

Provisional report on diving-related fatalities in Australian waters 2010

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Abstract

(Lippmann J, Lawrence CL, Wodak T, Fock A, Jamieson S, Walker D, Harris R. Provisional report on diving-related fatalities in Australian waters 2010. *Diving and Hyperbaric Medicine*. 2015 September;45(3):154-175.)

Introduction: An individual case review was conducted of known diving-related deaths that occurred in Australia in 2010.

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

Results: There were 20 reported fatalities, one less than the previous year. Five of the victims were female (four scuba divers) and 15 were males. Twelve deaths occurred while snorkelling and/or breath-hold diving, seven while scuba diving (one of whom was using a rebreather), and one diver died while using surface supplied breathing apparatus. At least two breath-hold divers likely drowned as a result of apnoeic hypoxia. Cardiac-related issues were thought to have contributed to the deaths of at least three and possibly five snorkellers, and of at least one, possibly two compressed gas divers.

Conclusions: Snorkelling or diving alone, poor supervision, apnoeic hypoxia, pre-existing medical conditions, lack of recent experience and unfamiliar and/or poorly-functioning equipment were features in several deaths in this series. Reducing delays to CT-scanning and autopsy and coroners' reports documenting that the victim of a drowning was snorkelling or scuba diving at the time are aspects of the investigation of these fatalities that could be improved.

Key words

Diving deaths; scuba; breath-hold diving; surface-supply breathing apparatus (SSBA); diving accidents; case reports

Introduction

Scuba diving and snorkelling are popular recreational activities in Australia in which, during or as a result of their participation, some die each year. Given that diving takes place in a relatively inhospitable environment, some of these deaths are unavoidable. However, analysis of diving-related fatalities indicates that many might have been avoided through appropriate preventative measures such as more extensive education and training, greater experience, better planning and decision-making, appropriate medical screening, improved supervision, or better equipment choice, familiarity and maintenance.

The aims of the Divers Alert Network (DAN) Dive Fatality Reporting Project are to:

- educate divers and the diving industry about good, safe diving and snorkelling practices;
- inform physicians on the causes of fatal dive accidents in the hope of reducing the incidence of similar accidents in the future and of detecting, in advance, those who may be at risk. This report includes the diving-related fatalities between 01 January and 31 December 2010 that are recorded on the DAN Asia-Pacific (AP) database. When an accident was unwitnessed, it is difficult to determine accurately what had occurred. 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 Victorian Department of Justice Human Research Ethics Committee to access and report on data included in the Australian National Coronial Information System (NCIS); the Royal Prince Alfred Hospital Human Research Ethics Committee; the Coronial Ethics Committee of the Coroner's Court of Western Australia; and the Queensland Office of the State Coroner. The methodology used for this report was identical to that described previously for the 2004 Australian diving-related fatalities.¹

Breath-hold and snorkelling fatalities

BH 10/01

This victim was a 39-year-old (y.o.) male who ran for exercise and, other than being obese (BMI 31.7 kg·m⁻²) appeared to have been relatively healthy. His medical history revealed a compound fracture of the right elbow with subsequent osteomyelitis, renal colic and recent ureteroscopy and laser lithotripsy to remove a kidney stone, after which he had been cleared to dive by his doctor. He was an experienced snorkeller and scuba diver who was certified seven years earlier but had been diving unqualified for many years prior to that. He regularly dived alone catching crabs. The victim was snorkelling alone at a familiar site on a warm, still night. In addition to a reef, there was a large wreck scuttled at this site as a breakwater at a depth of 4–6 metres' sea water (msw). He wore a mask, snorkel, fins, full wetsuit with attached hood, booties and gloves and carried a torch and a catch bag.

Table 1 Summary of snorkelling and breath-hold diving-related fatalities 2010; BMI – body mass index; BNS – buddy not separated; BSB – buddy separated before problem; GNS – group not separated; GSB – group separated before; mw – metres’ water; n/a – not applicable; n/s – not stated; jkt – wearing lifejacket

BH	Age (yr)	Sex	Height (cm)	Weight (kg)	BMI (kg·m ⁻²)	Experience	Dive group	Dive purpose	Depth (mw)	Incident (mw)	Weight belt, weights (kg)	Disabling injury
10/01	39	M	181	104	31.7	Yes	Solo	Hunting	4–6	n/s	Yes, n/s	Unknown, asphyxia?
10/02	77	M	184	111	32.8	n/s	BNS	Recreation	n/s	surface	No, jkt	Cardiac incident
10/03	27	M	185	83	24.3	Yes	Solo	Training	1–1.5	n/s	n/s	Asphyxia
10/04	24	M	–	–	–	n/s	Solo	Recreation	n/s	n/s	n/s	Unknown, asphyxia
10/05	55	M	173	130	43.4	n/s	GNS	Recreation	n/s	surface	No, n/a	Cardiac incident
10/06	27	M	173	64	21.4	n/s	GSB	Recreation	5–6	n/s	n/s	Unknown, asphyxia?
10/07	73	M	197	120	30.9	Some	GNS	Recreation	n/s	surface	n/s	Cardiac incident
10/08	60	M	175	83	27.1	Yes	BSB	Spearfishing	10–15	surface	Yes, n/s	Cardiac incident?
10/09	30	M	180	78	24.1	Yes	GSB	Spearfishing	10	n/s	Yes, n/s	Cardiac incident? asphyxia?
10/10	64	F	164	58	21.6	nil	GSB	Recreation	15–20	surface	n/s	Unknown, asphyxia
10/11	31	M	185	85	24.8	Yes	BNS	Spearfishing	23–30	n/s	Yes, 4.5	Asphyxia
10/12	28	M	178	78	24.6	Yes	GSB	Recreation	16	n/s	n/s	Asphyxia? cardiac incident?

His wife alerted family members early the next morning as she became concerned that he had not returned home. His car was soon located near where his wife believed he would have been diving. The police were notified and a large air, sea and underwater search was conducted, without success. Police divers searched inside the wreck but found no trace of the victim. Three months later, the victim’s badly decomposed body was found within a compartment inside the wreck; his weight belt was still in place but his mask, snorkel and one fin had been displaced.

Autopsy: At autopsy four months post incident, the body showed decompositional change including adipocere (decompositional breakdown of fatty acids in moist conditions) which made any interpretation of autopsy findings difficult. The cause of death was reported as unascertained. Possibilities include drowning due to entrapment or disorientation and a sudden natural event such as cardiac arrhythmia.

Toxicology: nil

Comments: How this victim died is unknown. The wreck is in an unstable state and prone to substantial silting, creating a high risk of entrapment, and is a prohibited site for divers and snorkellers. The victim likely became disoriented or trapped inside the wreck and drowned. It is impossible to diagnose drowning in the presence of significant decomposition.

Summary: Male, 39 y.o.; experienced snorkeller and scuba diver; snorkelling alone at night, most likely inside a wreck; body found four months later; unknown cause of death

BH 10/02

This 77 y.o. male overseas tourist was obese (BMI 32.8 kg·m⁻²), with a history of coronary bypass surgery eight years prior, hypertension, hypercholesterolaemia and prostatic hyperplasia. He was taking terazosin, simvastatin, furosemide, metoprolol, telmisartan and aspirin. He had visited a general practitioner one month earlier before travelling but it is unknown what, if any, advice was provided about snorkelling. His swimming and snorkelling ability and experience were unreported.

He and a friend were on a day trip to the Great Barrier Reef (GBR) on a large tourist vessel with 291 guests. The group was taken to a large pontoon anchored on the GBR, from which organised snorkelling was conducted. In addition to public announcements of the risks posed by various health conditions when snorkelling, there was a pre-snorkel briefing and guests were asked to declare relevant medical details from which a ‘risk register’ was created. The victim was not recorded on this register.

The victim was provided with a mask, snorkel, fins, stinger suit and a life vest. There was a moderate wind (15 knots), a surface chop and waves 0.5–1 m high, visibility was described as “good” and the water temperature was 28°C.

The friend reported that there was a strong current. On entering the water from the pontoon, the victim initially seemed to be calm and swam a short distance along a rope before being swamped by some swells and banging his head on a buoy. He appeared to panic and tried to climb onto his friend whilst signalling for help. The lookout saw this and a nearby tender was sent to assist. The tender driver asked the victim if he was okay, to which he replied "No". The driver reached out and held the victim's hand shortly before the victim became limp, unconscious and cyanotic. The tender driver and two assistants could not lift the victim into the tender due to his size, so they towed him the 15 metres to the pontoon. Basic life support (BLS) was soon commenced by trained staff, and oxygen (O₂) gear and an AED were requested. The AED battery was flat and needed to be replaced, delaying its use by several minutes. Oxygen supplementation was provided to ventilations. When the functional AED was attached, no shock was advised. BLS continued. When a guest, who was a doctor was found, he re-assessed the victim and provided adrenaline orally. BLS was continued for a total of about 50 minutes before the doctor pronounced the victim dead.

Autopsy: The autopsy was performed two days after death. External examination revealed a small bruise on the right forehead and a midline thoracotomy scar and vein harvesting scars consistent with coronary artery bypass surgery. There were no bites or stings. The heart was large, weighing 900 g (normal range (NR) 400 ± 69 g) and the pericardial sac was obliterated by fibrous adhesions from the previous surgery. The left ventricle was hypertrophied. The native coronary arteries showed severe occlusive atheroma, including distally, although the grafts were patent. The myocardium showed extensive fibrous scarring but no acute ischaemia. There was a stent in the left renal artery. The upper airways showed no pulmonary oedema and the right (R) and left (L) lungs weighed 600 g (NR 663 ± 217 g) and 569 g (NR 569 ± 221 g) respectively and appeared slightly over-expanded.

Toxicology: nil

Comments: It is likely that this victim's cardiac-related death was precipitated by the combination of immersion, exertion, aspiration and anxiety in a person predisposed to sudden cardiac death in a variety of circumstances, not specifically diving-related. This man had significant enlargement of the heart with progressive coronary atheroma despite bypass grafting. He was probably unfit for snorkelling. Relatively minor trauma can precipitate drowning especially in an unfit snorkeller in a current. The snorkelling was well-organised and well-supervised, and the tour operator's staff acted swiftly and appropriately. However, he was not on the risk register and the AED had a flat battery despite purported regular checks. It is fortunate that a spare, charged battery was available. This should serve as a warning to those who keep an AED in their workplace or at home to ensure it is operational at all times.

Summary: Male, 77 y.o.; history of open heart surgery and hypertension; swimming and snorkelling ability unknown; conditions choppy with current; panicked when swamped by waves; prompt rescue; BLS unsuccessful; cardiac death in a predisposed person

BH 10/03

This fit, active, 27 y.o. man swam five or six days per week and had no known medical conditions. He was a qualified scuba diver and keen spearfisherman. Dressed in board shorts and wearing a mask, snorkel and fins, he was apparently practicing extending his breath-hold time in the swimming pool of the residential complex where he lived. The pool was 20 m long and 1 to 1.5 m deep.

Another tenant entered the pool area and noticed the victim lying motionless and apparently unconscious on the pool bottom. He called for help and for an ambulance. Another tenant entered the water and, with difficulty, lifted the victim out of the pool, unconscious, apnoeic and cyanotic. When another person arrived, two-operator BLS was commenced and continued until paramedics arrived approximately 10 minutes later. There were stomach contents and frothy sputum in the victim's mouth. Advanced life support (ALS) was implemented and spontaneous circulation was restored after defibrillation. The victim was transported to hospital where a CT scan revealed diffuse cerebral oedema consistent with severe hypoxic brain injury. He died the next day.

Autopsy: The trachea and bronchi contained pink frothy fluid. The lungs were heavy (R = 1045 g, NR 651 ± 241 g; L = 959 g, NR 579 ± 201 g) and oedematous. The heart weighed 403 g (NR 370 ± 75 g) and was normal. The cause of death was drowning.

Toxicology: nil

Comments: This young man likely became unconscious from apnoeic hypoxia, with or without hyperventilation. Loss of consciousness in water often ends tragically, especially if there is no rescuer immediately available. Although there was a surveillance camera in the area, the monitor was in an unmanned security room, so was useless in this incident. It is important for the community (diving and general) to understand that apnoeic hypoxia can occur after extended breath holding even in shallow water. Drowning after loss of consciousness due to a cardiac arrhythmia such as long QT remains a possibility, although specific enquiries disclosed no family history of sudden death or syncope.

Summary: Male, 27 y.o.; fit and healthy; regular swimmer, qualified diver and keen spearfisherman; likely practising breath holding in pool alone; found on pool bottom; defibrillation restored spontaneous circulation; died next day; drowning

BH 10/04

This 24 y.o., male overseas tourist was in Australia on a working holiday. His medical history is unknown although his friend believed him to be healthy, but “*not a strong swimmer*”. The victim and his friend were on a guided tour of a semi-tropical island. The group walked about 2.5 km to an inland freshwater lake. Wearing shorts, swim goggles and a snorkel, the victim snorkelled for a short time before returning to shore. He then re-entered the water and the friend noticed him snorkelling about five metres from the shore. The friend looked away for possibly 30 seconds and, when he turned back, his friend was nowhere in sight. Despite a short search by the group and others, the victim was not found. The group then walked back to the waiting tour guide, alerted him, and the police were contacted. Police divers found the victim’s body the next day, after a presumed submersion time of 16 hours.

Autopsy: Autopsy, performed five days after death, revealed early decompositional changes and some post-mortem skin damage to the right thigh. Post-mortem X-rays revealed no bony damage. There was no pulmonary oedema in the upper airways (this feature may be lost with decomposition) and the R and L lungs, which weighed 720 g (NR 663 ± 239 g) and 600 g (NR 583 ± 216 g) respectively, appeared overexpanded and contained pulmonary oedema fluid. The heart weighed 395 g (NR 365 ± 71 g) and was normal. The cause of death was given as drowning.

Toxicology: nil

Comments: The victim’s disappearance was unwitnessed and apparently silent. Precisely how and why he died is unknown. He was reportedly not a good swimmer and likely an inexperienced snorkeller. He may have aspirated water through the snorkel or his nose and subsequently drowned.

Summary: Male, 24 y.o.; apparently healthy; poor swimmer; using goggles and snorkel; submerged silently; drowning

BH 10/05

This 55 y.o. man was severely obese with a BMI of 43.4 kg·m⁻². He had a history of coronary artery bypass surgery (six years prior), diabetes, hypertension and hypercholesterolemia. His prescription medications included felodipine, irbesartan, hydrochlorothiazide, spironolactone, metformin hydrochloride, glimepiride, isosorbide mononitrate, atorvastatin, carbamazepine, aspirin and tadalafil. His swimming ability and snorkelling experience were not reported.

The victim went on a snorkel safari on the GBR. At the dive shop, he and others were briefed on medical issues and snorkelling and were asked to write any personal medical conditions on the relevant form. The victim declared hypertension but no other medical conditions. Because of

his size, the tour operator assessed him as a potential risk and allocated him to a small group with a snorkel guide. The victim entered the water wearing a mask, snorkel, fins and a two-piece wetsuit without a weight belt. He also took a ‘noodle’ buoyancy aid. The water was described as calm and visibility was 3–6 metres. There was no current.

Shortly after entering the water, the victim rolled onto his back, holding onto the ‘noodle’. The dive guide was soon with him. The victim complained that his wetsuit was too tight. The guide handed him a life ring to help support him while she removed his wetsuit top. He became distressed, and asked to return to the boat. The guide signalled to the tender driver and they began to swim towards the tender. When the tender arrived, the victim could not lift himself into it and became less responsive. The tender driver was unable to drag him aboard owing to his size. The guide used the ‘noodle’ to support the victim as they were towed about 50 m to the boat by the tender. Two staff dragged the now unconscious victim onto the boat and rolled him into the recovery position. Frothy sputum emerged from his mouth. He was soon apnoeic and cyanotic and the guide and captain began BLS, promptly adding supplemental O₂ via a resuscitation mask with oxygen inlet. Contrary to local regulations, there was no defibrillator available on the boat. The victim was taken to a nearby island, arriving about 55 minutes post incident. Two nurses attached a defibrillator but no shock was indicated. Adrenalin was administered but the victim failed to respond, so resuscitation efforts were soon abandoned.

Autopsy: This was conducted two days after death. The heart was significantly enlarged weighing 990 g (NR 400 ± 69 g). The pericardial sac was densely adherent to the heart due to previous coronary artery grafting. The native coronary arteries showed severe occlusive atheroma and there was severe stenosis distal to the vein grafts although the graft anastomoses were patent. There was left ventricular hypertrophy. Histology showed ischaemic fibrosis without acute infarction. The upper airways showed no pulmonary oedema. The R and L lungs weighed 760 g (NR 663 g +/- 217 g) and 800 g (NR 658 g +/- 257 g) respectively, and showed pulmonary oedema. The cause of death was given as ischaemic heart disease.

Toxicology: nil

Comments: Despite snorkelling on a tropical reef being on many people’s ‘bucket list’, not everyone is compatible with snorkelling, whether they realise it or not. With his severe obesity, cardiac disease, diabetes and extensive list of medications, this man was at very high risk. Added to the effects of immersion and exertion, the tight wetsuit top may have compromised his breathing and increased his anxiety. Had he fully declared his medical conditions he may likely not have been permitted to snorkel. Although it may not have been a factor in this incident, there is sometimes tension between commercial interests, the fear of

upsetting a customer, and provision of sufficient information to deter those most at risk, by spelling out clearly what those risks may lead to. The snorkelling staff appear to have done well under difficult circumstances. However, it is important to have a pre-determined and well-practiced protocol for dealing with such eventualities, such as lifting an unconscious and/or large person into a tender.

Summary: Male, 55 y.o.; history of coronary artery bypass surgery, diabetes, hypertension in a very obese man; swimming and snorkelling ability unknown; calm conditions, no current; complained wetsuit too tight; became anxious; delayed rescue; BLS unsuccessful; cardiac death

BH 10/06

This 27 y.o., male tourist was on a working holiday in Australia. There was no information about his medical history or whether he was taking any medications. He was described by his friends as a “*weak swimmer at best*”. He and four friends went swimming from a surf-prone beach with a coral reef nearby. At the time, waves were reported to be less than one metre, there was a light wind and the weather was warm but cloudy. The visibility was not reported, but a local diver later stated that it typically became poor in the afternoons, owing to a freshening wind and choppy surface conditions. The victim was wearing a mask, snorkel and board shorts.

After swimming together for a while, the friends headed further from shore while the victim remained closer to the beach. When the friends returned around 20 minutes later, there was no sign of him. They notified locals who contacted the police. The others did not return to the water to look for the friend as they considered themselves poor swimmers. There was little information provided due to language difficulties and the absence of a proper interpreter. Eventually the victim’s body was found the next morning lying on the seabed about 10 m from shore, at a depth of 5–6 msw. He was still wearing his mask and snorkel.

Autopsy: Autopsy was limited to external examination. There was foamy fluid in the mouth consistent with drowning.

Toxicology: nil

Comments: It is inappropriate, although not uncommon, that this likely inexperienced snorkeller, a weak swimmer, was left to snorkel alone. An alert buddy could have raised the alarm earlier when the victim got into difficulties or disappeared. The depth of the snorkelling site was not stated, however, given that the body was found only 10 metres from shore at a depth of 5–6 msw, it is likely that the victim would have been unable to stand to rectify any problems even a very short distance from shore.

Summary: Male, 27 y.o.; medical history unknown; weak swimmer; not wearing fins; buddy separation; unwitnessed submersion; body found next day; drowning

BH 10/07

This 73 y.o. man, an interstate tourist holidaying on the GBR, had a history of atrial fibrillation and bilateral hip arthroplasty. His regular medications were candesartan, clexetil and low-dose aspirin. He was also taking cephalixin for a toe infection and had taken two hyoscine hydrobromide tablets that morning to prevent sea-sickness. His swimming experience was not reported. He had snorkelled before, but it seems he was relatively inexperienced as two days earlier he was reported to have “*swallowed a lot of water*”.

He was on a vessel with six friends when they decided to snorkel. He was wearing a mask, snorkel and ‘rashie’ but no fins. The water temperature was 24°C, surface conditions were not reported, though one friend stated that there was not much current. After about 20 minutes, the victim signalled to the tender driver that he wanted to be picked up. He said that he was OK but did not want to snorkel any longer. While trying to board the tender, made more difficult due to his large size, he became exhausted, short of breath and began coughing. He was unable to climb the ladder despite assistance from others. With his leg straddled over the tender, he was slowly towed 50 m to the main vessel.

After being helped aboard, he was sitting in a deck chair near the stern, looking very ill, and wheezing, exhausted and dyspnoeic. He fell out of the chair and was unable to get back into it. He became unconscious and was rolled onto his side so that “*muck*” could be cleared from his mouth. BLS was commenced and continued during the 15-minute boat ride to a nearby island, where two nurses from the island attached a defibrillator (it is not clear whether or not any shock was delivered) and continued resuscitative efforts, including administration of adrenaline, unsuccessfully.

Autopsy: The heart weighed 630 g (NR 400 ± 69 g) and showed left and right ventricular hypertrophy and some mitral valve prolapse. The left coronary artery and its branches were 60% occluded by atherosclerosis. Histology revealed mild fibrosis and some early ischaemia (eosinophilia of the myocytes). The R and L lungs weighed 1210 g, (NR 663 ± 217 g) and 990 g (NR 569 ± 217 g) respectively and were oedematous. The cause of death was given as drowning due to cardiac arrhythmia due to cardiomegaly.

Toxicology: nil

Comments: Given his reportedly poor snorkelling skills, he likely aspirated water. This, combined with the effects of immersion and exertion, could have triggered a fatal arrhythmia in a man with a history of atrial fibrillation. While generally neither 75% stenosis nor unstable plaques are regarded as significant lesions, the combination of 60% stenosis with left and right ventricular hypertrophy in the presence of atrial fibrillation is probably sufficient to account for an arrhythmia sufficient to cause drowning. However, immersion pulmonary oedema (IPO) cannot be ruled out as a possible differential diagnosis.

Summary: Male, 73 y.o.; history of atrial fibrillation; poor snorkel technique; possible aspiration; exertion trying to board tender; collapsed on board vessel; resuscitation unsuccessful; drowning? (cardiac related?, IPE related?)

BH 10/08

This 60 y.o. man was reported as “*fit for his age*”, a highly experienced freediver and spearfisherman (being the recipient of several freediving awards and accolades), as well as an active and experienced recreational and commercial scuba diver. He was being treated for well-controlled bipolar affective disorder, depression, hypothyroidism and insomnia. Medications included olanzapine, lithium carbonate, thyroxine sodium and temazepam.

The victim went spearfishing with a friend, also an experienced spearfisherman, at a site familiar to both of them. Dressed in a wetsuit, weight belt and carrying mask, snorkel, fins and a line with float, the pair walked about 300–400 m from the car park down a rocky hill to reach the shoreline. The victim then returned to the car to retrieve a forgotten item. They entered the water from the rocky shore. The weather was warm, there was a light wind and the swell was around 1.5 metres high. The buddy later described the conditions as “*challenging, but not beyond [their] capabilities*”. After swimming through a channel in the rocks they began spearfishing in 10–15 msw. After several dives, the victim reported that he was “*having trouble catching my breath and am going in*”. The buddy said that he would follow soon and, after several more dives, he also swam towards the agreed exit point against a current. When nearby, the buddy noticed the victim’s fins on a rock and saw the victim floating face-up at the surface near the rocky shoreline. When the buddy reached him, the victim was unconscious, cyanotic and apparently apnoeic and was not wearing his weight belt.

The buddy dragged his friend out of the water, rolled him onto his side and noticed some bile and water draining from his mouth. He began BLS, assisted by bystanders. After every few cycles, the airway needed to be cleared of water and stomach contents. An ambulance was called and volunteer paramedics arrived 35 minutes later, continuing resuscitation efforts for another 30 minutes before ceasing. A defibrillator was attached but it is unclear if any shock was delivered.

The friend later reported that on their last dive outing approximately five weeks earlier, which involved strenuous breath-hold dives over an extended period, the victim “*ran out of steam*” while swimming back to shore. The buddy noted that his friend looked unwell and, on palpating his pulse believed it to be very fast. He advised the victim to see a doctor but this advice went unheeded. Apparently he had been scuba diving in the interim.

Autopsy: This was conducted two days after death and there were early decompositional changes. The heart weighed 456 g (NR 400 g ± 69 g) and the left and right ventricles were slightly dilated. The coronary arteries were between 50 and 70% narrowed by atherosclerosis. The upper airways were clear the R and L lungs weighed 424 g (NR 663 g ± 217 g) and 340 g (NR 569 g ± 221g) respectively. The cause of death given was consistent with coronary atherosclerosis.

Toxicology: citalopram, temazepam and olanzapine detected; measurement of lithium is usually performed on serum rather than whole blood and obtaining serum at post mortem is difficult if there has been any post-mortem delay.

Comments: This victim apparently ignored warning signs of increasing dyspnoea while diving and consequently the opportunity to investigate his cardiac function. Although his coronary atherosclerosis was marginal, combined with exercise, breath holding and possible drug effects it likely sufficed to cause the cardiac event. This was possibly further exacerbated by the need to return to shore against a current. It is always good practice to accompany a buddy out of the water, especially if unwell. It is unlikely that this affected the outcome in this instance, given the remote location and the delay in availability of a defibrillator.

Summary: Male, 60 y.o.; history of bipolar affective disorder, hypothyroidism, insomnia and depression; highly experienced breath-hold and scuba diver; challenging conditions; previous episode of breathlessness while spearfishing; became unwell and swam to shore alone; found unconscious by buddy; BLS unsuccessful; moderate coronary atherosclerosis; cardiac-related death; ?immersion pulmonary oedema

BH 10/09

This 30 y.o. man was an experienced and apparently competent breath-hold diver and a member of a spearfishing club. His family reported that he appeared to be healthy and on no medical treatment. He went spearfishing with two others, one of whom had dived with him previously. They dived from a small boat. The victim was wearing mask, snorkel, fins, full-length wetsuit, weight belt; and carried a speargun, float and a Shark Shield.

The weather was warm, the water temperature 22°C, the current was described as “*light – less than 1 knot*” and visibility was at least 15 metres. The surface conditions were not reported. They initially anchored the boat in a depth of 14–17 msw and dived there for about an hour. When they reboarded the boat, the victim seemed to be fine but mentioned that it had been a bit deep for him. They subsequently moved and anchored in water about 10 msw deep. After snorkelling with the others for about 10 to 15 minutes, the victim swam off by himself and snorkelled nearer to the boat. When one of the divers returned briefly to

the boat to offload a fish, he passed by the victim and called out to him. The victim was swimming steadily, appearing to be concentrating on something below and failed to respond but appeared to be fine.

When his companions returned to the boat about 30 to 40 minutes later, the victim was found nearby, floating vertically just below the surface, unconscious, with his weight belt in place. His speargun was missing. His belt was ditched and he was dragged aboard the boat, unconscious and apnoeic with a grey appearance. When checking, one companion initially thought that he felt a faint pulse. He was placed on his side and a large amount of water flowed from his mouth and nose. One companion commenced BLS while the other made a Mayday call on the boat radio. It was necessary to place the victim onto his side periodically to drain large amounts of water and blood-stained froth. A large vessel came to assist, the victim was transferred aboard and BLS was continued en route to the harbour. On arrival, they were met by an ambulance crew who continued resuscitation efforts. An AED was attached and, although initially no shock was advised (i.e., the victim was likely in asystole), after a period one shock was advised and given, albeit unsuccessfully. The victim was declared dead shortly afterwards.

Autopsy: The autopsy was performed three days after death. The heart weighed 322 g (NR 370 ± 75 g). The coronary arteries showed a 90% narrowing at the midpoint of the left anterior descending (LAD) coronary artery with 40% occlusion of the right coronary artery and 50% stenosis of the left main and left circumflex coronary arteries. The R and L lungs weighed 764 g (NR 651 ± 214 g) and 700 g (NR 579 ± 201 g) respectively. There was frothy fluid in the oropharynx, trachea and bronchi and the lungs were congested and oedematous. The cause of death was given as secondary drowning due to ischaemic heart disease.

Toxicology: nil

Comments: The police report suggested that this victim might have drowned as a result of 'shallow water blackout'. There was no mention in any of the reports whether the victim practiced pre-dive hyperventilation. Given the evidence of significant coronary atherosclerosis, the victim may have suffered an arrhythmia, become unconscious and subsequently drowned. The absence of a nearby and vigilant buddy made survival highly unlikely.

Summary: Male, 30 y.o.; apparently healthy; experienced spearfisherman; separation; found unconscious in water; BLS unsuccessful; significant coronary atherosclerosis; drowning (likely cardiac-related)

BH 10/10

This 64 y.o. woman was an overseas tourist with a history of dyslipidaemia. She was reported to be a competent swimmer but she had no prior snorkelling experience. The victim, her husband and daughter were among 10 tourists

on a commercial snorkel tour on a charter boat. Prior to departure, she signed a liability waiver that confirmed that she could swim and was aware of the risks on the planned activity. Although she spoke no English, her daughter, a fluent English-speaker, translated it for her. She was issued with a mask, snorkel, fins and wetsuit which were dry-tested for correct fit.

Once at the site, the victim entered the water with nine other snorkellers and a guide to snorkel with some manta rays. The depth and visibility were about 15 to 20 m, and the water was described as calm with no current or surge and a temperature of 24°C. After a while, her husband had problems with his mask. Their daughter accompanied him to the boat and was told to come aboard as it was time for another group to enter the water. The first group was then recalled. As the rest of her group was re-boarding, the victim was seen snorkelling without obvious distress, with her arms by her side and finning some 10 m from the boat. A crew member entered the water to help her but before he reached her she went limp. He rolled her over and noticed that she was unconscious with froth flowing from her mouth. Another crew member jumped in and helped to tow the victim back to the vessel.

She was brought aboard and placed in the recovery position as she was vomiting. Her airway was cleared and she was assessed as apnoeic. Shortly afterwards, when another passenger, a nurse, was recalled to the boat, he again rolled the victim into the recovery position to drain water and froth from her airway before beginning BLS, assisted by another passenger, a doctor. Oxygen equipment was provided but proved useless as the only delivery device was a non-rebreather mask which is unsuitable for use with a non-breathing victim. BLS was continued en route to the wharf and maintained for a short time by an attending ambulance crew. They attached a defibrillator and no shock was advised (asystole). Resuscitation efforts were abandoned about one hour after being commenced because of the lack of response.

Autopsy: At the request of the family, only an external autopsy was conducted and, as a result, the cause of death was recorded as "unascertainable".

Toxicology: nil

Comments: Given the lack of an internal autopsy, it is impossible to ascertain whether a cardiac or other medical condition played any part in this incident. However, given her lack of snorkelling experience, and her insignificant medical history, it is quite possible that drowning was the primary event. The available O₂ equipment, while being suitable for use with many spontaneously breathing victims, was unsuitable for oxygen-supplemented ventilation. The investigating coroner recommended that dive charter vessels carry a positive pressure O₂ system.

Summary: Female; 64 y.o.; history of dyslipidaemia; competent swimmer; first snorkel experience; brief

separation from group; sudden unconsciousness; O₂ equipment unusable; BLS unsuccessful; disabling agent and cause of death unknown

BH 10/11

This fit, 31 y.o. man was an experienced breath-hold diver and spearfisherman. He had recently attended an extended apnoea training programme to enable him to dive deeper and longer. He and six friends, also experienced, set out to spearfish from two boats. The weather and sea conditions were not reported. After some 'warm-up' diving at depths of 11–13 msw, they moved to a new site, anchoring the boats on a wreck. The depth ranged from 23 msw at the top of the wreck to 27–30 msw to the sand. The water temperature was 29°C and visibility varied from around 7 m at the surface to 2–4 m on the wreck.

The victim and five of his friends entered the water while one of the group remained on board as a lookout. The victim was wearing a mask, snorkel, fins, a 1.5 mm thick wetsuit with hood, weight belt with 4.5 kg and was carrying a speargun. When they entered the water there was no current. They dived for a while using a 'one-down-one-up' protocol for greater safety. After a while one of the group's spear became stuck in the wreck and several divers tried unsuccessfully to retrieve it. The victim offered to get it and was reported to be seen "*breathing up*" on the surface before descending, carrying a friend's speargun. After about 30 seconds, the owner of the stuck spear felt the tension on its attached cord release, indicating that the victim had freed it. However, he became concerned after about another 30 seconds when the victim failed to surface. The buddies then performed many dives in an unsuccessful attempt to find their friend, hampered by the depth, increasing current and poor visibility. His speargun was found floating on the surface 100–200 m from the wreck about 45 minutes after he disappeared. The spear had been discharged and was later found under the wreck. The two-metre cord that had attached it to the speargun had been sheared, which, according to the police had likely resulted from rubbing against the wreck.

Almost four hours later, about five minutes into their search, police divers located his body lying on his back about three metres from the wreck at a depth of 30 msw. He was brought to the surface and declared dead by a doctor who had arrived with one of the search teams.

Autopsy: The autopsy was done three days after death. There were petechiae on the orbital conjunctiva and on the eyelids (possibly from mask squeeze). There was white frothy fluid in the mouth. The R and L lungs weighed 800 g (NR 651 ± 241 g) and 740 g (NR 579 g ± 201 g) respectively and were unremarkable apart from some congestion. The heart weighed 270 g (NR 370 g ± 75 g) and was normal without significant coronary atheroma. The cause of death was given as drowning.

Toxicology: nil

Comments: This drowning resulted from apnoeic hypoxia either from pre-dive hyperventilation, or possibly, after freeing the initial spear from the wreck, the victim may have speared a fish using the gun he was carrying and the cord from his spear snagged on the wreck delaying the ascent and causing unconsciousness. Being negatively-buoyant he sank to the bottom. Whatever the actual sequence of events leading to this death, the practice of pre-dive hyperventilation is known to be dangerous. The combination of pre-dive hyperventilation, depth, extended breath holding and exertion was a potentially lethal mixture.

Summary: Male, 31 y.o.; healthy and fit; experienced breath-hold diver and spearfisherman; deep dive to retrieve friend's spear; breath-hold search made difficult by depth, poor visibility and current; BLS not attempted; drowning (apnoeic hypoxia post hyperventilation or entrapment?)

BH 10/12

This 28 y.o., male overseas tourist was an experienced spearfisherman who had qualified as an Open Water Diver in his home country some four months earlier. He was on a large live-aboard vessel on the GBR and had arranged to do some general work on the boat for part of the four-day trip in exchange for a discount on accommodation and diving. The victim did not declare any medical conditions on a pre-dive/snorkel medical questionnaire. Another casual worker/tourist who had snorkelled with him earlier on during the trip reported that he could hold his breath underwater for 60–90 seconds and tended to snorkel alone.

On this day, the victim had done an early-morning scuba dive from another vessel. No details of this are available but nothing untoward was reported. He was said to have been of "*normal disposition*" afterwards and had not consumed any alcohol. He then transferred back to the large vessel which was carrying approximately 80 passengers and 11 crew. After a briefing, the victim entered the water with around 30 others. He was wearing mask, snorkel and fins, a stinger vest and bathers. He was not wearing a wetsuit despite this being specified as a requirement by the operator. The weather and sea conditions were described as "*good*" with a slight breeze and current, and visibility of 10 metres. The skipper of the vessel was reported to have been acting as the sole look-out.

When a pre-departure head-count was taken about two hours later, the victim was missing. After an on-board search, some tenders and snorkellers entered the water and, after about 20 minutes, found the victim's body close to where he had last been seen by a witness, and reportedly by the skipper, outside the designated snorkelling area. He was lying on the seabed. His dive watch indicated that his last submersion was to a maximum depth of 16 msw for 90 minutes.

The victim was brought on board, where some crew who were qualified in first aid and O₂ provision began BLS. They were soon assisted by a passenger who was a doctor

who noted that the victim was apnoeic and cyanotic with fixed dilated pupils. There was bloodstained, frothy sputum coming from his mouth and nose. It was necessary to roll the victim onto his side periodically to clear his airway. The doctor reported that the boat's bag-valve-mask O₂ unit was not functional owing to a missing part. BLS was continued until a rescue helicopter arrived, when he was found to be in asystole and ALS was commenced, including endotracheal intubation, intravenous cannulation and administration of adrenalin. This was abandoned after 20 minutes when the victim failed to respond.

The skipper was generally uncooperative with the investigation conducted by the workplace authority and with the subsequent coronial enquiry. He also discouraged his crew from assisting. As a result, important information may not have become available.

Autopsy: The heart weighed 365 g (NR 400 g ± 69 g). The LAD showed a greater than 75% stenosis proximally with focal scarring and there was equivocal left ventricular hypertrophy (14–16 mm). The R and L lungs were heavy, weighing 1027 g (NR 663 g ± 217 g) and 973 g (NR 569 g ± 221 g) respectively and were oedematous. The cause of death was given as secondary drowning due to a cardiac arrhythmia and ischaemic heart disease.

Toxicology: nil

Comments: It is likely that the victim drowned as a result of a cardiac arrhythmia, although blackout subsequent to apnoeic hypoxia is also possible. It was reported that the skipper was acting as the sole lookout most of the time. It is difficult, often impossible, for a single lookout to adequately monitor such a large group of snorkellers. One guest reported that she developed a cramp and raised her arm for assistance, as advised to do, but received no response or assistance from the staff of the vessel. The skipper stated that he and another crew member had seen the victim swimming alone outside the designated snorkelling area, but had not followed up on this until the victim was found to be missing, possibly 90 minutes later.

It is generally accepted that appropriate O₂ equipment and at least one trained provider should be available where diving or snorkelling activities are conducted. This is an industry standard of care, especially in Queensland where it is required by regulation. Although it would have made no difference to the outcome in this case, it can be invaluable. It is unacceptable for O₂ equipment to not be fully functional. If the skipper and crew were aware of the state of the O₂ equipment before setting out, then this is also unacceptable.

Although the operator had written instructions that all divers were required to wear wetsuits, this was not adhered to. Wearing a wetsuit provides some added buoyancy (as well as some protection from stingers, if present). In practice, many snorkellers are unwilling to wear a wetsuit in warmer waters, and it can sometimes be unreasonable to try to force

the issue. In a case such as this, where a person becomes unconscious in the water, the additional buoyancy from a wetsuit may cause the body to float to the surface where it can be more quickly and easily seen. This is obviously dependent on whether or not the diver is wearing weights and, if so, how much, as well as on their natural buoyancy.

It is very concerning to note that the operator obstructed the investigation, and encouraged his crew to do so as well. This behaviour was displayed again by the same operator after a subsequent death of another snorkeller from the same vessel. Learning as much as possible from each such tragedy allows trends and deficiencies to be identified and appropriate management and preventive strategies to be established, or reinforced. In this case, there appear to have been breaches of guidelines and regulations, adherence to which might possibly have altered the outcome of this incident.

Summary: Male, 28 y.o.; significant coronary stenosis; experienced breath-hold diver; snorkelling alone away from large group; ineffective lookout; submerged for approximately 90 minutes; BLS unsuccessful; likely cardiac-related; operator unco-operative with investigations

Scuba diving fatalities

SC 10/01

Although still obese (BMI 32.5 kg·m⁻²), this 46 y.o. woman had lost 40 kg since having gastric banding surgery five years earlier. She was described as being in good health since losing weight and led a reasonably active lifestyle. She was taking perindopril for hypertension but the dosage had been reduced and her hypertension had become better controlled. Her medical history also included past glomerulonephritis (non-IgA mesangio-proliferative type) and a cholecystectomy. She had begun diver training 17 months earlier but withdrew shortly into it. At that time it is thought that she had undergone a diving medical examination although there is no evidence of this in the coronial documents. One year later, she recommenced training and successfully completed this several months before this incident. She had completed several post-certification dives.

On this day, the victim and her buddy, a considerably more experienced diver, set out on a shore dive in a small harbour, largely sheltered although exposed to the ocean near the breakwater. This was their fifth dive together and the buddy stated that victim appeared anxious. The weather was described as cool but sunny, there was a slight chop on the surface of the sheltered waters although it was rougher beyond the shelter of the rocks, where there was also some surge. The water temperature was 21°C. The victim was wearing a mask, snorkel and fins, rented 5-mm wetsuit without hood, weight belt with about 8 kg of weights, buoyancy compensation device (BCD) and a regulator with 'octopus' attached to a hired 10.5 L steel cylinder, filled to over 200 bar.

Table 2
 Summary of scuba and surface-supply diving-related fatalities in Australian waters in 2010; BNS – buddy not separated; BSB – buddy separated before problem; BSD – buddy separated during problem; GNS – group not separated; + sufficient air (to surface safely); ++ 1/4–1/2 full tank; +++ > 50% full; nad – nothing abnormal discovered; n/a – not applicable; n/i – not inflated; n/s – not stated; CAGE – cerebral arterial gas embolism; IPE – immersion pulmonary oedema; mw – metres’ water

SC	Age	Sex	Height (cm)	Weight (kg)	BMI (kg·m ⁻²)	Training	Experience	Dive group	Dive purpose	Depth (mw)	Incident (mw)	Weight belt	Wts (kg)	BCD	Residual air	Equipment test	Disabling injury	
10/01	46	F	156	79	32.5	Yes	Some	BNS	Recreation	14	surface	Off	8	n/s	+	Some issues	Asphyxia	
10/02	46	F	170	63	21.8	Yes	Some	solo	Recreation	1–5	n/s	On	5.5	n/s	nil	Poor condition	Asphyxia	
10/03	51	M	–	–	–	Yes	Experienced	BSD	Recreation	45	35	n/s	n/s	n/s	nil	nad	Asphyxia	
10/04	48	M	173	102	34.1	Yes	Experienced	BNS	Hunting	6	surface	n/s	n/s	inflated	+++	nad	Cardiac incident	
10/05	31	F	167	64	22.9	Yes	Some	BSB	Recreation	4	n/s	On	9	n/s	+++	Some issues	Asphyxia	
10/06	49	F	160	105	41.0	Training	nil	GNS	Training	2.5	surface	n/s	17	inflated	+++	n/s	IPE	
RB																		
10/01	49	M	181	111	33.9	Yes	Experienced	BSD	Recreation	36	36	n/s	11	n/s	+++	Some issues	Asphyxia	
SS																		
10/01	48	M	174	112	36.9	n/s	Experienced	BSB	Hunting	12	surface	On	n/s	not worn	+++	Poor condition	CAGE	

They entered the water from the boat ramp and swam underwater towards a rock wall. Visibility was good initially but deteriorated nearer to the wall. The victim indicated that her dive computer was not working although at this time she seemed to be fine, swimming in sheltered water and stopping to look at marine life. On reaching the rock wall, the buddy checked and noted that the victim had 140 bar of remaining air (compared to her own 170 bar). She seemed to be fine so the buddy lead her around the rock wall after which they descended to their maximum depth of 14 msw and then swam along the outside of the rock wall. About 40 minutes into the dive, the victim grabbed her buddy’s arm and showed her gauge, which now read 30 bar. After checking her own gauge (which read 120 bar), the buddy handed her ‘octopus’ to the victim and they swam along together for about five minutes at a depth of approximately 7 msw before the victim grabbed the buddy and indicated, insistently, that she wanted to surface.

On reaching the surface after what was described as a slow, controlled ascent, the victim was very anxious, gasping for air and unable to speak, only communicating by nodding or shaking her head. They were now about 100 m from shore and, as they were being swamped by waves, the buddy suggested they re-descend but the victim was unable to use either her regulator or snorkel, even with her buddy’s assistance. When the victim continued to shake her head and struggle, the buddy told her to roll onto her back and began to tow her towards a moored boat. While towing, the buddy turned to check on the victim a couple of times, and saw her continuing to gasp for air. After about five minutes she observed that the victim was unconscious and then waved her arm and called for help.

Within about two minutes, a pair of swimmers arrived at the scene. One (a nurse) described the victim as unconscious and cyanotic with fixed dilated pupils. There was froth coming from her mouth and nose. The nurse gave three rescue breaths while her companion supported the victim. A short time later, a boat arrived and, after the victim’s gear was removed, she was pulled into it. The swimmers had boarded as well and performed BLS while the boat motored towards shore, a trip estimated to have taken eight minutes. Waiting paramedics boarded the boat on arrival and continued resuscitative efforts. When attached, a defibrillator indicated fine VF/asystole. Given that this was a non-shockable rhythm according to ambulance protocol, and that the victim was lying on the wet floor of an aluminium boat, no shock was given. Another ambulance with intensive care paramedics arrived. Intravenous cannulation was unsuccessful but the victim was intubated, transferred into the ambulance and ALS (asystole protocol) was performed en route to the hospital. The victim failed to respond.

When later tested by the police, the remaining air conformed to relevant purity standards, the regulator was functional, but there was a substantial leak where the scuba-feed hose attached to the BCD inflator/deflator mechanism. This could explain the victim's high air usage (the BCD still held air so buoyancy was not affected), although the buddy did not notice a leak at the time and stated that the mechanism might well have been damaged while she was towing the victim.

Autopsy: Post-mortem radiology revealed no obvious gas and there was no surgical emphysema. The actual dive profile is not known because the dive computer had malfunctioned. The heart weighed 290 g (NR 362 g \pm 77 g), with normal left and right ventricular wall thicknesses (13 mm and 3 mm respectively). There was no coronary atherosclerosis. Some myocyte hypertrophy was noted on histology of the heart. The R and L lungs weighed 420 g (NR 561 g \pm 256 g) and 370 g (NR 491 g \pm 204 g) respectively, there was moderate oedema and histology showed changes of *emphysema aquosum*. The cause of death was given as drowning. Toxicology: 2% carboxyhaemoglobin (non-toxic level, consistent with smoking).

Comments: It appears that the victim became anxious during the latter part of the dive, in deeper water, poorer visibility, some surge and her air was getting low. The buddy reported that on previous dives the victim had used much more air than she did, unsurprising given the differing experience. The buddy believed that she would have noticed a significant leak from the victim's equipment. There are at least two possible explanations for the victim becoming so distressed and dyspnoeic on surfacing. Firstly, it may have been anxiety from the dive, concern at being so low on air and distant from the shore. Secondly, as mentioned by the pathologist, she may have suffered from a cardiac arrhythmia and subsequently became dyspnoeic and unconscious. There is no compelling pathological evidence to support this (the evidence of left ventricular hypertrophy is minimal with normal heart weight and normal left ventricular thickness). In any case, an inexperienced, panicking and breathless diver surfacing into rough conditions with waves washing over her created a potent scenario for drowning. The efforts of the buddy and other rescuers were impressive and appropriate, but unfortunately in vain.

Summary: Female, 46 y.o.; history of hypertension, gastric band surgery, glomerulonephritis and cholecystectomy; swimming ability unreported; recently certified; high air consumption (possible faulty equipment); octopus breathing; anxiety; rough conditions; drowning

SC 10/02

The victim, a 46 y.o. woman with an unremarkable medical history, led an active and healthy lifestyle. She was a strong swimmer and participated in a variety of aquatic activities including surfing, windsurfing and kite surfing. She certified

as a diver 27 years earlier and had done more than 86 dives, although had not dived for the past 11 years. She had two sets of her own regulators – one was old and familiar, the other newer and yet unused. A friend had lent the victim and her husband a full cylinder which her husband had tried out some three months earlier, leaving it with a residual pressure thought to be about 150 bar.

The victim rode a bicycle to the beach towing a trailer carrying her dive equipment. The dive site was off a sandy beach in a protected bay with surrounding reef and a small island about 300 m offshore. On arrival, she had dressed into a 3-mm wetsuit, weight belt with 5.5 kg of weights, mask, snorkel, fins, BCD and used her old scuba regulator and a 10 L steel tank. She entered the water alone. Conditions at the time were reported to have been a light wind, “quite choppy”, a swell of less than one metre inside the reef, a depth of 1–5 msw, a slight current, a water temperature of 18°C and visibility likely to be less than 2 m. She was reported missing approximately 4 to 6 hours later when her bicycle was again noticed where it was left.

Police divers located her body two days later at a depth of less than 1 msw, 20 m from shore and about 150 m from where she had entered. Most of her equipment was still in place, including her weight belt, although her regulator was out of her mouth and her mask was slightly displaced (although marks on her forehead indicated that this was recent) and it contained some “pink fluid”. The cylinder was empty.

When later tested by police, the equipment was found to be in poor condition. The cylinder contained some seawater which was tested and believed likely to have been introduced post mortem. All components of the regulator were in poor condition with sediment deposits, corrosion and distorted o-rings, among other defects. However, despite this, the first stage was mainly functional. The low pressure hose had some obvious weaknesses and was easily bent and, when this occurred, the air supply to the demand valve was completely cut off. The demand valve which, although reported to have a slight ‘free-flow’, was found to be difficult to breathe from (in the flow setting found) and allowed water ingress in inverted positions. The BCD inflator/deflator mechanism was also faulty, leaking air into the BCD indicating that the wearer would need to dump air regularly to maintain their position in the water. Her contents gauge was found to be reasonably accurate.

Autopsy: The autopsy was performed four days after death. A post-mortem CT scan showed a fluid column in the upper airway and fluid in the lungs. There was no significant intravascular gas. There were no significant injuries apart from some minor and irrelevant abrasions on the face, and evidence of mask squeeze and haemorrhage in the middle ear which probably occurred on descent. Some gas was noted in the mediastinum but this may be due to early

decompositional change (the body was not found for two days and there were early decompositional changes to the skin). The heart weighed 246 g (NR 308 g \pm 68 g) and was normal with no coronary atherosclerosis. The R and L lungs weighed 604 g (NR 547 g \pm 256 g) and 612 g (NR 491 \pm 204 g) respectively and appeared over-distended and covered most of the mediastinum. There was sand in the trachea and frothy fluid on the cut surface of the lung. The stomach contained 382 g of partly digested food. The cause of death was given as drowning.

Toxicology: nil

Comments: This diver, who was considered to be a “*risk-taker*”, had not dived for 11 years and entered the water alone with poorly-functioning equipment, a wetsuit that would not have provided adequate thermal protection for an extended period in water of that temperature, and the amount of weight that she had previously used with a thicker wetsuit. It is likely that the dive was difficult given the stressors of poor visibility, poorly functioning regulator, probable buoyancy control issues due to overweighting and poor BCD function and becoming cold, among other possible factors.

The presence of bilateral middle ear barotrauma at autopsy can be an indicator of an unconscious descent as the victim doesn't have the ability to equalise. This may indicate that the victim reached the surface before becoming unconscious and sank owing to being overweighted. This is consistent with the presence of water in the empty cylinder, a situation that could occur if the cylinder was empty on the surface and then returned to depth. There are several possible scenarios which could have led to her demise, all of them somewhat speculative. However, it seems likely that the victim had ascended to the surface and run out of air before subsequently drowning and sinking back to the seafloor.

Summary: Female, 46 y.o.; no significant medical history; apparently fit and healthy; strong swimmer and experienced diver but not for a decade; overweighted; solo dive; tank empty; poorly maintained equipment; drowning

SC 10/03

The victim was a 51 y.o., experienced, male cave diver. Although the coronial documents for this fatality were not made available, reliable information was obtained through a variety of other sources including police reports and witness statements. The victim had no known medical problems and appeared healthy. He had been diving for approximately 20 years and had performed many freshwater cave dives with a regular cave diving buddy over the past nine years. This buddy described him as a calm and safe diver. The victim normally dived with twin back-mounted cylinders of air. On this particular weekend he was trying a side mount diving system for the first time. He was also using new regulators and a new drysuit, although he was an experienced drysuit diver. He and his regular cave diving buddy completed two cave dives the previous day in relatively restrictive sites

without incident, aside from the victim falling and injuring his toe. That night the victim had an early night after a pleasant dinner, with no alcohol being consumed.

The next day the pair prepared to dive in a deeper, less restrictive cave. The visibility was very clear and fixed lines were already present in the site to orientate divers. His buddy stated that the victim was not himself. In fact, he had been somewhat withdrawn and unhappy all weekend. He was distracted, disorganised and required several reminders about usually routine aspects of dive preparation. They placed a cylinder with a decompression mixture of nitrox80 with two second stage regulators on a decompression shotline at 9 metres' fresh water (mfw) depth prior to the dive. The divers both utilised twin cylinders of air (the victim in his new side-mount configuration) and each diver also carried an additional 'travel' gas cylinder containing nitrox (33% oxygen in the victim's case and 44% with the buddy).

The descent proceeded uneventfully, except that the buddy stated that the victim looked “*clumsy*” in the water. After approximately seven to eight minutes, the pair dropped their travel gas cylinders at 35 mfw depth (a dive computer, set for air, was attached to the victim's stage cylinder). The victim needed some assistance with this task. From this point, the victim did not respond swiftly to buddy signals and was already possibly suffering the effects of narcosis. A degree of buddy separation then followed with the buddy dropping down to 45 mfw before being joined by the victim. The buddy descended to 52.3 mfw for three minutes before noting the victim back at 45 mfw, inverted in his drysuit. The buddy assisted righting the victim who indicated he wanted to ascend. The buddy led the pair back to the travel cylinders but again the victim fell behind. He had stopped and was motionless and facing back into the cave. A light signal attracted his attention, and the victim swam out past the buddy but failed to stop and collect his travel cylinder. He became inverted again but, on this occasion, when the buddy tried to assist, the victim appeared to panic and pulled the buddy's mask off. The buddy performed a barely controlled ascent along the steep roof of the cave, closely avoiding drowning himself. After recomposing himself on the surface, he descended to the nitrox 80% decompression cylinder to do his decompression. He looked down to see the victim swimming along the cave floor at around 35 mfw before he became inverted for the last time and stopped breathing.

The buddy completed his decompression obligation and surfaced to alert the authorities of his friend's demise. When police divers recovered the victim's body the next day, they found him significantly entangled in the guideline and his side-mount cylinders were completely empty. When tested, all other equipment was found to be in good working order.

Autopsy: All findings were consistent with drowning. There were no other contributory findings and the toxicology screen was clear.

Comments: The story as presented contains several elements that are difficult to reconcile. These include the breaking of several basic cave diving rules concerning depth and gas usage. In particular, the rule of thirds (i.e., use one third of breathing gas going in, one third coming out and leaving one third in reserve), the placement of a dive computer on a stage cylinder, and the depositing of the stage cylinders at a depth beyond the maximum safe breathable depth of the gases within them. Given that this is a cavern where direct access to the surface is almost possible from the site of the victim's demise, it seems strange that, if he was critically low on gas, he would not have simply ascended as did his buddy. Indeed, the analysis of the victim's dive computer indicates several ascents including one of up to 14 mfw before he finally died. Although the buddy did not report any signs of the victim struggling or trying to free himself from the guideline in the final moments before he stopped moving, entanglement was clearly documented during the recovery. Unfortunately, further investigation of these events was not pursued at the request of the family so no further understanding or lessons can be gleaned from this event. It was suggested that the victim had not dived (at least in caves) for many months and he was using new equipment, some being unfamiliar to him. Although he had dived without incident the day before, this was in a more confined, shallower area where buoyancy was more easily controlled and he would have been less affected by narcosis. It is likely that the interaction of his unexplained poor mental state pre-dive and profound narcosis contributed to the sequence of events that led to this tragedy.

Summary: Male, 51 y.o.; apparently healthy; experienced; unfamiliar equipment; unexplained poor mental state pre-dive; narcosis; inversion and entanglement; out of air; drowning

SC 10/04

This 48 y.o. man was described as overweight with a history of diabetes and cardiac disease and had undergone angioplasty approximately 11 months earlier. He had been prescribed aspirin and clopidogrel but was non-compliant with his medication. He was a keen and regular diver although he had not dived since his angioplasty. It is unknown whether he sought advice about his fitness to dive post surgery. He had spent a few days fishing with friends and had complained of chest pain and dyspnoea several days before going diving.

On this day, the victim and his buddy, with whom he dived six or seven times a year, went diving from a small boat. One friend remained on board and other friends were on another boat nearby. Earlier that day, the victim had complained of breathing difficulty and chest pain. He appeared to be stressed while gearing up. He was wearing mask, snorkel and fins, a 3-mm wetsuit with hood, gloves and booties; BCD and scuba gear; and was carrying a knife; he was also

presumably wearing weights but this was not mentioned. The plan was to catch some crayfish and abalone. There was no description of the conditions.

The victim and his buddy entered the water and descended 5–6 msw to the seabed. They collected some abalone. After about 10 minutes, the victim indicated that he was having difficulty breathing. Initially he signalled that he did not wish to ascend but soon changed his mind and signalled to his buddy to ascend, before inflating his own BCD in doing so. On the surface, he was distressed and told his buddy that his chest hurt and he could not breathe. The boats came alongside, the buddy removed the victim's BCD and tank and the victim was dragged onto one of the boats. He was described as "*in and out of consciousness*" and there was froth coming from his mouth. He was placed in the recovery position to try to assist his breathing. The emergency services were called during the 20-minute boat ride to land, by which time the victim was unresponsive and apnoeic. One of his companions began BLS for a short time before paramedics arrived, who found him to be in asystole and implemented ALS for about 25 minutes before pronouncing him dead.

His equipment was found to be functional. The 'cracking pressure' of his primary second stage was found to be relatively high and the subsequent flow was also high. The secondary demand valve worked effectively and was believed to have been likely what the victim had been breathing from. There was 140 bar of air remaining in his tank and the air met relevant purity standards.

Autopsy: The autopsy was performed four days after death. X-rays showed air in the great vessels and heart, some or all of which could be due to decomposition and or post-mortem decompression artefact. The heart weighed 499 g (NR 400 ± 69 g) and was heavy. The right coronary artery was dominant, and showed a proximal 50–70% stenosis. The left main coronary artery had a 40% stenosis, whilst the LAD had an 85% stenosis with a stent which contained thrombus. The left circumflex coronary artery had a 75% stenosis, with a distal stent. The R and L lungs weighed 732 g (NR 663 ± 217 g) and 644 g (NR 569 g ± 221 g) respectively and were congested with marked oedema. Vitreous glucose was 7.6 mmol·L⁻¹ which is high (normal upper limit < 5.7 mmol·L⁻¹) and his HbA1c was 14% which also is high and suggests his diabetic control was poor. The cause of death was given as ischaemic heart disease.

Toxicology: nil

Comments: This man had obvious cardiac-related symptoms, was non-compliant with medication and grossly unfit for diving. This death could well have occurred during terrestrial activities.

Summary: Male, 48 y.o.; history of diabetes and angioplasty; non-compliant with medication; chest pain and dyspnoea before dive; unfit for diving; cardiac death

SC 10/05

This 31 y.o. woman had no known significant medical history and appeared to be healthy. She had suffered a non-fatal drowning incident as a child. She and her partner had been certified as Open Water Divers in Thailand two years earlier in an attempt to help her overcome her fear of the water. Both were inexperienced, having done only seven dives, all under supervision, the last being nine months prior, and all in Thailand's tropical waters.

She and her partner/buddy entered the water from the shore for their first unsupervised dive. The aim of the dive was to view cuttlefish. She was wearing mask, snorkel and fins, 5-mm semi-drysuit, separate hood, boots and gloves, BCD, weight belt with 9 kg of weights and a regulator on a 7.7 L steel tank. The police reported that there was a light wind and surface conditions were likely to have been calm, with visibility of around 8 metres. The water temperature was 13–14°C; there was no mention of any current.

After about 20 minutes diving at a depth of 3–4 msw, the buddy could not see the victim and surfaced to look for her or her bubbles. Unable to see either, he re-submerged for another five minutes before surfacing and returning to shore. He then phoned a local dive shop to ask for advice. The owner immediately contacted other divers whom he knew were nearby and asked them to help with a search.

A boat with three men soon arrived and soon sighted the victim lying face-up on the bottom at a depth of 4 msw. She was visible from the surface. Her rescuer could not recall if she was wearing her mask, snorkel and hood but noted that her regulator was out of her mouth. Using a 'bail-out' tank one of the men dived down to the victim, released her weight belt and brought her to the surface. She was dragged onto the boat, unconscious and apnoeic. BLS was begun and continued en route to shore until paramedics arrived and continued resuscitative efforts before abandoning these as there was no response.

The victim's weight belt, mask and snorkel were recovered the next day. On examination, her equipment was all found to be serviceable. There was 180 bar of air remaining and this met relevant purity standards. There was a slight tear in one of the second stage regulators which would likely have "breathed wet", although this was not believed to have been substantial. The other second stage was set into pre-dive mode and would have been more difficult to breathe from in this setting. However, it was unclear which one she had used as her primary demand valve.

Autopsy: A chest X-ray performed on the day of death did not identify air in the great vessels or the heart and no pneumothorax was evident. The autopsy was performed three days after death. The heart weighed 270 g (NR 308 ± 77 g). The origin of the left coronary artery was high

(just above the coronary sinus) and there was focal 30% narrowing of the LAD. There was no gas in the heart or major vessels. Examination of the conduction system revealed no abnormality. There was frothy fluid in the main bronchi. The R and L lungs weighed 675 g (NR 547 g ± 203 g) and 652 g (NR 472 g ± 181 g) respectively, and felt heavy and airless with congestion and marked oedema. The cause of death was given as undetermined but the pathologist commented that the frothy fluid in the bronchi was supportive of drowning. Toxicology: nil

Comments: The victim was an inexperienced diver who had only ever dived in the tropics and under supervision. This was her first dive for nine months and, very significantly, the first in colder water, wearing a full wetsuit and a substantial amount of weight; quite possibly too much. This was also the first time that she and her buddy had dived unsupervised. Given her inherent fear of the water she was likely to have been very anxious. She might have got into difficulties unnoticed by her buddy or after separating from him. In either case, there was a breakdown in the buddy system in these inexperienced divers – not an uncommon event. If she had reached the surface, she would have found it very difficult to remain there without inflating her BCD and/or dropping her weight belt. She likely sank and drowned.

Summary: Female, 31 y.o.; apparently healthy; diving to help overcome fear of drowning; very inexperienced with inexperienced buddy; first dive in colder water; separation; drowning

SC 10/06

This 49 y.o. woman was severely obese (BMI 41 kg·m⁻²), with a history of mild hypertension, hypercholesterolaemia, anxiety, depression and laparoscopic cholecystectomy. She appears to have been taking paroxetine for depression, alprazolam for anxiety and levonorgestrel at the time, and had been treated previously with diuretics for ankle oedema. Over the previous year she had been hospitalised several times for acute chest pain which settled after the administration of glycerol trinitrate. Standard cardiac investigations at that time showed no evidence of myocardial infarction and the pain was thought to be of biliary origin. She subsequently underwent a laparoscopic cholecystectomy. On-going symptoms resulted in a thallium exercise cardiogram which showed ECG changes during maximal exercise and scan abnormalities suggestive of reduced blood flow to the anterior wall of the left ventricle. It was unclear whether this was artefact owing to the overlying breast tissue. These changes were asymptomatic and normalised post exercise. She also suffered episodes of dyspnoea requiring hospital admission via ambulance. Chest X-ray showed non-specific changes and a CT pulmonary angiogram showed no evidence of pulmonary embolism or focal lung or pleural abnormality. She was subsequently prescribed salbutamol, although there was no definitive diagnosis of asthma.

In an effort to improve her fitness, the victim enrolled in a scuba diving course. She underwent a diving medical with a doctor with training in the assessment of fitness to dive but it appears that she failed to reveal her previous cardiac and respiratory problems. The doctor noted her obesity and hypertension (160/83 mmHg) and issued a fitness-to-dive certificate. Some problems during her initial pool training were largely attributed to the victim's ill-fitting wetsuit and she subsequently obtained a custom-made semi-drysuit.

On the day of the first open-water dive, the victim and four other students were under the supervision of two instructors and a trainee divemaster. The dive was from the shore and along a jetty, a relatively shallow site with sandbanks en route to deeper water. The conditions were described as windy with a slight surface current and the water "looked clear". The group geared up on the beach. The victim was wearing a mask, snorkel and fins; 6.5-mm semi-drysuit and hood, BCD, 14 kg of weights distributed between a weight belt, integrated pockets and ankle weights and a scuba unit. She was buddied with the trainee divemaster. The divers waded about 50 m into the water parallel to the pier until they reached chest-deep water. They then put on their fins and snorkelled for a few minutes to the dive buoy to descend. The depth here was 2.5 msw. However, the victim was too buoyant, so her buddy put an additional 3 kg of weights into her BCD pockets before she was able to descend.

Almost immediately, after possibly a metre of descent, the victim signalled that she wanted to ascend. When she and her buddy reached the surface, the buddy inflated the victim's BCD. The victim discarded her regulator, complained of dyspnoea and of "feeling sick" and was noted to be breathing rapidly and deeply with a faint wheeze. Her buddy began to tow her to shallower water but the victim began to panic when a wave washed over her. The buddy continued to alternately tow the victim and support her as they walked slowly towards shore. After another small wave splashed over the victim's face, she began to cough and became flushed. She asked a bystander to fetch her ventolin (salbutamol) from her bag. Once in shallower water the victim was helped to remove her hood and scuba unit and to unzip her wetsuit. She self-administered a total of four puffs of salbutamol and an ambulance was called. However, she soon deteriorated and became unresponsive and cyanotic with yellow, frothy sputum coming from her mouth. She was dragged to shore and placed in the recovery position as the rescuers believed that she was still breathing spontaneously, albeit with frothy sputum still oozing from her mouth and nose. Paramedics arrived soon afterwards and found her to be unconscious, cyanotic, with agonal respirations and no palpable pulse. A defibrillator was attached and indicated Pulseless Electrical Activity (36 beats per minute) decreasing to asystole within seconds. ALS was implemented between the rescuers and the paramedics. Suction was required frequently. Resuscitation was continued for 30 minutes but the victim failed to respond.

When examined later, her equipment was found to be functioning correctly although there was a small perforation in the mouthpiece of the primary demand valve. There was 200 bar of remaining air which was found to meet acceptable purity standards. The total weight of equipment carried by the victim was estimated to have been 37 kg.

Autopsy: The autopsy was four days after death. A post-mortem CT scan was taken but the results are not reported. The heart was enlarged 513 g (NR 285–439 g). The ventricles appeared of normal dimensions and there was only mild atherosclerosis of the coronary arteries. There was some fatty infiltration of the right ventricle but no other features suggestive of arrhythmogenic cardiomyopathy and the mitral valve showed thickening of the anterior leaflet with shortening and thickening of the papillary muscle (possibly mild mitral valve prolapse). Histology confirmed fatty infiltration of the heart which may be a feature in obesity). The AV node showed mild muscular hypertrophy and myxoid changes in some vessels as well as in the mitral valve. The kidneys showed occasional sclerosed glomeruli and a patchy cortical lymphocytic infiltrate but no features diagnostic of hypertension. The R and L lungs weighed 895 g (NR 561 g \pm 256 g) and 700 g (NR 491 g \pm 204 g) respectively and appeared slightly hyper-inflated and firm. There was 100 ml of fluid in the right pleural cavity, a small amount of frothy fluid in the airways and moderate oedema of the lungs. Histology of the lungs showed no evidence of asthma. The cause of death was unascertained. The mild cardiomegaly and mild mitral valve changes were discussed but the degree of disease was felt to be insufficient to account for death. The possibility of sudden death due to a cardiac arrhythmia due to a cardiac channelopathy was raised.

Toxicology: paroxetine 0.1 mg·L⁻¹

Comments: This morbidly obese woman with a history of cardiac-like pain and dyspnoea requiring repeated hospital admissions was an unsuitable candidate for scuba training and had she declared her past medical history would almost certainly not have been passed as fit. Spirometry was performed in the dive medical and was not suggestive of the presence of asthma. It is likely that the combination of the physical, physiological and psychological stresses on her first open-water dive and the effects of immersion precipitated acute pulmonary oedema in a predisposed individual. It is also possible that the administration of salbutamol in this situation may have precipitated or worsened an arrhythmia, a situation not unlikely given the already existing cardiac changes.

Summary: Female, 49 y.o.; severe obesity, mild hypertension, hypercholesterolaemia, anxiety, depression, episodes of cardiac-like chest pain and dyspnoea; first open water dive; likely carrying 37 kg (including scuba unit); brief submersion; severe dyspnoea; collapse; acute pulmonary oedema with probable terminal arrhythmia

Rebreather fatality

RB 10/01

This 49 y.o. man was obese (BMI 33.9 kg·m⁻²) and had a history of depression and migraine. Past history also included an episode of pleuritic-type chest pain in 2001. A ventilation-perfusion scan at that time showed a large unmatched perfusion defect in the left lung base suggestive of pulmonary embolism. His latest ECG, taken seven months prior to the incident, was reported to have been normal, as had a stress test in 1999. He was taking paroxetine hydrochloride and pizotifen malate. He was a qualified divemaster and had been an active and experienced open-circuit diver. He had recently purchased a 10-year-old Dräger Dolphin rebreather which had been converted from a semi-closed to a fully-closed unit by the friend who had sold it to him. That friend had also certified him to use a Dolphin rebreather two months earlier. There is some debate as to the configuration of the unit during this training. The diver's logs indicated that he had possibly done about 10 dives using this unit. The log also indicated that all of these dives were relatively shallow.

On the day of the incident, the victim's buddy, with whom he had dived about 10 times before, stated that the victim appeared to be quieter than usual and complained of having a headache. He said that he would take some medication for his headache and was sure that he would be able to dive. His buddy offered him a seasickness medication (hyoscine hydrobromide) which he took. The pair then set out with 15 other divers on a charter boat which took them to a wreck sitting in the ocean at a maximum depth of about 39 msw.

The victim and his buddy were the second pair to enter the water. Conditions were described as quite good, with some surface chop. The victim was wearing a drysuit with undergarments, a hood, leg gaiters, boots and fins, mask, BCD, his rebreather (with one cylinder of air and one of oxygen), a 5-L bail-out cylinder (containing nitrox29.6) which was connected to his drysuit inflator. He carried 11 kg of weight, distributed around the shoulders of his rebreather (1.5 kg each) and in two ditchable mesh bags (4 kg each). He was also carrying his camera. The buddy was diving on open-circuit breathing nitrox30.

They began descending the shotline together and did a mutual bubble check under the surface. On reaching a depth of about 23 msw, the buddy noticed that the victim was well above him and ascending so he swam towards him, meeting at the surface. When asked if he was okay, the victim replied "just me", stated that he wished to continue the dive and they re-descended to the wreck at 36 msw. The buddy reported that there was a slight surge and current on the bottom, visibility was 10 m and water temperature 13°C.

The pair swam around the wreck while the victim took photographs. Wishing to stay within his no-decompression

limits, the buddy indicated that he wanted to surface, the victim signalled agreement and they began to ascend. However, after rising about 7–8 msw, the buddy looked down and noticed that the victim was still near the wreck, sinking despite efforts to ascend. On reaching him and concerned that he did not understand rebreathers and was unsure of what to do, the buddy offered the victim his 'octopus' in case he needed it. However, the now wide-eyed and anxious-looking victim pushed the 'octopus' away. The buddy gestured towards the victim's bail-out bottle but again his hand was brushed aside by the victim who didn't respond to his signals. In light of the rejection of both alternate breathing supplies, the buddy, believing the victim to be negatively buoyant, reached for the victim's BCD inflator but again the victim, behaving erratically, pushed him away. The buddy then looked for the victim's weight belt but could not see it.

Finally, the buddy decided to hold onto the victim and use his own BCD to lift them both to the surface. When he grabbed the victim the latter did not push away, so the buddy inflated his own BCD but this was insufficient to lift them as the victim was so heavy. When the buddy let go of the victim his own positive buoyancy caused him to rise rapidly until he could dump some gas. After descending a few metres and being unable to see the victim, he decided to do a controlled ascent (of about four minutes) to get help. He believed that the victim was conscious and breathing when he last saw him.

Shortly afterwards, a trio of divers found the victim lying on the deck of the wreck. He was unresponsive. His eyes were closed and his mouthpiece was hanging loosely in one corner of his mouth. One of the group tried unsuccessfully to replace his mouthpiece. Two of the trio grabbed the victim; one inflated her BCD and the other finned hard and they began to rise. Their ascent rate became rapid nearer to the surface from the expanding air in their BCDs.

On reaching the surface the rescuer called for help. She struggled to keep the victim's head above the water as he was so heavy. He was unconscious and frothy sputum was oozing from his mouth and nose. Assisted by one of her buddies, the rescuer managed to remove the victim's rebreather which sank quickly. The victim was soon dragged aboard the dive boat, rolled onto his side to drain his airway and an oropharyngeal airway was inserted. BLS was commenced by some of the crew and continued as the boat sped back to the jetty. Ventilations were provided via a manually-triggered oxygen-powered resuscitator. The rescuers, one of whom was a nurse, needed to turn the victim onto his side regularly to clear bloody, frothy sputum and water from his mouth. On reaching the jetty, paramedics implemented ALS, without success.

Two weight pouches belonging to the victim were recovered the next day. Neither the buddy nor subsequent rescuers had reported ditching these so it is likely that they had been

ditched by the victim in an attempt to ascend. The rebreather unit was received by police four days later. When examined it had been modified to work as a mechanically operated closed circuit unit. Both the oxygen and diluent tanks were empty and the diluent tank contained seawater. The mouthpiece was partially bitten through. The bailout cylinder was turned off and contained 190 bar pressure.

Autopsy: Post-mortem CT scan showed widespread gas within the arterial and venous circulation. Since the victim's body was brought up rapidly from 40 msw, it is highly likely this was post-mortem decompression artefact. The heart weighed 400 g (NR 400 ± 69 g) and appeared normal with no coronary atherosclerosis. The R and L lungs weighed 690 g (NR 663 g ± 217 g) and 670 g (NR 569 ± 221 g) respectively and appeared mildly expanded. Fluid exuded from the cut surface. On initial presentation, there was a plume of pulmonary oedema fluid coming from his mouth. No pathological abnormality was detected in the brain, which weighed 1515 g, and there was no evidence of pulmonary embolism (see history). The pathologist commented on the possibility of carbon dioxide narcosis; however, it is not possible to determine post-mortem carbon dioxide levels. The cause of death was given as unascertained.

Toxicology: nil

Comments: This case raises a number of issues, many of them of a moral nature. The instructor stated that he had converted the unit back to semi-closed-circuit rebreather (SCR) configuration during training and that he had only certified the victim as a Dolphin SCR diver, but that he had supplied all the parts to convert it back to CCR configuration. One might then question why, as an instructor, he allowed the victim to dive with him without insisting that he get appropriate training and qualification in CCR mode if he was going to dive with the unit in that configuration, especially as such training is readily available. Furthermore, the dive operator was unaware that the victim was untrained in the use of the unit as a CCR, and stated that he would not have allowed him to dive from the boat had he been aware. He was assured by the instructor that training had been completed although the certification had not yet been received. At the time, this instructor was not qualified to teach CCR diving.

The use of air as a diluent at 39 msw reflects to some extent this lack of training. Not only would this have provided significant narcosis at this depth to a diver relatively unfamiliar and untrained with his CCR, but also would create a significant work of breathing in a unit not designed as a CCR or for such depth. It is quite probable that narcosis contributed to his inability to solve his problem underwater.

From the evidence of the witnesses and the state of the equipment, it would appear that the victim was considerably over-weighted. Analysis of his dive computer implies that this was the deepest dive that he had conducted on the CCR unit. It would seem that, for some reason, the victim exhausted his diluent gas before the end of the dive. This

would not normally be an emergency situation as diluent is not required when on the bottom or at a stable depth. However, as this cylinder also inflated his BCD and the bailout cylinder which was attached to his drysuit was turned off, he was unable to get sufficient, positive buoyancy to ascend. He seems not to have recognised that his bailout cylinder was turned off (a practice that may have been carried over from his open-circuit diving). When his buddy attempted to rescue him and dragged him up by inflating his BCD, his CCR would have vented gas from the breathing loop. When he was subsequently released, the descent would have required the addition of gas to prevent the loop from collapsing. The only gas remaining to provide this would have been oxygen. It is possible that the victim realised this and attempted to remove his ditchable weights before being overcome by oxygen toxicity. While a convulsion was not observed, the indication that the mouth-piece was bitten through is highly suggestive of convulsion.

Summary: Male, 49 y.o.; history of depression and migraine; divemaster open-circuit scuba diver; untrained closed-circuit diver; modified rebreather; overweighted; loss of diluent; likely narcosis and subsequent oxygen seizure; drowning

Surface-supplied breathing apparatus diving fatality

SS 10/01

This 48 y.o. man had a history of single shoulder and hip arthroplasties, palpitations and dizziness, angina, paroxysmal atrial tachycardia, ventricular tachycardia, and tight stenosis of a small LAD-origin septal vessel. He had had a positive stress ECG two years earlier and an associated technesium scan indicated areas of ischaemia. He had undergone Holter monitoring three months prior to the accident to investigate the recurrence of palpitations. Although he had previously been on a variety of medications, there was no record of any currently prescribed medications. Despite severe obesity (BMI 36.9 kg·m⁻²), his wife described him as “quite healthy for his age ... had extra weight but was reasonably fit and he played underwater hockey”. There is no record of his having any training, certification or medical examination for scuba diving. He was said to have been a keen and active fisherman and scallop diver of many years.

He went diving for scallops with two friends from a 7-m boat. The weather was reported to have been sunny and calm with a light wind. The water temperature was around 12°C. After an uneventful first dive to 6 msw, the group moved to a new site, anchoring their boat in about 8 msw depth. The victim was wearing a 5-mm wetsuit with an additional 3-mm vest with attached hood, weight belt (weights not reported), mask (snorkel unknown), boots, fins and gloves, and he was carrying a catch bag. He was not wearing a BCD.

After a surface interval of 30 minutes, he and one of his friends dived together using a home-made ‘Hookah’ while their friend remained on the boat to watch the compressor.

The victim's 'hookah' hose was threaded under his weight belt from behind, between his legs and under his weight belt at the front, around his left shoulder and, finally, around his neck to the demand valve. He did not carry a bail-out bottle. After swimming together for about 5–10 minutes at a depth of 12 msw, the pair separated when the bottom became stirred-up and visibility deteriorated. The buddy surfaced an estimated 15 minutes later as he had filled his bag and swam back to the boat. After a short time, the buddy looked back and saw the victim on the surface about 40 m away, apparently struggling, with his head and shoulders just above the water. He was wearing his mask and his regulator was out his mouth. He sank briefly before surfacing again and calling for help. The buddy jumped back in and swam to where the victim had been but he had submerged and could not be seen. The hookah line was vertical and there were no visible bubbles.

The friend in the boat began to haul in the line while the buddy swam back to the boat. The victim was brought to the surface unconscious, cyanotic and apparently apnoeic about one to two minutes from when he was last seen. The buddy ditched the victim's weight belt (which possibly had the catch bag attached to it) and supported him from behind in the water while the friend on the boat removed his mask (which contained a small amount of blood) and tried to give a rescue breath. Unable to lift the victim, the friend on the boat went to the radio to call the emergency services while the buddy supported his friend and heard what are likely to have been agonal respirations.

In response to a flare, a large boat with divers arrived 10 minutes later and one of them helped to lift the victim into this boat and roll him onto his side to drain water and mucus from his mouth. He and the buddy began BLS and continued on the way to the jetty. The buddy described a regular "liquid" sound when they gave rescue breaths and rolled the victim onto his side periodically, although little water came from his mouth. On arrival, they were met by a police rescue vessel and its crew took over resuscitation, adding supplemental oxygen via a manually-triggered ventilator. After about five minutes, they were relieved by ambulance crew who found the victim to be in asystole with fixed, dilated pupils and signs of post-mortem lividity. Resuscitation was abandoned shortly afterwards, approximately 70 minutes after the victim had been found unconscious.

When later tested the compressor unit was found to be in poor condition with multiple faults. These included a fuel leak, the absence of a suitable air filter or water trap, the absence of non-return valves, an incorrect supply pressure setting, minimal distance between the inlet and exhaust as well as other faults, such as a small hose that kinked easily, reducing or stopping the air flow to the divers. The tests revealed that if a diver on the surface purged his demand valve it would greatly reduce the airflow to the other diver at depth. His primary demand valve was functional. His secondary demand valve, if used, could have caused some

water aspiration. The air test results indicated that both the carbon monoxide (CO, 70 ppm) and moisture content ($> 160 \text{ mg}\cdot\text{m}^{-3}$) of the air in the compressor reservoir greatly exceeded the relevant Australian Standard (10 ppm and $160 \text{ mg}\cdot\text{m}^{-3}$ respectively).

Autopsy: A whole-body CT scan was carried out five hours after death. This showed gas in both ventricles of the heart, in the aorta and in the liver with relatively small amounts of gas in the portal venous system. Large amounts of gas were seen in the vessels of the brain. At post mortem, there was 70 ml of gas in the right ventricle and 20 ml of gas in the left ventricle. There was a 70-mm-long, deep laceration on the scalp which probably occurred during recovery of the body (supported by comment from police). The heart weighed 446 g (NR $400 \text{ g} \pm 69 \text{ g}$) with left dominant circulation and a 30% narrowing of the LAD. The proximal stenosis of the small septal branch of the LAD, reported on angiography, was not seen. Histology of the heart showed mild hypertrophy but no scarring. The R and L lungs weighed 470 g (NR $663 \text{ g} \pm 217 \text{ g}$) and 450 g (NR $569 \text{ g} \pm 221 \text{ g}$) respectively, and appeared slightly over-expanded. There were a few small apical bullae, a small quantity of oedema fluid in the upper airways but little in the lungs. The cause of death was given as cerebral arterial gas embolism (CAGE) due to pulmonary barotrauma while surface supply diving for scallops. There was also a history of ventricular tachycardia and tight stenosis of a small LAD-origin septal vessel which may have contributed to death.

Toxicology: carboxyhaemoglobin negative

Comments: Although when tested, the compressor was found to produce a high level of CO, there was no evidence that this was a factor in the victim's demise as his toxicology was negative for carboxyhaemoglobin and his buddy had no problems. It is likely that this diver had an interrupted gas supply resulting from a drop in pressure from surface purging or the kinking of a vulnerable narrow hose. Without a 'bail-out' cylinder and/or BCD he would have to swim to the surface (possibly from about 12 msw), likely overweighted by scallops. Despite his experience, such circumstances created a high risk of inadvertent breath-holding which can lead to pulmonary barotrauma and consequent CAGE. It is possible given the strong clinical history of cardiac arrhythmia that the rapid ascent causing the CAGE could have been precipitated by a cardiac arrhythmia. The other interpretation is that death was caused by a cardiac arrhythmia and that gas seen at post mortem represents post-mortem decompression artefact. However, it was the examining pathologist's (CL) impression at the time that the gas represented CAGE. Post-mortem examination will usually identify structural heart disease but is poor for diagnosis of functional cardiac arrhythmia.

Summary: Male, 48 y.o.; severely obese; history of palpitations, angina, paroxysmal atrial tachycardia, ventricular tachycardia, and tight stenosis of a small septal coronary vessel; active lifestyle and played underwater

Table 3
Root cause analysis of diving-related fatalities in Australian waters in 2010

Case	Trigger	Disabling agent	Disabling injury	Cause of death
BH10/01	Unknown; silting? Disorientation?	Unknown; entrapment?	Asphyxia?	Drowning?
BH10/02	Immersion, exertion, aspiration, anxiety	Cardiovascular disease	Cardiac incident	Cardiac-related
BH10/03	Prolonged breath holding	Apneic hypoxia	Asphyxia	Drowning
BH10/04	Unknown; inexperience? Panic?	Unknown; aspiration? Sudden unconsciousness?	Unknown; asphyxia?	Unknown; drowning
BH10/05	Immersion, tight wetsuit, anxiety.	Cardiovascular disease	Cardiac incident	Cardiac-related
BH10/06	Unknown, inexperience? Panic?	Unknown, aspiration? Sudden unconsciousness?	Unknown; asphyxia?	Unknown; drowning?
BH10/07	Inexperience, exertion, aspiration	Atrial fibrillation	Cardiac incident	Cardiac-related
BH10/08	Exertion	Cardiovascular disease	Cardiac incident?	Cardiac-related?
BH10/09	Immersion? Exertion? Prolonged breath holding?	Unknown; cardiovascular disease? Apnoeic hypoxia?	Cardiac incident? Asphyxia?	Drowning
BH10/10	Unknown; inexperience? Panic?	Unknown; aspiration? Sudden unconscious?	Unknown; asphyxia?	Unknown; drowning?
BH10/11	Prolonged breath holding	Apnoeic hypoxia	Asphyxia	Drowning
BH10/12	Prolonged breath holding	Unknown; apneic hypoxia? Cardiovascular disease?	Asphyxia? Cardiac incident?	Drowning
SC10/01	Anxiety, low air, rough conditions	Aspiration	Asphyxia	Drowning
SC10/02	Unknown; buoyancy-, equipment-, gas supply- related?	Unknown; buoyancy-related?	Asphyxia	Drowning
SC10/03	Poor mental state, narcosis, unfamiliar equipment, gas supply-related	Buoyancy-related, gas supply- related, entanglement	Asphyxia	Drowning
SC10/04	Exertion	Ischaemic heart disease	Cardiac incident	Cardiac-related
SC10/05	Unknown; anxiety?	Buoyancy-related?	Asphyxia	Drowning
SC10/06	Exertion, immersion	Morbid obesity, poor cardiopulmonary fitness	Immersion pulmonary oedema	Cardiac-related
RB10/01	No formal CCR training, narcosis	Oxygen toxicity	Asphyxia	Drowning
SS10/01	Unknown; gas supply-related?	Ascent-related	CAGE	CAGE

hockey regularly; training unknown; experienced; using faulty 'hookah' compressor; surfaced, called for help and sank; BLS unsuccessful; CAGE/pulmonary barotrauma

Discussion

A summary of the possible sequence of events (root cause analysis) in each of these incidents is shown in Table 3.

APNOEIC HYPOXIA

In this series, it is likely that at least two BH divers died as a result of apnoeic hypoxia. As in the 2009 report,² one victim (BH10/03) was alone and doing underwater laps in a pool. In another (BH10/11), the dive may have been complicated by entrapment. It is possible that apnoeic hypoxia led to the death of another victim (BH10/12); however, the reviewers believe this death was more likely the result of a cardiac arrhythmia triggered by breathholding.

SOLO DIVING OR SEPARATION AND/OR SUPERVISION PROBLEMS

Solo diving or separation has contributed to many diving deaths.²⁻⁵ It is a recurring theme in dive accident reports and this series is no exception, likely being implicated in five of the breath-hold (BH10/01, BH 10/04, BH10/06, BH10/08 and BH 10/12), one scuba (SC10/03) and the SSBA fatalities. Having a buddy nearby does not guarantee rescue but it generally increases the likelihood of support and assistance. However, as highlighted in SC 10/03 and RB 10/01, a dive buddy can sometimes be at risk when trying to assist a stricken companion. In both incidents, the buddy was finally forced to make the unenviable decision to abandon his companion for the sake of his own survival.

Poor supervision appears to have been a factor in at least two incidents. In BH 10/04, the victim was on a guided tour and went snorkelling alone from the shore of a lake. It is not clear what the arrangements were with the tour guide or what assessment and briefing was done, but this "*poor swimmer*" went snorkelling alone, under what turned out to be inadequate supervision from friends. In BH 10/12, the captain chose to be the single observer for up to 30 snorkellers; clearly inadequate since one disappeared and another reported signalling for help and not receiving any. Commercial operators need to have and adhere to realistic ratios for supervision and do so diligently.

EQUIPMENT

Equipment problems were implicated as a likely or possible contributor to at least four incidents. Equipment-related problems are commonly reported to be associated with diving incidents, whether fatal or non-fatal.³⁻⁷ In SC 10/03 and RB10/01, the victims were using relatively unfamiliar equipment. Faults were found in the equipment used by the

victims in SC 10/02, RB 10/01 and SS 10/01 and these may have precipitated or exacerbated the incident.

In addition to issues with diving equipment, problems with first-aid-related equipment were also obvious in three cases. In one (BH 10/02), although an AED was available, the battery was flat. In another two, the O₂ equipment was unusable either because the delivery device was unsuitable (BH 10/10) or because an integral part was missing (BH 10/12). In all cases, the problems could have been readily averted by having the appropriate equipment in the first place, including an adequate O₂ supply to enable delivery of near-100% O₂ until medical assistance (with more O₂) was available.⁹ Dive operators should have and adhere to appropriate protocols for checking and maintenance of first-aid equipment and supplies and the performance of pre- and post-excursion function testing. This might have been beneficial for BH 10/10. It cannot be emphasised enough that any operator catering for diving activities must ensure that they have appropriate and functional O₂ equipment and trained personnel readily available at the dive site.

DIVE PREPARATION

There are several lessons to learn from SC 10/04. Experience is important but dive currency perhaps more so. If new equipment is being used, divers should revert to simple open-water dives until the equipment is mastered and only then return to their previous level/complexity of diving. Furthermore, divers need to recognise when they are not feeling up to a dive on the day, whether because of feeling unwell, the presence of poor diving conditions or perhaps due to problems with equipment, and either abandon the dive altogether or refine their dive plan to something shallower or less challenging. This is not only for their own sake, but in the interests of their buddy and other divers. Finally, the risks of deep air diving are well described and seem to have been ignored in this case.

CARDIAC-RELATED FATALITIES AND OBESITY

Once again, cardiac-related deaths were well-represented in this series and are thought to have been contributory in at least a quarter and possibly nearly half of these fatalities. The effects of immersion are known to precipitate cardiac arrhythmias in both breath-hold and scuba divers, especially in cold or deep water.¹⁰⁻¹³ Of note, nine of these 20 divers were obese, with BMIs ranging from 30.9 to 43.4 kg·m⁻². At least five of these obese divers are believed to have been disabled by a cardiac-related event. Obesity is incompatible with safe diving. The effects of what is often a restrictive wetsuit, excessive weighting to overcome positive buoyancy, impairment of respiratory function, especially when immersed and increased cardiac demands to overcome these can present a serious hazard. Even if a cardiac event did not underlie the death in some obese divers, obesity per se can be a contributory factor.^{14,15} As indicated in BH 10/02, BH

10/07 and SS 10/01, it can be more difficult to lift an obese person onto a boat or platform and this should be considered in advance when dealing with such divers.

IMMERSION PULMONARY OEDEMA (IPE)

The topic of IPE is currently of great interest to researchers as there have been an increasing number of reported cases, both fatal and otherwise.^{16,17} IPE was discussed by the authors as a possible contributing factor or differential diagnosis in several of the above cases. However, a definitive diagnosis can be elusive in the absence of a clear clinical history, as autopsy findings can readily be attributed to cardiac disease or drowning.

DELAY TO AUTOPSY

In a number of these cases, there was an interval of three or more days between death and the autopsy. A study of drowning fatalities demonstrated a time-dependent fall in the combined lung weights in drowning, thought to be due to post-mortem transudation from the lungs and an increase in fluid in the pleural cavity especially after three days.¹⁸ Given this and the problem with post-mortem decompositional gas formation, the sooner these autopsies are carried out the more likely the pathologist is to be able to identify features of drowning. Given the large number of CT scanners in Australia now, all scuba diving fatalities should have a CT scan as soon as possible after death and preferably within eight (8) hours of death. This does not entirely solve the problem of post-mortem decompression artefact but it is helpful if there is a delay in autopsy examination.

REBREATHERS

Rebreather deaths have been rare in Australia up to 2010. In a review conducted in 2013, CCR divers were estimated to be ten times more likely to be involved in a fatal diving accident than were recreational open-circuit scuba divers.⁸ The perception of increased risk with CCR diving is well known in the dive industry and amongst divers and, therefore, it seems inexplicable that this diver would be supported to dive a CCR unit without appropriate training by a senior diving instructor (himself a CCR diver but not a CCR instructor). While CCR units can be dived safely, there is no place for home-made units dived by untrained individuals in what is already a risky undertaking. Training on semi-closed rebreathers does not substitute for CCR training as, apart from the basic breathing loop, the two types have little in common.

DISCLOSURE OF MEDICAL CONDITIONS AND THE NEED FOR PROPER MEDICAL ASSESSMENT

Once again, some of these cases (e.g., BH 10/02 and BH 10/05) highlight the importance of prospective or active snorkellers and divers disclosing medical conditions to the

dive physician or dive operator to enable a more appropriate decision to be made about their fitness to dive or snorkel, and/or indicate the need for closer supervision. Some (such as SC 10/04 and SC 10/06) also showcase the need for divers or potential divers with significant medical conditions, not only to undergo a fitness-to-dive assessment (preferably by a doctor with relevant training and experience), but also for them to provide an honest and complete medical history to facilitate a more accurate assessment.

CORONERS' FINDINGS

Several of the coroners' findings do not mention that the victim was scuba diving or snorkelling at the time of their death; it is simply stated, for example, that death was due to drowning or ischaemic heart disease. The addition of several words to indicate the circumstances of death provide context for the death. It would also enable easier tracking by researchers who do not have access to the complete file and are trying to track diving-related (or other) deaths. This need will be communicated to the Coronial Service.

LIMITATIONS OF THE STUDY

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

- Incomplete case data: fatalities were sometimes unwitnessed, and reports provided by any witnesses and by police varied in their likely reliability, as well as the content and expertise of the investigators.
- Autopsy reports may 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 (Table 3) 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: 20 deaths are too few to reliably determine trends.

Conclusions

- There were 20 reported diving-related fatalities during 2010 including 12 deaths while snorkelling and/or breath-hold diving, seven while scuba diving (one of these while using a closed-circuit rebreather) and one while using surface-supply breathing apparatus.
- Snorkelling or diving alone, poor supervision, apnoeic

hypoxia, pre-existing medical conditions, lack of recent experience and unfamiliar and/or poorly-functioning equipment were features in several deaths in this series.

- Other contributory or causal factors were entanglement and diver error.
- With snorkellers, the likely disabling injuries were asphyxia and cardiac causes.
- In scuba divers, the disabling injuries appear to have been asphyxia, CAGE and cardiac-related causes.
- Factors that may reduce mortality in the future include the avoidance of solo diving and snorkelling and improved buddy oversight; better supervision of organised activities; improved medical screening of older divers; operational integrity of equipment and ensuring familiarity with new equipment in a controlled environment.
- Reducing delays to CT-scanning and autopsy and coroners' reports documenting that the victim of a drowning was snorkelling or scuba diving at the time are aspects of the investigation of these fatalities that could be improved.

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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.

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.

The study of diving-related fatalities in the Asia-Pacific region has been funded by DAN AP on an on-going basis.

Submitted: 19 January 2015; revised 21 April 2015

Accepted: 01 July 2015

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