortem, revealed water immersion changes of hands and feet and marked decomposition changes with discolouration marbling and skin slippage. His weight was not reported. The heart, which weighed 290 g (n.r. 295–445 g), was of normal size and configuration and there was no atherosclerosis. There was a small amount of frothy fluid in the upper airways. The right and left lungs weighed 500 g (n.r. 410–892 g) and 459 g (n.r. 378–780 g) respectively, and were variably expanded and soft. There was a large accumulation of haemorrhagic fluid in the left pleural cavity. The cause of death was given as "*probable drowning due to methamphetamine and alcohol intoxication*".
Toxicology: Alcohol 0.109 g·100 ml^{-1}; amphetamine < 0.007 $mg \cdot kg^{-1}$ (contaminant of methyl amphetamine); methyl amphetamine 0.20 $mg \cdot kg^{-1}$; THC not detected (however, metabolites of cannabis were detected, suggesting past cannabis use).

Comments: Toxicology revealed methamphetamine based on body cavity blood. Normally, toxicology is performed on femoral venous blood but this was probably not available due to decomposition. Cavity blood may be inaccurate due to post-mortem redistribution of drugs. In addition, some of the alcohol detected could have been from post-mortem decomposition. It is likely that the victim was drug-affected, became disoriented and was unable to return to the agreed meeting place. It was speculated that he hid from the rescuers out of concern that he would be in trouble for having an illegal speargun. However, there remain many questions about his state of mind and what lead to his apparent drowning. Methyl amphetamine can have toxic effects on the heart and this level of drug could have directly caused death, although the circumstances probably do not suggest it. Methyl amphetamine also predisposes to erratic behaviour and is associated with an increased risk of self-harm.

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

BH 11/07

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

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

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

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

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

Autopsy: This was performed four days post mortem. BMI was 27 $kg \cdot m^{-2}$. There were numerous haemorrhagic 10 mm puncture marks on the head, chest, abdomen, arms and legs. There were also facial and rib fractures and puncture wounds of the lung and liver, with intra-abdominal haemorrhage. The heart weighed 365 g (n.r. 331–469 g) and was normal in size and configuration with minimal atheroma of the coronary arteries. The upper airway contained fluid. The right and left lungs weighed 588 g (n.r. 446–880 g) and 497 g (n.r. 348–790 g) respectively, and showed moderate pulmonary oedema. The cause of death was recorded as drowning secondary to a crocodile attack.
Toxicology: Alcohol 0.039 $g \cdot 100\ ml^{-1}$ on cavity (not femoral) blood, some or all of which may be due to decomposition

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

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

BH 11/08

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

The conditions were described as clear with a light wind and very little current. The victim was fitted with mask, snorkel and fins and a wetsuit. He and his wife entered the water together but soon separated as she was having trouble swimming. Sometime later she saw her husband "*bobbing up and down between the boat and shore*". She tried to swim to him but others reached him first and towed him to shore. The victim was unconscious, apnoeic and cyanotic and BLS was commenced by a crew member and a passenger. Supplementary oxygen was provided. Possibly 10 min had elapsed from the time he was sighted to the commencement of BLS. He was then transported by boat to a clinic at a nearby resort. On arrival, some 30–40 min after the victim was found, the nurse noted that the victim's pupils were fixed and dilated and that he was regurgitating water and stomach contents. She attached an AED but no shock was advised. BLS was continued for 25 min without a response.

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

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

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

BH 11/09

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

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

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

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

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

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

Summary: 59 y.o. woman with a history of NIDDM, hypercholesterolaemia and asthma not declared and reportedly stable; anxious, relatively inexperienced snorkeller; snorkelling without buddy but near others; 'silent' drowning (cardiac-related)

BH 11/10

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

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

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

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

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

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

BH 11/11

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

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

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

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

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

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

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

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

BH 11/12

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

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

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

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

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

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

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

BH 11/13

This 75 y.o., male overseas tourist, with a history of coronary angioplasty and cervical spine surgery, was on a day trip to a popular island on the GBR. He was reported to have been a competent swimmer but an inexperienced snorkeller, having only snorkelled on two occasions in Fiji wearing a life jacket. A standard snorkel briefing by means of a DVD was conducted on the vessel en route to the island and potential snorkellers were advised to notify staff if they suffered from certain medical conditions. The victim did not do so. He and two friends hired snorkelling equipment from the dive shop (at which there was a sign outlining the potential hazards of diving with various health conditions). The victim declined the offer of a life jacket as it would incur an extra charge. The weather was overcast but the sea was calm and clear. No current was reported.

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

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

No faults were found with the snorkelling equipment.

Autopsy: This was performed two days post mortem. BMI was 29 $kg \cdot m^{-2}$.The heart weighed 325 g (n.r. 331–469 g), the size and configuration being normal. All major coronary arteries showed proximal near occlusion by severe calcific atherosclerosis with stents in the LAD and right coronary arteries. There was microscopic but not macroscopic fibrosis with some small vessel disease. The right and left lungs weighed 545 g (n.r. 446–880 g) and 429 g (n.r. 348–790 g) respectively. They appeared hyper-inflated with moderate pulmonary oedema. The cause of death was given as drowning (cardiac-related).
Toxicology: Ephedrine/pseudoephedrine 1.4 $mg \cdot kg^{-1}$ (potentially toxic range)

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

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

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

BH 11/14

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

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

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

Approximately 10 min later, he began to splash and signalled that he was trouble. He submerged and then reappeared once before re-submerging. The friend ran to the nearby carpark where he asked a bystander to call for help. He then had a short aborted swim towards the float before returning to the carpark and borrowing a board and paddling to where he had last seen the victim, possibly some 20 min earlier. He could not locate his friend and, when the police arrived after another 15 min, they asked him to return to shore. The search was continued by life savers and police and the victims' body was finally found by police divers, 4 h after he was last seen, about 200 m from shore and 50 m from his float. He was unconscious, lying face-up on the seabed at a depth of 5 msw. His mask was around his neck, with the snorkel on the sand nearby. His weight belt was in place and it required two police divers to lift him to the surface.

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

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

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

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

BH 11/15

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

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

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

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

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

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

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

Scuba diving fatalities

SC 11/01

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

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

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

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

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

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

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

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

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

SC 11/02

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

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

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

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

Table 2

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

SC	Age (y)	Sex	Height (m)	Weight (kg)	BMI (kg·m^{-1})	Training	Experience	Dive group	Dive purpose	Depth (msw)	Incident (msw)	Weights on/off	Weights kg	BCD	Remaining air	Equipment test	Disabling injury
11/01	51	F	167	89	32	Yes	experienced	BNS	recreation	18	14	buddy off	5.8	inflated	++	nad	IPE
11/02	48	M	172	91	31	Yes	experienced	GNS	recreation	14	11	rescuer off	5.5	inflated	+++	some issues	PBt
11/03	29	F	172	68	23	Yes	experienced	solo	cave	n/s	n/s	n/s	n/s	inflated	nil	some issues	Asphyxia
11/04	38	M	185	100	29	Yes	limited	BSD	wreck	28	surface	n/s	5.5	inflated	+	nad	Asphyxia
11/05	55	M	172	77	26	Yes	limited	BSB	recreation	4	surface	rescuer off	n/s	inflated	n/s	some issues	Cardiac incident (IPE?)
11/06	23	F	178	78	25	in training	nil	BSB	training	11	n/s	on	5.5	n/i	+	nad	Asphyxia
11/07	37	M	185	97	28	Yes	experienced	BNS	recreation		surface	n/s	10.0	n/s	n/s	nad	Cardiac incident (IPE?)
11/08	47	M	175	122	40	Yes	some	solo	recreation	n/s	surface	n/s	n/s	n/s	n/s	some issues	Cardiac incident
11/09	52	M	171	111	38	Yes	experienced	BNS	recreation	21	n/s	self off	n/s	removed	n/s	nad	Cardiac incident
11/10	40	M	189	107	30	Yes	experienced	BSB	cave	15 mfw	n/s	on	3.8		nil	n/s	Asphyxia
11/11	32	M	178	68	22	Yes	some	solo	spearfishing	12	n/s	n/s	n/s	n/s	n/s	n/s	Trauma
11/12	28	F	156	70	29	in training	nil	GSB	training	5	n/s	rescuer off	8.2	n/i	++	nad	PBt/CAGE? asphyxia?
11/13	47	M	162	77	29	Yes	limited	solo	hunting	5	surface	rescuer off	11.7	n/i	nil	nad	Asphyxia? cardiac incident?
11/14	56	M	172	80	27	Yes	experienced	BSB	recreation	3	surface	off	n/s	inflated	nil	some issues	Asphyxia
SS																	
11/01	50	M	–	–	–	Yes	experienced	solo	commercial	25	surface	n/s	n/s	n/s	+++	–	Trauma? (no body)

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

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

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

SC 11/03

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

The victim was diving a 'side-mount' configuration with a harness and wing-style BCD, wearing a mask (with spare in pocket) and fins; a drysuit with undergarments, hood, boots and gloves; a canister torch (with two back-ups in pockets); a dive computer and separate timer; two 12-L steel cylinders (air) each fitted with a regulator, demand valve and contents gauge; a line cutter and a reel (in pocket); and a wrist slate and pencil. Prior to diving, the victim had recorded that her intended dive time was 220 min. Water temperature was 14^{O}C.

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

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

Autopsy: This was performed five days post mortem. The body showed decomposition changes and, because of this, assessment for barotrauma was not possible, although erect chest X-rays were taken. BMI was 23 kg·m^{-2}. The heart weighed 297 g (n.r. 240–376 g) and was normal. There was a 10 x 2 mm segment of myocardial bridging in the LAD coronary artery (not significant) and no atherosclerosis. Histologically there were two focal microscopic areas of mononuclear cells with focal myocyte necrosis which were thought to be incidental. The airways showed putrefactive haemolytic staining. The right and left lungs weighed 868 g (n.r. 344–750 g) and 568 g (n.r. 291–653 g) respectively, being heavy and hyperinflated. There was 150 ml of dark red fluid in the left pleural cavity and 50 ml in the right (fluid in the lungs appears to migrate into the pleural cavities during the post-mortem interval). The cause of death was given as freshwater drowning.
Toxicology: Alcohol: 0.014 g·100 ml^{-1} (due to putrefaction); carboxyhaemoglobin (COHb): 3% (within normal range)

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

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

SC 11/04

This 38 y.o. man was described as overweight and unfit. His swimming and snorkelling competence was largely unknown. He had a history of hypertension, for which he was taking perindopril, and asthma, for which he used salbutamol infrequently. He was not taking any 'preventer' medication for asthma. At the time of a diving medical just over 12 months earlier, his blood pressure was 142/80; FVC 4.66 L, and FEV_1 3.89 L (83%); he was declared 'fit to dive'. He completed an advanced open water certification in Thailand several weeks later. In total, he had done 10–12 dives; which possibly included three dives to around 30 msw in Thailand. He had not dived beyond 18 msw in temperate Australian waters, in which the incident occurred. It appears that he had not dived for almost a year. His last recorded blood pressure was 163/93, two months prior to the incident. Eight days prior, he had used a borrowed salbutamol inhaler and had taken some over-the-counter cold and flu medication for an upper respiratory track infection several days before diving.

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

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

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

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

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

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

atheroma histologically. There was myocyte hypertrophy but no fibrosis of the myocardium. There was blood-tinged pulmonary oedema in the upper airways. The right and left lungs weighed 880 g (n.r. 446–880 g) and 668 g (n.r. 348–790 g) respectively. These were heavy and crepitant but not over-expanded and showed moderate pulmonary oedema. There were no histological changes of asthma. Ocular fluid showed [Na^+] 153 mmol·L^{-1}, [Cl^-] 124 mmol·L^{-1} (PMVSC 277 mmol·L^{-1}), consistent with salt water drowning.[3] The pathologist gave the cause of death as unascertained but considered drowning to be a possibility. The coronary artery disease and hypertension were not deemed to be sufficient to account for sudden cardiac death and the possibility of a cardiac channelopathy could not be excluded.
Toxicology: Paracetamol: 10 mg·L^{-1} (within therapeutic range)

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

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

SC 11/05

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

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

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

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

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

When tested, the remaining air in the cylinder was found to have a water content of 215 ± 21 mg·m^{-3} (182 ± 18 ppm), over four times higher than the 50 mg·m^{-3} recommended.[8]

Autopsy: This was performed four days post mortem. BMI was 26 kg·m^{-2}. The heart weighed 377 g (n.r. 331–469 g),

the atria appeared dilated (80 ml), there was left ventricular hypertrophy 18 mm (n.r. ≤ 14 mm) and right ventricular hypertrophy 9 mm (n.r. ≤ 4 mm). The mitral valve showed thickening and myxoid degeneration of the anterior valve leaflet consistent with mitral valve prolapse. There was less than 10% narrowing of the LAD coronary artery. Histology of the heart showed mild to moderate perivascular and pericellular fibrosis and scattered microscopic sub-endocardial scars in the left ventricle. No contraction band necrosis was described. The upper airways contained thin blood-stained fluid mixed with gastric contents. The right and left lungs weighed 1250 g (n.r. 446–880 g) and 1276 g (n.r. 348–790 g) and were heavy, congested and oedematous. There was 150 ml straw-coloured fluid in the right pleural cavity and 100 ml in the left. There was an early aspiration pneumonia. The right and left kidneys weighed 143 g (n.r. 132–206 g) and 144 g (n.r. 139–209 g) respectively. The left kidney showed focal scarring and chronic interstitial inflammation and fibro-intimal thickening of arteries and arterioles (due to hypertension). The cause of death was given as "*unascertained*".
Toxicology: Morphine 0.21 $mg \cdot L^{-1}$ (within therapeutic range)

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

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

SC 11/06

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

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

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

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

When later tested by police, the equipment was found to be in "*average and serviceable condition*". A pressure of 50 bar remained in the tank. The carbon dioxide content (658 ppm) and water content (220 $mg.m^{-3}$), of the air were both in excess of the then current standards of 480 ppm and 50 $mg \cdot m^{-3}$ respectively.[8]

Autopsy: Early decompositional changes were noted at the autopsy, performed two days post mortem. The CT scan showed gas within the vessels consistent with decomposition and resuscitation. BMI was 25 $kg \cdot m^{-2}$. The heart had a normal configuration (weight not recorded) and the coronary arteries were widely patent. Frothy fluid was noted in the mouth and nose, with gastric contents and blood-stained fluid in the airways. The lungs were overexpanded and voluminous, crossing the midline. The right and left lungs weighed 530 g (n.r. 305–817 g) and 500 g (n.r. 287–695 g) respectively. There were no pleural effusions. The cause of death was given as drowning.
Toxicology: Citalopram 0.16 $mg \cdot kg^{-1}$; desmethylcitalopram 0.05 $mg \cdot kg^{-1}$

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

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

SC 11/07

This 37 y.o. male had a history of depression for which he was taking duloxetine. His medical history also included drug (cannabis and methyl amphetamine) and alcohol abuse and seizures subsequent to this. His last medical consultation was for a driving medical assessment, three months prior to the incident. His records indicate that he had apparently been seizure-free for nine years and off anticonvulsant medication for the past eight years. However, his wife indicated that three years earlier, the victim had briefly lost consciousness while on a bus and had not reported this to his doctor. It is likely that he also suffered from sleep apnoea and, the previous week, had complained of feeling very tired and having indigestion.

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

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

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

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

Autopsy: This was performed three days post mortem. An erect chest X-ray taken the day prior to autopsy showed no apparent gas bubbles in the heart. There were a few small bubbles in the right atrium of doubtful significance due to the post-mortem delay. BMI was 28 $kg \cdot m^{-2}$. The heart weighed 481 g (n.r. 331–469 g), with equivocal left ventricular hypertrophy of 15 mm (n.r. ≤ 14 mm) and right ventricle 5 mm (n.r. ≤ 4 mm). There was mild mitral valve prolapse but no coronary atherosclerosis. The upper airways contained a small amount of blood-stained froth. The right and left lungs weighed 806 g (n.r. 446–880 g) and 821 g (n.r. 348–790 g) respectively, and were oedematous and congested. Occular fluid showed [Na^+] 138 $mmol \cdot L^{-1}$, [Cl^-] 121 $mmol \cdot L^{-1}$ (PMVSC 259 $mmol \cdot L^{-1}$), borderline for salt-water drowning.[3] The cause of death was given as drowning.
Toxicology: duloxetine 0.16 $mg \cdot L^{-1}$ (within therapeutic range); cannabis 2 $\mu g \cdot L^{-1}$ (consistent with recent cannabis use but not acute intoxication)

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

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

SC 11/8

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

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

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

Autopsy: This was performed three days post mortem. A CT scan (prior to autopsy) revealed no air embolism or evidence of barotrauma. BMI was 40 $kg \cdot m^{-2}$. The heart was heavy, weighing 500 g (n.r. 331–469 g). There was lipomatous hypertrophy of the interatrial septum (25 mm, n.r. ≤ 6 mm) (this can cause arrhythmias and sudden cardiac death). The right ventricular free wall and pulmonary outflow tract showed fatty and fibrous infiltration which the cardiac pathologist suggested may represent arrhythmogenic cardiomyopathy. There was a 40–50% stenosis of the LAD coronary artery. The upper airways contained a film of liquid but no froth or gastric contents. The right and left lungs weighed 571 g (n.r. 446–880 g) and 543 g (n.r. 348–790 g) respectively, with normal expansion and mild to moderate pulmonary oedema. Ocular fluid showed [Na^+] 142 $mmol \cdot L^{-1}$, [Cl^-] 120 $mmol \cdot L^{-1}$ (PMVSC 262 $mmol \cdot L^{-1}$), suggesting salt water drowning. The cause of death was given as arrhythmogenic cardiomyopathy with lipomatous hypertrophy of the interatrial septum.
Toxicology: enalapril 0.01 $mg \cdot L^{-1}$; enalaprilat 0.1 $mg \cdot L^{-1}$; verapamil 033 $mg \cdot L^{-1}$

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

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

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

SC 11/09

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

The victim and his buddy entered the water first and initially descended to 13 msw over 3 min, stopping regularly to take photographs. They swam against a strong current as they worked their way down to 21 msw, where the visibility was poor. They continued to swim against the current, for a time holding hands. However, about 16 min into the dive, the victim appeared to be disoriented and became almost stationary. He coughed loudly before grabbing his buddy's arm and signalling that he wished to ascend. He then ascended rapidly to the surface, omitting the usual safety stop. The buddy ascended behind the victim and, on surfacing, noticed that he was surrounded by what she described as "*yellow vomit*" and his regulator was out of his mouth. He had taken off his mask, hood and BCD and was trying to ditch his weights. When the buddy swam to him and asked if he was okay, he answered "*no*", so she waved to the boat, some 200–300 m away. The victim was cyanotic, gasping, coughing and vomiting and becoming increasingly unresponsive.

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

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

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

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

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

SC 11/10

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

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

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

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

On surfacing, he was informed the victim had not yet appeared. The dive supervisor, already concerned that the pair was overdue, immediately raised the alarm and sent the buddy and another diver back into the cave to briefly search. Neither diver saw the victim until they were exiting the cave, when they finally saw him floating against the ceiling, just 30 m into the cave at a depth of 6.4 mfw. It was clear the diver was dead and so they exited, awaiting formal recovery later that evening. The recovery divers found the victim to be positively buoyant and hence difficult to extricate from the ceiling of the cave.

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

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

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

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

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

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

SC 11/11

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

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

Using the boat hook, the friends dragged the victim's body onto the transom, covered it with a blanket and secured it. No resuscitation attempts were made. A large shark, reported to be a white pointer (*Carcharodon cacharias*) more than 3 m long surfaced next to the boat and followed it until it gained speed. On arrival at the island, death was confirmed by a nurse practitioner. A shark expert confirmed that the injuries were consistent with those from a white pointer shark in excess of 3.5 m long.

Autopsy: The autopsy was performed four days after death. There were multiple traumatic injuries, with part of the left chest wall and the left lower lobe of the left lung missing, and traumatic amputation of the left arm. The injuries were consistent with a shark although no tooth fragments were recovered. BMI was 22 $kg \cdot m^{-2}$. The heart weighed 350 g (n.r. 295–445 g) and was normal with no atherosclerosis of the coronary arteries. There was frothy fluid in the upper airways. The right lung weighed 352 g (n.r. 410–892 g). The cause of death was given as multiple injuries due to shark attack.
Toxicology: Alcohol 0.013 g 100 ml^{-1} (probably artefactual); naproxen 2 $mg \cdot L^{-1}$ (sub-therapeutic)

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

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

SC 11/12

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

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

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

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

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

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

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

The victim's BCD, regulator and tank were found to be functioning correctly. The gauge indicated a pressure of 70 bar and the remaining air was found to be compliant with Australian Standards. Her weight belt was recovered by police on the following day, approximately 20 m from shore and at a depth of 5 msw. Her dive computer records indicated that about 35 min into the dive (possibly three minutes after she was last seen) the victim did a fast ascent from 5.2 msw to 1.25 msw and then sank to the bottom where she remained motionless for 23 min before being taken rapidly to the surface by the rescuer.

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

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

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

SC 11/13

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

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

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

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

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

When tested, his equipment was found to be in good condition and functional and the remaining air (only 5 bar) met relevant purity standards. His dive computer indicated that he had dived to a maximum depth of 5.3 msw for a total of 46 minutes. His catch bag contained 104 abalone and weighed 17.5 kg, whilst his BCD was rated with a maximum lift of 17.2 kg.

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

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

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

SC 11/14

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

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

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

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

Autopsy: The autopsy was conducted three days after death. A CT scan (7.5 h post mortem) revealed no evidence of gas in the heart (either the right or left ventricles) or in the cerebral vessels, and no gas in the soft tissues. BMI was 27 $kg \cdot m^{-2}$. There was some patchy consolidation of the lungs, consistent with drowning. There was a 40 mm bruise on the left parietal scalp but no underlying head injury, and a 20 mm bruise on the right side of the tongue. The heart weighed 406 g (n.r. 331–469 g). The right coronary artery was 60% occluded by calcified atherosclerosis, with no evidence of an unstable plaque. The LAD coronary artery showed approximately 30% narrowing and the circumflex coronary artery less than 10% narrowing by atherosclerosis. The left ventricle showed mild concentric hypertrophy (15 mm; n.r. ≤ 14 mm). Histology showed microscopic fibrosis and subendocardial haemorrhage. There was over 20 ml of gas in the right ventricle at autopsy, although there was no gas in the left ventricle and none obvious in the inferior vena cava. There was pulmonary oedema fluid and water in the mouth and upper airways. The right and left lungs weighed 1212 g (n.r. 446–880 g) and 1108 g (n.r. 348–790 g) respectively, being over-expanded and very heavy. There was severe pulmonary oedema consistent with the diagnosis of drowning. There was anthracosis and mild chronic lung disease. The cause of death was given as drowning following a head injury in a man with ischaemic heart disease.
Toxicology: Nicotine

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

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

Surface-supplied breathing apparatus fatality

SS 11/01

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

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

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

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

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

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

Discussion

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

PRE-EXISTING HEALTH CONDITIONS

Pre-existing health-related conditions are believed to have been a likely or possible contributor to at least 10 (67%) of the snorkelling, and up to 9 (60%) of the compressed gas-related deaths as indicated in Table 3. One experienced snorkeller died directly as the result of asthma which was not well-controlled and was likely exacerbated by common triggers in the diving environment, which include exertion, salt water aspiration and cold. The disabling injury is believed to have been cardiac-related in at least seven (47%) of snorkelling victims, and possibly five (33%) of the deceased compressed gas divers. This is consistent with the increased proportion of cardiac-related incidents in divers over more recent times.[13] Some of these individuals clearly should not have been diving or snorkelling based on their known medical history. Data from various surveys indicate that it is likely that more than 20–30% of active divers have a significant medical condition that may adversely affect their diving safety.[14,15] Therefore, it is important to learn more about the risks associated with diving with clinically significant co-existing medical conditions.

MEDICATIONS

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

SHARK AND CROCODILE ATTACKS

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

Table 3
Chain of events analysis of breath-hold diving-related fatalities in Australian waters in 2011;
AVD – aortic valve disease; CAD – coronary artery disease

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

Table 4
Chain of events analysis of compressed gas diving-related fatalities in Australian waters in 2011; CAGE – cerebral arterial gas embolism; IPE – immersion pulmonary oedema; LADCA – left anterior descending coronary artery; PBt – pulmonary barotrauma

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

AIRWAY PROBLEMS FROM STOMACH CONTENTS AND FLUIDS DURING RESUSCITATION

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

IN-WATER RESCUE BREATHING AND/OR CHEST COMPRESSIONS

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

OTHER ISSUES WITH RESUSCITATION

Premature cessation

It was reported that the victim in BH11/02 was recovered relatively quickly and BLS was begun promptly. However, this was interrupted after a short time as "*she looked like she was gone*". Although efforts were later recommenced, this was after a considerable delay and any opportunity to resuscitate the victim was lost. Lay rescuers are encouraged to continue resuscitation efforts until: the victim responds or begins breathing normally; it is impossible to continue; a healthcare professional takes over BLS or a healthcare professional directs that BLS be ceased.[28] In SC11/04, it was reported that one of the rescuers used a demand valve to try to ventilate the victim. This technique is not recommended for several reasons including: (1) the difficulty in obtaining an airtight seal using a diving demand valve with mouthpiece; (2) the flow rate from a demand valve when purged is very high, often several hundred litres per minute. Such high flow rates easily cause gastric insufflation and consequent regurgitation. By comparison, oxygen resuscitation equipment is limited to 40–60 $L \cdot min^{-1}$ and (3) whereas oxygen resuscitators are fitted with one or more pressure relief valves to prevent pulmonary barotrauma, diving demand valves are not. In circumstances where a rescuer is reluctant to perform mouth-to-mouth or mouth-to-mask ventilation due to the presence of regurgitated stomach contents or other discharge, and/or fear of cross infection, it is better to perform compression-only CPR rather than not attempting or continuing BLS. However, rescuers should be aware that the risk of cross infection in such circumstances is very low.[29]

Defibrillation

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

FATALITIES INVOLVING DIVE STUDENTS

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

BUDDY OVERSIGHT

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

DITCHING OF WEIGHTS IN AN EMERGENCY

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

This highlights an on-going problem of divers being reluctant, or unable, to ditch their weights when they get into trouble. It is likely that, on many occasions, by the time the diver recognises the need to ditch weights, they are too incapacitated to do so. Dive instructors should ensure that they devote appropriate training time to this important factor to imbed the skill. Divers need to remain cognizant of the importance of gaining positive buoyancy in an emergency and practice the skill periodically, at least mentally. In addition, if a diver is planning to use a different weighting system to usual (e.g., changing from a belt to integrated weights), a thorough familiarisation is recommended.

CAVE DIVING

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

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

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

IMMERSION PULMONARY OEDEMA IN DIVERS

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

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

POST-MORTEM VITREOUS SODIUM AND CHLORIDE

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

POST-MORTEM DELAY

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

CORONIAL REPORTS

The purpose of this on-going review of deaths in association with diving is to identify areas in which changes can be suggested to further reduce the incidence of such deaths. The predominant source of the necessary data is the records of Coronial investigations and these investigators are very grateful to the State and Territory Coroners, and the National Coronial Information System (NCIS) for their on-going support with this research and for their efforts in obtaining and providing the relevant documents. These include police reports, witness statements, medical histories, ambulance records, pre-autopsy CT scans, autopsy, toxicological reports and coronial findings. With scuba and SSBA divers, access to prompt (within eight hours is the target) pre-autopsy CT scans can help to determine the presence of gas embolism. Equipment reports and gas analyses are invaluable in trying to ascertain if and how equipment faults played a part in the death. Dive computer downloads can provide good records of some of the victim's actions and the delay to recovery.[40] When reports are unavailable, important information can be missed.

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

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

LIMITATIONS OF THE STUDY

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

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

Conclusions

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

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Acknowledgements

We acknowledge Monash University National Centre for Coronial Information for providing access to the National Coronial Information System; State and Territory Coronial Offices; various police officers, dive operators and divers who provided information on these fatalities. We also acknowledge the input of Dr Douglas Walker and New South Wales Coroner, Michael Barnes.

Conflict of interest and funding

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

Submitted: 10 August 2016; revised 20 September 2016
Accepted: 22 September 2016

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