Diving and Hyperbaric Medicine

The Journal of the South Pacific Underwater Medicine Society (Incorporated in Victoria) A0020660B and the European Underwater and Baromedical Society

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New Zealand's worst diving accident

Oxygen monitoring for closed-circuit rebreathers

Problems with a hyperbaric patient ventilator

2003 Australian diving fatality case reports

Clinical audit of decompression sickness

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PURPOSES OF THE SOCIETIES

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

SOUTH PACIFIC UNDERWATER MEDICINE SOCIETY

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DIVING and HYPERBARIC MEDICINE

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

The Editor's offering

Fire! The devasting bush fires in Victoria have razed entire communities and caused many deaths and injuries. Medical resources have been hard-pressed, but such disasters always bring out the best in health care services. Members of SPUMS have been directly affected both as victims and care-givers, and we were relieved to hear that, despite fire reaching his property, Ian Millar from the Alfred Hospital hyperbaric unit and his family are safe and their house spared. His colleague Andrew Fock's wife's family are also all safe apparently, though they have lost at least one home. Sadly a registrar who used to work in intensive care at the Alfred died with his wife in Kingslake. As I write this, I am told Ian is in Buxton on 'embers watch' and providing medical services to the local community. On behalf of all SPUMS and EUBS members, our thoughts and sympathies are with everyone involved in these tragic events.

Nature has always taken its toll of humanity, whether by fire, wind, water or pestilence, either through its very force or through misjudgment and error on our parts. In this issue, the theme of human tragedy is continued with the publication of the case reports of the 2003 diving fatalities in Australia and a detailed report on the worst scuba diving accident in New Zealand's history. The latter has had major ramifications for recreational diving in that country, and, combined with more recent diving deaths there, has resulted in increasingly strident calls from New Zealand coroners for greater regulation of the diving industry because of a perception that it has failed to put its own house in order. Whether regulation is the answer is a matter of vigorous debate, but it is hard to see how one can legislate to safeguard against human error, stupidity, ignorance, poor physical fitness or occult ill health.

Some years ago at a SPUMS ASM, Professor Des Gorman was highly critical of the lack of adequate follow up of patients after treatment for decompression sickness in the data being reported by hyperbaric treatment centres. The general dearth of formal clinical audit is only too apparent from reading the literature, and is absent from the majority of papers published in this Journal in the past. Therefore, the development of an audit tool as part of the establishment of the National Recompression Registration Service in Scotland is felt to be of interest to many readers. It will be interesting to see how useful this process proves to be prospectively. At least two other countries, Singapore and New Zealand, have expressed interest in utilising this tool to examine their own clinical records, initially retrospectively. Perhaps this is the start of developing consistent international criteria so that we may compare apples with apples in the future?

Oxygen is at the heart of diving and hyperbaric medicine. Failure of oxygen delivery in rebreathers, whether leading to hypoxia or acute oxygen toxicity, has contributed to many of the deaths in recreational 'technical' diving. Whilst human error is often to blame, there is a greater degree of equipment problems in rebreather diving than that seen in open-circuit scuba-air diving. Understanding of these processes is important for diving physicians as rebreather technology is developing fast and the number of divers using rebreathers is increasing rapidly. In a new section for the Journal – Technical reports – Sieber and his colleagues describe a new approach, which they believe ensures improved detection of faults in in-circuit oxygen sensors and which has now been introduced into a commercially available unit.

In the second technical report, the findings of ventilator malfunction by Bosma and his colleagues from the East of England Hyperbaric Unit are of considerable concern to hyperbaric intensive care physicians. Delivery of mechanical ventilation to critically ill patients under hyperbaric conditions has always been a challenge. No one model of ventilator has had all the answers and most will not deliver the range of ventilation options used in the ordinary intensive care setting. It would seem that this is the case even for modern ventilators specifically designed for use in hyperbaric chambers. The message is clear – a detailed assessment of a newly purchased ventilator's performance under hyperbaric conditions is mandatory prior to its release into clinical service.

Plans for the SPUMS ASM are well advanced and a preliminary programme may be found on the Society website. The deadline for original papers has been extended to 31 March, so there is still time to get that submission in. There is also room for more delegates. This will be a first-class meeting, recognised for continuing education purposes, and Vanuatu is a relatively inexpensive venue in this time of economic austerity.

By the time you receive this issue, the Journal will have a new e-mail address, <editor@dhmjournal.com>. The old address will run in parallel until the end of 2008 when it will cease to exist. Please note this change now in your e-mail address list.

The summary German diving accident guidelines in the last issue came with an extensive reference list.[1] This resource can be found in the full version (in German and English) on the German Society website <www.gtuem.org>.

Mike Davis

Reference

1 Müller PHJ, Beuster W, Hühn W, Knessl P, Roggenbach J, Warninghoff V et al. Diving accident guidelines of the German Society for Diving and Hyperbaric Medicine: summary version. *Diving and Hyperbaric Medicine*. 2008;38:212-7.

Front page picture of the SPUMS Education Officer, David Smart, and his wife, Annette, was taken in Naigoro Passage, Kadavu Island, Fiji 2008.

The Presidents' pages

As I write, planning is well under way, from Scotland to Tasmania, for those intending to get to the ASM in Vanuatu. David Smart has done an outstanding job organising the scientific programme and this meeting should be memorable for that alone. Add the attractions of a good resort, access to some decent diving and a few tempting restaurants nearby, and I think this year will be one out of the box.

Meanwhile our Committee is dealing with some other matters of importance to the Society. At the November meeting we discussed a number of issues including the aging of our current membership and the need to attract some new blood. The membership package I signalled in my last column will be ready for presentation and distribution at the ASM. We have also personally contacted all members with unpaid dues for the last year to ask them why they may have decided to suspend their membership – I hope to summarise the responses in my next column. Glen Hawkins gave us a formal presentation on his plans for the new website under development and convinced us that a move to a new provider would be cheaper and give us much greater flexibility to provide what our members are asking for. We hope to move quickly on this one.

The journal continues to be the jewel in our crown. The merging of our own publication with that of the EUBS is starting to take shape now and the initial hiccoughs are largely over. Our editor reports a significant increase in submissions from both organisations and the newly constituted Editorial Board have all been active in recruiting and reviewing those submissions. Our next task is to successfully undertake an application to be listed on the National Library of Medicine database in Washington DC, from where we will be listed on MEDLINE in addition to our current indexing in EMBASE and the Science Citations Index (Expanded) (SCIE). We will soon receive an official impact factor from the latter organisation and are therefore making steady progress in establishing ourselves on the global scale.

For those who would like to use the journal to supplement their continuing education needs, plans are well advanced to add a CME exercise to each issue. I presented a sample of such an exercise at the committee meeting and there was general agreement that this idea would be very worthwhile across a range of specialties. I would be glad to hear details from anyone concerning the requirements of their professional organisations in regard to such activities and I am happy to assist such applications where I can.

Following that committee meeting in November, we were joined by a small group of invited experts and spent the rest of the weekend in a detailed review of the draft proposals for a new SPUMS medical. The fruits of that review are currently being vetted one more time by the Committee and I am hoping we will be able to present the new document for discussion during the ASM. We are certainly planning a briefing on the proposals for change in the areas of asthma and diabetes for those who are interested. These will be briefer and less formal summaries following our detailed presentations at the last two ASMs.

Our congratulations are extended to those members who have achieved their Diploma in Diving and Hyperbaric Medicine in the past year. As is becoming customary, we plan to honour those individuals during our Gala Dinner in Vanuatu, so I won't spoil the surprise for this potential audience. The Diploma is something all medical practitioners interested in the field should consider. Undoubtedly the greatest barrier for most people is the time requirement, but there are creative ways in which to satisfy that requirement and anyone interested should contact their local hyperbaric facility to have a chat about what is possible.

I look forward to seeing many of you in Vanuatu. If not there, then perhaps next year, when our meeting will be combined with that of the Asian Hyperbaric and Diving Medicine Association (AHDMA) and take place on the island of Redang in Malaysia. It is an exciting new destination for SPUMS and those who have been to one of the previous AHDMA meetings will confirm that they and SPUMS will get on just fine!

Michael Bennett, President of SPUMS

I hope you all have had a quiet and pleasant Christmas and are looking forward to a good New Year with new challenges and new possibilities.

The EUBS annual meeting in Graz was a success and I am sure that all of you who went there had a good and interesting time. Regretfully I could not participate this year; I was sorry for that as I always enjoy meeting old and new friends, finding out what is new in our field. As mentioned in a previous message, we arranged the Haldane symposium to celebrate 100 years of diving research, looking towards the future. Over 70 scientists and doctors from all over the world participated; it was recognized that one of the most important goals for the future was to attract young, talented doctors and scientists into our field. A book will be published describing the results from the meeting.

The main challenge in 2008 has been to upgrade *Diving and Hyperbaric Medicine* (DHM). Our editor in chief, Mike Davis, has done a marvellous job with help from the European Editor, Peter Müller and a new Editorial Board. The joint journal has gone through its first year, and we are very pleased that an increasing number of members are willing to publish here. However, we are still totally dependent on your cooperation. EUBS and SPUMS started this joint venture in the belief that it would benefit the diving and hyperbaric communities in our corners of the world and that this journal could significantly help to promote diving and hyperbaric research all over the world.

Embarking on such a joint venture is not easy; there is considerable competition. In order to be established and accepted in the medical field, we need to be accepted and recognised in PUBMED, the database for the National Library of Medicine, MEDLINE. Our indexing on Science Citation Index Extended from the start of 2007 will allow the journal to gradually develop an Impact Factor. It is difficult for small specialty journals such as *Diving and Hyperbaric Medicine* to achieve a high impact factor even with a high quality of published papers submitted, but this and MEDLINE citation will lead to better finances and more support for all our activities. An application for MEDLINE citation will be made early this year. In order to improve our chances, we need you to send us papers. For instance, a number of you have presented at EUBS. In the future, we will not be publishing all meeting abstracts in the journal, so please support us and your organisation by submitting full papers to DHM. In particular, I will again encourage those of you in senior positions; your contribution is vital.

The Zetterström Award is awarded on the basis of scientific merit. It is an absolute requirement that the winner publishes his or her results in DHM; we hope that this is done without any further pressure from us!

EUBS's financial position is not the best. Thankfully we have not had any negative comments on the increased dues this year. This was absolutely necessary if we wanted to make joining the Society more attractive, and participation in the DHM journal has been a severe drain on our resources. We encourage you to pay your dues as soon as possible after you receive the invoice. In order to simplify the process of payment, we have decided to use the PayPal system as this is considerably cheaper than other means. We are also having the money paid in Euros. The money can now be paid by going to our website, go to <www.EUBS.org> and then on to the membership page. Even if you have paid your dues for 2008–2009, we encourage you to pay for 2009–2010 as soon as possible, this will then be valid until 30 June 2010. I have already done this and encourage you to do the same; this will be a great help in a difficult situation. If at least 30 members of EUBS are willing to pay their dues for 2009–2010 by 15 April, our current financial problem is solved.

We have established a membership page on our website, as mentioned above. You can pay your dues here but you will also get access to a very large database of literature related to diving and hyperbaric medicine;

- access to your own membership data and membership status
- possibility to renew your membership with a few mouse-clicks
- browsing the EUBS Membership Directory (who is who, and how to contact them)
- secure access to the full-text Literature Database of the German Society for Diving and Underwater Medicine (GTUEM)
- a 'discussion forum' to make contacts, exchange information and more...

If you have forgotten your password, a temporary one will be given to you.

The planning for the EUBS annual meeting in Aberdeen 25–28 August 2009 is well under way. Please go to our website for more information.

And those of you who are planning to present papers, please consider submitting papers to our Journal!

Alf O Brubakk, President of EUBS

Original articles

Provisional report on diving-related fatalities in Australian waters 2003

Douglas Walker and John Lippmann

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

Abstract

(Walker D, Lippmann J. Provisional report on diving-related fatalities in Australian waters 2003. *Diving and Hyperbaric Medicine*. 2009;39:4-19.)
An individual case review of the diving-related deaths that were reported to have occurred in Australia in 2003 was conducted as part of the combined Project Stickybeak / DAN Asia-Pacific dive fatality reporting project. The case studies were compiled using reports from witnesses, the police and coroners. In each case, the particular circumstances of the accident are provided, as well as details from the post mortem examination, where available. In total there were 22 reported fatalities, 18 men and four women. Twelve deaths occurred while snorkelling and/or breath-hold diving, nine while scuba diving and one while using surface-supply breathing apparatus. Cardiac-related issues were thought to have contributed to the deaths of six snorkel divers (50%) and four scuba divers (44%) in this series. There were three deaths in breath-hold divers likely to have been associated with apnoeic hypoxia blackout. Inexperience, time away from diving and lack of common sense were features in several scuba deaths.

Introduction

Diving is a potentially dangerous recreational activity and each year in Australia (and elsewhere) there are fatalities associated with it. Some of these accidents are unavoidable. However, many of these fatalities could have been avoided through better education, greater experience, appropriate medical screening, better equipment maintenance and design, a sounder attitude and common sense. The aim of the DAN Asia-Pacific Dive Fatality Reporting Project (incorporating Project Stickybeak) is to educate divers and inform diving physicians on the causes of fatal dive accidents in the hope of reducing the incidence of similar accidents in the future.

Douglas Walker has reported on Australian diving fatalities since 1972 through Project Stickybeak, which has arguably been the most thorough on-going investigation of diving fatalities anywhere in the world.[1–6] The Divers Alert Network Asia-Pacific (DAN AP) is now collaborating with Dr Walker to ensure that these investigations and reports continue well into the future.

This report includes the diving-related fatalities between 1 January and 31 December 2003 that are recorded on the DAN AP database.

Methods

As part of its on-going research into, and reporting of, general diving fatalities in Australia and elsewhere in the Asia-Pacific region, DAN AP has obtained ethical approval from the Human Research Ethics Committee, Department of Justice, Government of Victoria, Australia to access and report on data included in the Australian National Coronial Information System (NCIS). A comprehensive search was made of NCIS to identify all diving-related cases that were reported to various State Coronial Services for the year 2003.

The other major source interrogated was the DAN AP dive fatality database for scuba diving fatalities occurring in 2003. DAN AP staff routinely monitors a variety of internet sites and newspapers for diving and snorkelling fatalities. DAN sometimes also receives reports from the diving community when a fatality has occurred.

Snorkelling and breath-hold diving fatalities

CASE BH 03/01

The victim, a 23-year-old male, was on a day trip to the Great Barrier Reef (GBR) as part of a large group. After stating that they were strong swimmers and experienced snorkellers, the victim and another person were permitted to snorkel independently from the rest of the group. Sea conditions were reported to be good.

After diving at a first site without mishap, the group moved to another area of reef where some of the scuba divers later reported seeing a breath-hold diver at 7–8 msw, swimming in a normal manner. When they later passed this area again, they noticed the victim lying on the coral at the edge of the reef drop-off, with his weight belt still in place. He had reportedly been underwater about two minutes before being brought back to the surface. Attempts at resuscitation (basic life support, BLS) were unsuccessful.

Autopsy: The autopsy confirmed drowning in an otherwise healthy man.
(Height = 192 cm, Weight = 81 kg, BMI = 22)

Comment: This victim was seen to do multiple breath-hold dives to around 6 msw including horizontal swimming at depth. Although he wasn't seen to hyperventilate, it is possible that he was a victim of apnoeic hypoxia with or without hyperventilation.

Summary: Experienced; multiple breath-hold dives alone; unconscious on the sea bed; drowning.

CASE BH 03/02

Two days before starting his vacation to Australia, this 68-year-old man arranged a 'check up' by his doctor, who was controlling the treatment of his mild Parkinsonism and the follow-up of his cerebrovascular accident four years ago and two TIAs two years ago, from which he had residual limitation of his speech and mobility. A year prior, he successfully underwent surgical closure of an atrial septal defect (ASD). He was advised that it was safe for him to make this trip.

After a briefing, the group was taken out to the GBR to stay on a moored boat. On arrival, they were each issued mask, snorkel and fins. The victim also obtained a foam-type floatation device to wear round his waist because he was not a confident swimmer. Although the dive organization later mentioned that he had not stated his health problems on the medical questionnaire, he had a significant disability that was obvious to all.

Obeying the advice to swim with a buddy, the victim entered the water with his wife and then swam around for about 15 minutes. There was a slight current and they drifted about six metres apart. When he failed to respond to her call, his wife swam to him and found him face-down and unconscious. She turned him face-up and called for assistance. One of the crew reached them and started in-water rescue breathing whilst the victim was taken back to the boat. Despite the arrival by helicopter of paramedics, resuscitation was unsuccessful. His wife revealed his medical history and that he was taking warfarin sodium, sarbidopa-levodopa, pramipexole dihydrochloride, and rasagiline, the latter being an experimental drug for Parkinsonism.

Autopsy: There was no evidence of trauma, jellyfish stings, or drowning. Examination of the lungs and intracranial cavity showed no abnormalities apart from some atheromatous changes in the cerebral arteries (40% stenosis). The heart was enlarged, 478 grams, and slightly dilated; the surgical repair to the ASD appeared unremarkable. There were significant atheromatous changes in the anterior descending (70% stenosis) and circumflex branches (90% stenosis) of the left coronary artery. The right coronary artery was only 50% patent. Histology revealed patchy fibrosis of the left ventricle. Both the description of the incident and the autopsy supported a diagnosis of a cardiac death.
(Height = 170 cm, Weight = 75 kg, BMI = 26)

Comment: This appears to be a death that could have happened at any time, as the coronary artery disease would have put him at high risk of an acute ischaemic event triggered by exertion, although this risk is somewhat reduced by the fact that he was anti-coagulated. This event may have been an acute myocardial infarction (AMI) or possibly an immersion dysrhythmia. Rasagiline and pramipexole (associated with falling asleep during driving and other activities of daily living) are known to alter vascular activity and how this is affected by immersion is unknown. The type of buoyancy aid provided assisted him when alert but was potentially lethal when consciousness was lost, floating him face down. The effect of Parkinson's disease in movement and swallowing function should not be overlooked and his fitness for undertaking snorkelling activity is questionable.

Summary: History of cardiovascular disease; atrial septal wall closure and Parkinson's disease; wore floatation device as not confident swimmer; silent unconsciousness; probable cardiac death.

CASE BH 03/03

The victim, a 28-year-old male who was reportedly a healthy, competent swimmer and divemaster, was with friends on a boat anchored about 80 metres from shore in water about 16 metres deep. During lunch, the victim was noted to consume about four gin-and-tonics but did not appear to be adversely affected by them. When the others took the tender to the fringing reef, he remained aboard the boat for about 15–20 minutes, and then swam out to join them, a distance of 60–80 metres. It is not known whether he had continued to drink alcohol in the interval. He was using a mask and snorkel but no fins. The sea conditions were reported to be good.

The water over the reef, which was about 20 metres from the beach, was approximately 3 msw deep. After about an hour, the victim said he was going to swim back to the boat. The water was calm and the current minimal. When the others returned to the boat about 20 minutes later they were surprised not to find him there. He had not been seen to dive below the surface during his return swim on the occasions anyone had looked towards him. After checking that he was not on any of the other boats anchored nearby, the police were notified and a search commenced. A little over two hours from when he was last seen, his body was found on the sea bed in 15 msw; his mask was in position, clear of water. BLS was attempted for a short time after he was brought ashore.

Table 1. Summary of diving-related fatalities (BNS – buddy not separated, BSB – buddy separation before incident,

ID BH	Sex	Age (years)	Training	Experience	Dive group	Dive purpose
03/01	male	23	n/s	experienced	solo	recreation
03/02	male	68	nil	nil	BSB	recreation
03/03	male	28	yes	experienced	GSB	recreation
03/04	female	66	n/s	n/s	BNS	recreation
03/05	male	25	n/s	experienced	solo	recreation
03/06	male	51	nil	nil	BSB	recreation
03/07	male	54	n/s	nil	GSB	spearfishing
03/08	male	61	nil	experienced	BSD	crayfishing
03/09	male	85	nil	nil	GSB	recreation
03/10	male	35	yes	experienced	GSB	spearfishing
03/11	male	65	nil	some	GSB	recreation
03/12	male	31	n/s	experienced	solo	recreation

Autopsy: The cause of death was determined to be drowning and no disease was present. The coronary arteries were described as being 'normal'.
(Height = 175 cm, Weight = 73 kg, BMI = 24)

Comment: The blood alcohol level was found to be 150 mg per 100 ml blood. Surprisingly the pathologist omitted mention of this finding from his formal report. Alcohol may have been a contributory factor to this death. The victim was not wearing fins and this would have impaired his swimming ability and also may have been an adverse factor.

Summary: Experienced; reportedly healthy; ingested substantial amount of alcohol prior to snorkelling; found dead on sea bed; drowning (possibly alcohol-related).

CASE BH 03/04

The victim, a 66-year-old overseas tourist, was due for review by her cardiologist when she returned home and expected to then be advised to have a cardiac operation. It was later revealed she had atrial fibrillation (AF), an ASD, pulmonary stenosis and asthma (her dominating concern). Her doctor had reportedly cleared her to travel on this holiday but it is unknown whether she had mentioned her intention to snorkel.

The victim and her companion were staying at a resort island and went snorkelling in front of their unit. After hiring equipment from the dive shop, they swam in the waist-deep water about 20 metres off the beach, looking at the coral. After about 10 minutes, the victim suggested that they return to the beach but when they were 10 metres from shore, she stood up and asked for help. Her friend noticed her breathing was laboured and lips blue. After helping her ashore, she sat her down upright and fetched her 'Ventolin' inhaler. The victim was scarcely able to depress the inhaler or to inhale, and was gasping. Help and oxygen were quickly brought from the resort's medical centre. Although the victim was unable to answer any questions, her friend was sure that she had not swallowed any water. Her condition initially appeared to improve and she was moved to the medical centre. A radio call was made for medical advice and assistance and paramedics were dispatched by helicopter. A doctor holidaying on the island attended her, but she became unconscious and failed to respond to BLS.

Autopsy: No autopsy was conducted given her known medical problems. The death certificate stated that death was due to cardiac arrhythmia associated with an ASD and pulmonary stenosis.

Comment: This victim was at risk of a cardiac event at any time during her normal activities. There is nothing to suggest

in Australian waters in 2003, snorkel and breath-hold incidents
BSD – buddy separation during incident, GSB – group separation before incident; n/s – not stated)

Depth of water (msw)	Incident depth (msw)	Weight belt	Weights (kg)	Floatation device	Cause of death
15	n/s	yes	4.5	no	drowning, ? hypoxic blackout
n/s	surface	no	n/a	yes	cardiac
15	unknown	no	n/a	no	drowning, ? alcohol-related
1	surface	no	n/a	no	cardiac
20	ascent (presumed)	no	n/a	no	drowning, ? hypoxic blackout
9	surface	no	n/a	no	? cardiac
2	surface	off	n/s	no	cardiac
n/s	surface	off	n/s	no	cardiac
n/s	surface	no	n/a	yes	cardiac
25	ascent (presumed)	yes	6	no	drowning, ? hypoxic blackout
n/s	surface	no	n/a	no	drowning, ? cardiac
n/s	n/s	no	n/a	no	unknown

her swimming required more than mild exertion. This death could have been a result of immersion arrhythmia or salt-water-induced asthma. An autopsy would have been of benefit in assessing the most probable cause of death.

Summary: History of AF, ASD, pulmonary stenosis and asthma; respiratory distress while snorkelling; cardiac failure, possibly resulting from cardiac arrhythmia.

CASE BH 03/05

The victim was a 25-year-old male who was an experienced breath-hold diver and the skipper of a charter vessel on the GBR. He challenged a divemaster to a breath-hold diving competition which the divemaster refused. After donning mask, snorkel and fins, the victim entered the water and began to hyperventilate before diving. The divemaster was heard to advise him to stop hyperventilating, but was ignored. After he failed to surface, an unsuccessful underwater search was made. The body was never found. On the basis of the witness statements, it was decided his death had likely resulted from post-hyperventilation apnoeic hypoxia leading to drowning.

Summary: Experienced; last seen hyperventilating prior to breath-hold diving; body never found; probable drowning due to post-hyperventilation apnoeic hypoxia.

CASE BH 03/06

The victim was a 51-year-old male who had never previously used a snorkel. He was aboard a friend's charter boat. The sea was somewhat choppy on the trip out and he became unwell, this being thought to be sea sickness. He said he was feeling better when they anchored at a reef, and even ate a little food. The skipper provided the victim and a companion with mask, snorkel and fins. Before they entered the water, the victim told his buddy that he had never previously used a snorkel. The water was still choppy, enough to occasionally enter a snorkel as one swam along. After they reached a coral bommie about 30 metres from the boat, the victim told his buddy he was managing better without using the snorkel. He seemed well to his buddy, who then dived to photograph fish. After he had finished taking pictures, he saw his companion was no longer close to him but was about a third of the way back to the boat, swimming freestyle. He appeared to be alright. The buddy decided that he would also swim back. They had only been in the water 10–15 minutes. When he soon overtook his friend, he noticed he had slowed down and his arm movements were sluggish. The buddy then saw they were being taken further from the boat by the current but that the crew was pulling up anchor. He reached the boat before its engine started and was taken aboard.

The skipper had watched them as they swam around the bommie. He saw the buddy dive and the victim start swimming towards the boat. He called out to the latter to wait to be picked up, and indicated this with his hand. He saw him stop swimming and lie quietly face-down at the surface, his snorkel sticking out of the water. While the buddy was coming aboard, the skipper had continued watching the other swimmer and became concerned when he realized he was too still so he quickly went to him. When they got him aboard they saw he was pallid with no signs of life, so commenced BLS. Despite the arrival of a doctor and some advanced life support (ALS) procedures, he could not be resuscitated.

Autopsy: The autopsy report notes there was blood in the pericardium, a fractured sternum, and blood in the mediastinum, and traumatic injury to the right ventricle, the result of vigorous BLS. There was early coronary atherosclerosis with 25% narrowing of both proximal and distal vessels, which, combined with the clinical story, was the basis for attributing death to cardiac arrhythmia.
(Height = 180 cm, Weight = 83 kg, BMI = 26)

Comment: It is probable the victim was unaware of the degree of his ill health and incorrectly ascribed his condition to sea sickness. The 25% narrowing of the coronary arteries should not be haemodynamically significant and the diagnosis of arrhythmia would appear rather speculative. His total inexperience in the use of a snorkel can be considered a significant adverse factor.

Summary: First use of snorkel; feeling unwell; swam against current; separation; silent unconsciousness; possible cardiac arrhythmia.

CASE BH 03/07

This victim was a 54-year-old male with a history of hypertension, profound deafness and surgery to both shoulders which had left him unable to raise his arms higher than his shoulders. He went spearfishing with two friends, who were also deaf, and had been loaned a wetsuit and all the other equipment except fins, which were his own. His spearfishing experience was not recorded but he was reported to be a good swimmer and had apparently done some scuba diving. The three men swam out in relatively calm conditions to where the water was about two metres deep. After about five minutes, the victim said he was going back to the beach. He gave no reason and showed no sign of having any problems, giving an 'OK' sign when asked. They saw him swim towards the beach and a few minutes later stand up and give another 'OK' signal. Believing that he was safely on the beach, the other two continued spearfishing for 20–30 minutes. As the victim was not on the beach when they returned, they thought that he had gone to their camp. It was only after they asked his wife where he was, and noticed that none of his gear was around, that the alarm was raised.

A man fishing off the rocks saw the three men enter the water and swim out past his line. A short time later, he saw one of them swimming freestyle back to the beach, the other two continuing away from the beach area. The solitary swimmer seemed to stand up, or float upright, when about 100 metres offshore. When he next looked, possibly 10 minutes later, he saw this swimmer was now 50 metres from him and floating away in the current and swell. He couldn't see his snorkel, or any kicking movements. This worried him and he called another fisherman nearby to come over and give his opinion. However by the time he came the person could no longer to be seen, then this man said he could see three heads out to sea and the two fishermen believed there was no cause for worry and so took no action. A search of the island and the water lasting several days was unsuccessful beyond recovery of his hand spear. The body was washed ashore 10 days later.

Autopsy: Moderately severe coronary atherosclerosis was reported, the left anterior descending showing 70–80% narrowing, the right coronary 60–70%. The pathologist stated his opinion that this was normal for someone of his age. The histology showed "*Autolysis 3+ myofibrosis, coronary artery - severe atherosclerosis*". The cause of death was recorded as being due to severe coronary atherosclerosis.
(Height = 162 cm, Weight = 85 kg, BMI = 32)

Comment: It is unknown whether the outcome would have been any different if the victim's buddies had escorted him to shore. However, it is important to establish and maintain a good 'buddy system' while snorkelling.

Summary: History of hypertension, deafness and bilateral shoulder operations; some experience; spearfishing; separation; last seen standing in shallow water; severe coronary artery disease, cardiac death.

CASE BH 03/08

The victim was a 61-year-old male who was an experienced spear fisherman. He was overweight, with hypertension, hyperlipidaemia, and liver changes. He had been prescribed ramipril and xenicol, but only took these sporadically. He had also undergone bilateral hip replacements successfully three years prior.

His buddy described how they knew this dive area well, that there was a relatively easy walk to a rock ledge, a requirement because of the victim's portly nature and residual hip disability. The buddy had to put his friend's fins on for him because he had difficulty in reaching down while standing on the slippery rock surface. They had donned their wetsuits in their car and carried their equipment to the water's edge. After entering the water they swam out to calm water beyond the turbulent area near the rocks, about 20–25 metres, where they stopped to adjust their equipment and load their spear guns. The victim was wearing a new weight belt with which his buddy saw he was having trouble. He removed it and handed both it and his speargun to his buddy and started to swim back to the area where they had entered the water. The buddy was used to being given the task of holding his friend's equipment and followed him back.

The current had carried them a little, so where they reached the reef its edge was about 2.5 metres vertically above the partially submerged ledge on which the victim rested, gripping its edge and seeming to be working his way along it. The buddy found an easier exit area a short distance away and deposited their equipment on rocks out of the water. He looked round and saw the victim floating 20 metres away and thought he saw him swimming but when he swam out to him he realised the victim's mask was on his forehead, he had lost one fin and was unconscious, floating with his mouth and nose out of the water. The buddy towed him back to the rocks keeping the victim's face out of the water and calling for help. People on the rocks helped pull the victim out of the water and BLS was commenced and continued for a time after ambulance officers arrived, but was unsuccessful.

Autopsy: Autopsy measurements confirmed his obesity. There was no evidence of either old or recent ischaemic myocardial damage. The right coronary artery was widely patent with only mild atherosclerosis. However, the anterior descending and circumflex branches of the left coronary artery showed approximately 70% and 50% narrowing respectively. Atherosclerosis was only mild in the distal aorta but the circle of Willis was more severely involved. The wall of the right ventricle measured 5 mm, the left 20 mm, thick. Histological examination showed severe fatty changes in the liver and there were scattered areas of fibrosis in the myocardium. The pathologist gave severe ischaemic heart disease due to coronary atherosclerosis as the cause of death. (Height = 183 cm, Weight = 124 kg, BMI = 37)

Comment: The victim was unfit, reportedly neglected to follow the medical treatment prescribed for him, and failed to appreciate the physical demands of his activity. If the loss of a fin occurred while the victim was conscious it would have reduced his swimming ability and increased exertion.

Summary: Obese; history of hypertension, hyperlipidaemia, some disability following bilateral hip replacements, fatty liver; spearfishing; silent unconsciousness; some coronary narrowing; cardiac death.

CASE BH 03/09

The victim was an 85-year-old male who exercised daily and was reported to have no health problems and to be generally fit and mobile for his age. He and his wife had travelled interstate to visit the GBR. While on the boat out to the reef, a talk and demonstration on snorkelling were given, and he completed a medical questionnaire. He had initially intended to scuba dive but was told that, due to his age, he would first be required to obtain a diving medical. There was another briefing on snorkel safety before passengers entered the water.

He entered the water wearing a shirt and bathers, mask, snorkel, fins and a floatation vest, all provided on the boat, he and his wife being among the last to enter the water, his wife before him. Shortly after entering the water, his wife heard a whistle blast and a shout and heard talk of an incident involving an elderly man. The victim was noticed to be floating face down in the water, not moving and with the snorkel submerged. The alarm was given and the lookout jumped into the water and swam to the victim who was about 10 metres away. BLS was unsuccessful.

Autopsy: Significant coronary atheroma was present, particularly on the left anterior descending artery, which had up to 70% narrowing caused by eccentric atheroma, with up to 65% in its circumflex branch. There was also 50–60% narrowing in the right coronary artery. There was no evidence of past or recent myocardial infarction. Mild left ventricular hypertrophy was noted; heart weight 396 gm. There was also evidence of an old cerebral haematoma, 2.5 cm greatest diameter, in the right frontal pole, with adjacent contusional damage; there is no information concerning this old injury. "*The lungs demonstrate pulmonary oedema with what appears to be terminal agonal aspiration of sea water*." Cause of death was diagnosed as a heart attack (with severe coronary atherosclerosis).

Comment: Even the apparently healthy aged can have hidden, high-risk health problems. There was significant coronary stenosis but no evidence of an infarct.

Summary: Apparently fit; elderly; inexperienced; wearing buoyancy vest; silent unconsciousness; severe coronary artery disease; cardiac death.

CASE BH 03/10

As well as being an experienced spear fisherman known locally to be a promoter of safety in that sport, the victim, a 35-year-old male, was also a scuba instructor and worked as a professional abalone diver. On this day, he was spearfishing from a boat with his girlfriend and a friend who was also an experienced spear fisherman. The friend was teaching the sport to the victim's girlfriend while the victim was spearfishing solo on the other side of the boat. After four hours, the others returned to the boat and noticed they could not see the victim come to the surface, and that his float was stationary. They attempted to pull it up and found that it was firmly attached to the sea bed. The friend dived down to find why this was so and found that the spear was through a fish and stuck in the bottom. He surfaced to relay this information and they visually checked around in the hope that the missing man had surfaced and been washed away. The friend then dived again and found the body in 25 msw near the spear, weight belt, which did not have a quick release buckle, in position. BLS was unavailing.

Autopsy: The autopsy revealed petechial haemorrhages in the conjunctivae, "intense" pulmonary oedema and right middle ear mucosal congestion. The pathologist noted an arteriovenous malformation in the brain and suggested that this had caused an epileptic seizure and possible cardiac arrhythmia (although this pathology does not appear in the autopsy report). The victim had no history of fits or ill health. The cause of death was reported to be "*immersion following an epileptiform seizure*".
(Height = 178 cm, Weight = 59 kg, BMI = 18.6)

Comment: Pulmonary oedema in a young person may arise from straining against a closed glottis (e.g., after laryngospasm). The finding of the petechial haemorrhage and pulmonary oedema raises the possibility that the victim overstayed his time underwater and drowned. The ear barotraumas are likely to have occurred as the body sank. This death may have occurred as a result of post-hyperventilation apnoeic hypoxia, rather than as a result of an epileptic event as suggested by the pathologist. The autopsy report contains no evidence that an epileptic event had occurred.

Summary: Very experienced spear fisherman; solo; no quick-release on weight belt; drowning (? seizure, ? apnoeic hypoxia).

CASE BH 03/11

The victim was a 65-year-old male, regarded as being in good health, who had recently retired after a lifetime of physical labour. After a light snack on the beach, the victim swam out about 15 metres. He then stood up in waist-deep water and said that there were things in the water biting him, before returning to the beach. Later, he joined others in the boat to check on set crab lines. He entered the water wearing loaned mask, snorkel and fins but handed back the snorkel a short time later. For some unexplained reason his daughter, who had remained in the boat, became worried and encouraged another relative to swim to check whether he had any problems. He mentioned seeing some crabs and then gave his fins to the relative who had swum to him. They swam back to the boat and, when they were about five metres from it, he ducked his head under the water then raised it and blew out. At first his relative thought he was being amusing, and then became alarmed at his expression. He was quickly brought into the boat and BLS commenced, but this was unsuccessful.

Autopsy: There was evidence of drowning and some particles of sand in the trachea but the heart and the coronary arteries were free of disease. The pathologist declared drowning as cause of death. He noted without any comment the presence of a small amount of quinidine in the blood.
(Height = 174cm, Weight = 83kg, BMI = 27.4)

Comment: The description of the incident, combined with the finding of quinidine in the blood, suggests that he may have had some form of cardiac arrhythmia, possibly initiated by inhalation of some water. There is no evidence of contact with his GP to ascertain his true health as he may have concealed this from his family. There was also a possible history of marine envenomation although the pathologist's report included no evidence of this. Either of these factors could have contributed to the drowning, but this is speculative.

Summary: Apparently healthy; sudden unconsciousness while swimming close to buddy; drowning; possible cardiac arrhythmia (taking a Class 1 antiarrhythmic agent, quinidine).

CASE BH 03/12

The victim was a 31-year-old male who went missing while snorkelling in rough water. His body was recovered the next day. No further details are available at the time of writing.

Scuba diving fatalities

CASE SC 03/01

The victim, a 51-year-old male, was on a cruise of the GBR. On his medical form he had reported he was taking medication for hypertension (analapril maleate) and that his doctor said he was fit to dive. Although he did not produce any documentation, his word was accepted. He failed to reveal he was also taking dothiepin hydrochloride for depression and that he had a history of alcoholism, suffering two 'post alcohol withdrawal' fits two years earlier. He claimed to have done over 1,000 dives over a 40-year period. Some passengers later expressed the view that the victim had boasted too much about his abilities and had expressed concern that he was uncertain if he was 'up to' doing the dive.

Four scuba divers and a divemaster were taken by tender to the dive location. Before they entered the water, they were all checked to ensure their equipment was in order, air turned on, the regulators purged, and BCD inflation and deflation tested. The victim had some problem locating his deflator and the divemaster helped him, prior to descending together hand over hand down their mooring line. Unexpectedly, at about 5 msw, the victim let go of the line and sank in an uncontrolled manner to the sea bed at about 9 msw. The instructor immediately descended after him and found that he was moving around in an uncoordinated manner and had a wide-eyed distressed stare. All his equipment was in place and he was breathing. He sat him down and tried to calm him without getting any response, but he was still breathing so he grabbed him and started to take him to the surface. However, when about half-way up, the victim grabbed the mooring line and would not let go, then grabbed the regulator from the instructor's mouth and held onto it while breathing from his own. As the divemaster started using his alternative regulator, the victim collapsed and let go of everything. The divemaster quickly ditched the victim's weight belt and took him to the surface, applying pressure on his sternum to ensure he exhaled. The whole dive had lasted only three to four minutes.

The victim was unconscious, cyanotic and not breathing when pulled into the safety boat. His airway was checked and rescue breathing with supplemental oxygen was commenced. The return to the boat only took a minute, and a radio call was made for the emergency helicopter. BLS was successful but he remained unconscious and fitting. He was airlifted to hospital where life support was withdrawn three days later with evidence of irreversible brain damage.

Equipment checks showed it was serviceable and there was adequate remaining air but that some maintenance was necessary before it was next issued.

Autopsy: The autopsy report is limited, merely stating that there was an enlarged cirrhotic liver, enlarged heart, coronary atherosclerosis, congested lungs, and skin lesions of psoriasis. There is also a simple notation that hypertension and ischaemic heart disease were noted. No supporting details were supplied. The cause of death was reported to be congestive heart failure and cerebral hypoxia.

Comment: The autopsy report is inadequate to determine the cause of death with any certainty. As no formal inquest was held there was no discussion concerning the observed actions of the deceased. While panic was probably an important factor, it is possible a cardiac factor was present, though "*delayed drowning death, cerebral anoxic damage*" was the actual final factor. It is notable that a four-year absence from scuba diving destroyed the confidence built up over 40 years. Statements of past diving experience should not be accepted uncritically.

Summary: History of hypertension, depression and alcoholism; trained and claimed 40 years' experience; no dives in past four years; anxious; probable panic; possible cardiac event underwater; initial resuscitation successful; delayed death; congestive cardiac failure and cerebral hypoxia.

CASE SC 03/02

This victim, a 22-year-old female, was visiting Australia with her mother and brother. They joined one of the trips to a pontoon on the GBR. The siblings signed up for a 'resort dive experience', the first dive for her but her brother had scuba dived previously. The chief instructor gave a standard briefing on the basics of scuba diving, with a knowledge review at the end of the presentation. The victim was obviously nervous before the dive and she admitted to the instructor to having a claustrophobia problem. The instructor said she would accompany her for the descent, and if she felt too nervous they could abort the dive.

While sitting on the pontoon's snorkelling platform at about one metre depth, the victim practised some basic skills, such as mask clearing, under the instructor's supervision. The victim had initial difficulties with breathing but, after practising, was able to continue. At this point, and soon thereafter, the instructor had not regarded the victim's anxiety level as more than that she often noted in those making their first scuba dive. The instructor held onto the victim's hand and regularly signalled 'OK' to her and each time she indicated that she was all right.

After they had dived for 20 minutes looking at their coral surroundings, her brother noticed that she had some water in her mask and was looking anxious as she failed in her attempts to expel it. She seemed to forget to breathe. Her instructor tried to help her, but she failed to breathe out through her nose and her mask became pushed up, allowing water to enter her nostrils. She reacted by turning to a vertical position, tore off her mask in panic, and started a rapid ascent from 9 msw with her eyes closed, so was unaware of her instructor's proximity. The instructor tried to guide the victim to the ascent lines to hang on there while clearing her mask, but she ripped it off after again failing to clear it of water. The instructor held onto her trying to slow her ascent and she seemed to be breathing the whole time as bubbles were coming from the regulator's exhaust. They came to the surface together and there the instructor inflated the victim's BCD and rolled her on her back. She responded when asked how she was, but had wheezy breathing. The instructor signaled for assistance, then saw the victim's eyes roll back in her head before her arms went rigid and she became unconscious. They were near the pontoon and help soon arrived. The victim appeared to have no signs of life and BLS using supplemental oxygen was commenced after minimal delay. An automated external defibrillator (AED) was available and was attached to the victim but no shock was indicated. However, despite this, a shock was given, as was an injection of adrenalin into her heart by a doctor; all to no avail.

An investigation found no fault with the equipment or in the conduct of the instructor. There was adequate remaining air.

Autopsy: Pre-autopsy X-rays showed extensive opacification of both lung fields and bilateral pleural effusion. Surgical emphysema was present around the heart, extending up into the mediastinum and the soft tissues of the neck. There was some evidence of gas within the portal venous system of the liver, possibly due to putrefaction. The pathologist reported finding oedematous congested lungs with extensive recent alveolar haemorrhages and no other disease. The cause of death was reported to be pulmonary barotrauma.
(Height = 167 cm, Weight = 56 kg, BMI = 20)

Comment: Although the autopsy makes no mention of intravascular gas, in this witnessed event, there is sufficient

Table 2. Summary of diving-related fatalities in Australian waters in 2003, scuba and surface-supply incidents BSD – buddy separation during incident, CAGE – cerebral arterial gas embolism

ID SC	Sex	Age	Training	Experience	Dive group	Dive purpose	Depth (msw)
03/01	male	51	yes	experienced (4-year gap)	BNS	recreation	9
03/02	female	22	no	nil	BSB	resort	9
03/03	female	26	yes	slight	BSD	recreation	30
03/04	male	47	no	nil	GSB	resort	6
03/05	male	29	yes	experienced	BSB	abalone	n/s
03/06	female	46	yes	experienced	BNS	recreation	29
03/07	male	56	yes	experienced	BSD	recreation	15
03/08	male	39	yes	experienced	GSD	recreation	15
03/09	male	25	partial	experienced	BSB	scalloping	10
SSBA							
03/01	male	25	no	nil	BSB	crayfishing	5

evidence to support the conclusion of cerebral arterial gas embolism (CAGE).

Summary: First resort dive; history of claustrophobia; anxious; mask flooded causing panic; collapsed and died on surface; pulmonary barotrauma (probably leading to CAGE).

CASE SC 03/03

The victim was a 26-year-old woman who was an inexperienced, recently trained diver. She and her husband, a more experienced diver, dived from a dive charter vessel in a moderately strong current on a wreck lying in 30 msw. Because the husband has been charged with the murder of the victim, no further details of this death can be reported at present.

Summary: Trained but inexperienced; first ocean dive; moderate current; reported panic separation; drowning; homicide investigation.

CASE SC 03/04

The victim, a 47-year-old male who was described as ‘looking elderly and thin’, was an overseas tourist on a day trip to the GBR. He completed a health questionnaire before being accepted to do a ‘resort dive’ along with three other people. During their outward trip to the GBR, there was a briefing on some of the basics of scuba diving. Concern was later expressed by the victim’s companions that no advice was provided about buoyancy control and of the importance of correct breathing in the event of a rapid ascent. The company stated that it was its policy not to mention control of buoyancy, the instructor being responsible for making any necessary adjustments.

After an uneventful first scuba dive, including practising mask clearing and regulator recovery, the victim and some others went for a short snorkel before lunch. The boat was then moved to another reef and the same four did a second dive with the same instructor. They entered the water before making ‘a fair swim’ underwater to reach the reef, the instructor leading but turning to look back at them, initially frequently. They followed him in line at about 5–6 msw depth with the closest about five metres behind him. One diver noticed it seemed rather long since the last check and when he looked behind he saw only two divers. He waited a short time then checked again as the instructor had not yet looked back, and again could see only two others. He swam hard to reach the instructor to gain his attention. The instructor signaled for them to ascend, though one did not see this and followed only when he saw the others ascending.

A witness, snorkelling about 100 metres from the boat saw a diver at the surface about 25 metres from him and he also saw a tender leaving the boat. He reached the victim at the same time as the tender. The victim sank just before they reached him and the skipper, who was driving the tender, dived in and brought him to the surface. He was not breathing; his

(BCD – buoyancy compensation device, BNS – buddy not separated, BSB – buddy separation before incident, GSB - group separation before incident; depths and weights rounded

Incident (msw)	Weight belt	Weights (kg)	BCD	Remaining air	Equipment test	Cause of death
5	ditched by buddy	6.2	n/i	++	nad	drowning, ?cardiac
on ascent	on	n/s	n/i	++	nad	pulmonary barotrauma
12	on	n/s	n/i	++	nad	drowning
6 on ascent	on	n/s	n/i	++	nad	? cardiac
n/s	off	n/s	n/i	nil	multiple faults	pulmonary barotrauma and CAGE
6	on	n/s	n/i	n/s	equipment lost	? cardiac
7	on	n/s	n/s	+	nad	? cardiac, ? CAGE
15	on	13	n/i	++	nad	drowning, ? head trauma
n/s	off	≥10	n/i	n/s	lost	? drowning
n/s	on	8	nil	++	nad	drowning

mouth and face were cyanotic. The victim was lifted into the tender and brought back to the boat where BLS was commenced. There was a quick response by the emergency services, but the paramedics declared him dead shortly after they arrived.

Autopsy: Pre-autopsy X-rays showed no abnormalities. No air was found in either the blood vessels or the tissues. The heart was slightly enlarged (422 gm), the left anterior descending coronary artery had a 70% narrowing close to its origin, the circumflex and right coronary arteries showing less severe, patchy narrowing. There was no evidence of either past or recent myocardial infarction, but histology confirmed the presence of minor areas of subendocardial fibrosis. It was concluded the victim died from coronary insufficiency due to stenosis of a major coronary artery. Beyond his declaration that he had no medical problems nothing is known concerning his health history. It was concluded that "*the likely cause of death was myocardial ischaemia as a result of undiagnosed coronary artery disease but that the possibility of CAGE as the precipitating event cannot be excluded*".
(Height = 178 cm, Weight = 86 kg, BMI = 27)

Comment: This incident highlights the importance of close supervision of all trainee divers by the supervising instructor. This problem is expanded upon in the discussion.

Summary: Second resort dive; separation from instructor and group; inadequate supervision; no instruction on use of BCD or ditching weight belt; surfaced but became unconscious and sank; probable cardiac death

CASE SC 03/05

Two friends were to scuba dive as they usually did, that is, independently. The victim, a 29-year-old male, was described by his buddy as being experienced, having qualified 12 years earlier and with about 24 dives over the past two years. However, he had taken a break from diving although no details of the length of this break are available.

The two scuba divers swam out from a beach to beyond the zone of rougher water near the beach. They separated early in the dive and the other diver returned to shore alone. He was not at first worried by his friend's absence, as they had dived 'together' previously about a dozen times and the victim had always swum back to shore using his snorkel when out of air. However, after half an hour he became anxious at his friend's continued absence. Sometime later, after a boat joined the search, the victim was found floating face down 100 metres from shore, weight belt off and BCD deflated. It is uncertain whether his mask was missing when he was found or was lost while he was being pulled into the boat. An attempt was made to resuscitate the victim but was soon abandoned.

When examined, the equipment was in poor condition and had been assembled incorrectly. The cylinder valve was an old 'J-valve' type which, being in the 'up' position, should have prevented access to the final 35 bar of air in the cylinder. However, there was insufficient air in the cylinder to register on the contents gauge. The BCD inflator button was stuck 'on', causing a free-flow and it had several obvious leaks. The first-stage regulator had widely fluctuating intermediate line pressures, the second stage free-flowed and the mouthpiece had several holes in it. The report concluded that the holes in the mouthpiece would result in a fine spray of salt water with each inhalation, and BCD malfunctions would have made it difficult for the diver to control buoyancy.

Autopsy: Pre-autopsy full-body CT scan showed gas in the cerebral arteries and a large amount in the ascending aorta and left ventricle, a small amount in the right ventricle and the inferior vena cava, quite a large amount in the liver, some in the anterior spinal region, a small amount in the psoas muscle and prostatic plexus, but none in the major leg muscles. The heart and coronary arteries were healthy. It was found that "*the deceased died as a result of drowning, following a CAGE due to pulmonary barotrauma*".
(Height = 182 cm, Weight = 69 kg, BMI = 21)

Comment: The combination of a small cylinder, equipment in poor condition, a habit of diving until the cylinder was empty, the J-valve in its 'closed' position, and solo diving, was a prescription for trouble. Unfortunately the CT scan was performed three days after death. Delays of greater than eight hours are likely to result in post mortem off-gassing. Gas in the psoas suggests post mortem off-gassing.

Summary: Trained; experienced; little recent diving; planned separation; multiple equipment faults; weight belt off; BC deflated; drowning as a result of CAGE.

CASE SC 03/06

The victim, a 46-year-old woman, had been diving for two years, taking several further courses and completing 123 dives since her basic course. She had also gained 12 kilos in weight. There had been no adverse comments at her diving medical concerning her weight or health, but now she had a BMI of 42. A friend later reported that she had become breathless on exertion on a number of occasions while getting ready for dives. However, she had recently made several dives on an overseas diving holiday without obvious problems.

She and three friends had joined a boat charter to dive a 60 msw deep wall, their dive plan being a 30-minute bottom time to a maximum depth of 30 msw. They planned to dive as a group of four, but just before they entered the water they were asked to accept a fifth diver. They swam to the shot line and descended to 29.4 msw, where they noticed that one of the group was missing. They separated into two buddy pairs, one pair ascending to find the fifth diver. Visibility was 6 metres and there was a weak downwards current. The victim and her buddy swam at about 27 msw for about seven minutes along a wide ledge until the buddy indicated they should commence a slow ascent up the wall. The victim appeared to be having no problems. When they reached the top of the wall the buddy indicated that he wanted to swim away from the shot line but the victim signaled that she wanted to ascend. At about 10 msw her buddy indicated to her that the shot line was behind her and she swam to it and used it in her ascent, her buddy utilising the reel from his surface marker buoy which he had deployed. They made a safety stop at 5–6 msw, but after only two minutes she continued her ascent to the surface.

She was seen to surface at the shot line and spent some time holding onto the buoy in the relatively strong current. Her buddy surfaced shortly after her and the boat collected him first. The skipper got no response from her but noted she still had the regulator in her mouth and mask in position. A rope was thrown to her and she relinquished the buoy and swam the 5–10 metres to reach it. She was pulled to the boat but was unable to climb the ladder. There was blood or vomit on her chin and the regulator was out of her mouth. It was necessary to ditch her equipment before it was possible to pull her aboard. The equipment was never recovered. She was not breathing at this time and her face was cyanotic. Rescue breathing was commenced and was complicated by regurgitation of the victim's stomach contents. BLS was started when no pulse could be palpated. A radio call was made for assistance while the dive boat returned to land. Paramedics met the boat on arrival at the jetty but ALS was unsuccessful.

Autopsy: The autopsy revealed moderate cardiac enlargement and greater than 90% stenosis of the diagonal branch of the left anterior descending coronary artery. The pathologist suggested a sudden lethal arrhythmia occurred in the context of the exertion of this dive, and noted that her obesity was a significant factor. No evidence of any pulmonary barotrauma or CAGE was found. (Height = 171cm, Weight = 123kg, BMI = 42)

Comment: This diver was very obese and reportedly easily breathless; scuba diving was, therefore, contra-indicated as an activity.

Summary: Trained; experienced; obese; previous reports of breathlessness; severe coronary stenosis in one vessel; cardiac death.

CASE SC 03/07

The victim was a 56-year-old experienced male with a history of acute myocardial infarction (AMI) some 20 years earlier but who apparently had had no problems since that time, despite being very overweight. He was on a club dive with 13 divers, all trained and experienced, travelling in several boats.

They made an uneventful first dive before relocating to a flat, calm area for an unhurried lunch. The victim and two others then did another dive, descending the anchor line to the sea bed at 14.6 msw, then swam deeper in line abreast with the victim in the middle. The visibility was 5–7 metres and one of the trio soon became separated while the victim helped his other buddy to refasten one of his fins. When this was done, they noticed that the other diver was missing and agreed to ascend. As they were ascending, the buddy again found the strap on one fin had come free and the victim helped him thread the strap through its buckle. As they ascended, they became separated at 6–8 msw depth. It was only when the buddy boarded the boat that he saw his friend floating face down about 100 metres away.

The victim was seen at the surface by several people in the boats, lying motionless on his side. When it was realised that he was unconscious, one person jumped into the water and started to give rescue breathing while others ditched his weights and pulled him into one of the boats. He did not respond to BLS or ALS once ashore.

Examination of the equipment showed the remaining air pressure was 134 bar and that the equipment was functional when test dived, though on dry land the valve on the BCD tended to stick open. This fault was thought to be the result of the presence of salt and not to have happened during the ascent.

Autopsy: The significance of coronary atheroma, which was producing some areas of 25 to 50% narrowing, was uncertain. There were no haemorrhages, plaques, or thrombi occluding their lumen. The right side of the heart showed distension by gas and both ventricles contained a very limited amount of frothy blood. There were a number of rib fractures due to the resuscitation efforts. Histology showed focal fibrosis in the left ventricle but no acute ischaemic lesions were identified. The victim was described as being moderately obese. The liver weighed 2,530 gm and it was diffusely enlarged without evidence of mass lesions or cirrhosis, histology showing mild macrovesicular steatosis.

The pathologist, who was familiar with the diving factors in such fatalities, consulted with several colleagues but the differential diagnosis could not be resolved between a cardiac event, CAGE, or possibly the reflex response to inhalation of cold water (the water temperature was 17^{o}C). (Height = 172 cm, Weight = 120 kg, BMI = 41)

Comment: The history is not overly suggestive of CAGE (other than sudden loss of consciousness on surfacing) or AMI, although the latter may have been silent. The autopsy shows no evidence of AMI, the coronary lesions are not haemodynamically significant and there is no evidence of clot formation. Gas was seen in both ventricles, which may well have been a post mortem artifact, and no gas was seen in the cerebral circulation. As the pathologist states, there is really insufficient evidence to confidently determine the cause of this death.

Summary: Experienced; AMI 20 years earlier; separation during apparently normal ascent; unconscious at surface; adequate air and equipment functioning; obese; moderate coronary atherosclerosis; possible cardiac death or possible CAGE.

CASE SC 03/08

The victim, a 39-year-old male, was an experienced diver who was described by friends as being very safety conscious. He was visiting the area to take a technical course to add to the wide range of diving qualifications he already held. This dive appears to have been booked at the last minute, as on the previous day he had told his girlfriend that he had intended to dive but had cancelled the dive because the water was too rough.

It is unknown whether any note was made of the experience of the four divers in the group before they were accepted for this unsupervised cave dive. One had only made 30 dives over 10 years; one had a divemaster certification, but had been diving for only five months, the victim had wreck-dive training but no cave-diving experience and the experience of the fourth diver is not stated. One of the dive shop owners acted as the coxswain and there was a diving instructor with three students on board. When they arrived at the dive location, a cave passage through a rock, they were given a dive briefing. The sea was described as calm, swell slight and visibility good in the open water. The victim was the only one among his group who wore a drysuit and required an 11.7 kg weight belt and 1.29 kg ankle weights. They all carried torches. After they entered the water, the boat took the others to an open-water dive location, and then it returned to the cave area to await the return of the four divers.

The cave entrance was visible from the boat in a depth of 15 msw to the sea floor. There was no dive leader to lead them through and there was some confusion about how the group was to swim through the cave. When about to enter the cave, they felt the surge pulling them in. The passage was apparently large because one diver described how, when deep in the cave and trying to locate the side passage through which they were to exit, he felt a water surge lift him 4–5 metres and he had to vent his BCD in order to descend and so avoid hitting the passage roof. The floor was at about 8 msw depth when they were 15–20 minutes into their dive and in the upper half of the cave the water was turbulent.

After this big surge, they discovered that one person was missing and, after trying unsuccessfully to locate him, the remaining three divers exited the cave. They advised the coxswain what had happened and he reassured them that the missing diver was so experienced he would be all right. Seeing bubbles bursting, he felt confirmed in his belief, but they came from the last diver to return. His advice was for them to continue diving around the passage's other entrance. This they did, surfacing about 10 minutes later and returning to board the dive boat.

The coxswain now believed that a diver was missing. After he had collected the instructor and his pupils, the boat returned to the cave entrance area. Not having any diving equipment of his own with him, the coxswain borrowed the instructor's equipment and, after arranging for an emergency service call to be made, dived to search the cave. He was unsuccessful and surfaced after 20 minutes. After a call to the dive shop, his own equipment was brought out. Both groups of divers were returned to shore, and he and another diver re-entered the cave. After about 12 minutes, the missing diver was located floating above them head-down with his mask under his chin. Both regulators were working, and the contents gauge showed 127 bar, but his tank had slipped from the tank band on which its valve was caught. Some cuts were noted on his nose and face. The body was recovered with difficulty three hours after the victim had started his fatal dive. Police examination of the equipment revealed no faults.

Autopsy: Pre-autopsy scans excluded pulmonary barotrauma. There was no evidence of CAGE. Superficial abrasions and bruising of the scalp were noted in the report summary but there was no evidence of skull fracture or brain trauma. The coronary arteries appeared healthy; the foramen ovale was probe-patent, and blood tests negative. The cause of death was given as drowning, likely as a result of a blow to the head.
(Height = 180 cm, Weight = 60.2 kg, BMI = 18.6)

Comment: Appropriate consideration was given to the potential for CAGE given the description of the incident, although this was rejected due to the presence and characteristics of other injuries and expert knowledge of the location that provided what appears to be a sound explanation of the circumstances.

Summary: Trained; experienced, although not in cave diving; strong wave surges in cave; separation; head trauma; drowning, probably as a result of a blow to the head.

CASE SC 03/09

The victim, a 25-year-old male, had never completed a scuba training course but was reported to have been diving for seven years. He was described as a good swimmer in good health.

On this occasion he, his brother, and two friends, were intending to collect scallops in a current-prone area, diving from a private boat. After anchoring the boat and placing two buoyed shot lines, the victim and his brother dived first. Despite advice and the coldness of the water (15°C), the victim declined to wear a wetsuit. It was later reported that he was wearing about 10–20 kg on his weight belt. The conditions were just beginning to become choppy and visibility was reported to have been in excess of 6 metres.

The two men entered the water with inflated BCDs, deflating these when they reached the shot line. During the descent the two became separated and the brother, after a short wait, surfaced to check if the victim had returned to the boat. A surface search was unsuccessful. About one hour later they notified the police but surface searches both then and over the following days failed to find any sign of the missing man or his equipment. His body, without any equipment, was found floating off a beach 24.5 km from the dive site five days later.

Autopsy: The condition of the body limited autopsy investigation to a finding of a possibility that "*exhaustion and hypothermia may have been significant factors in the ultimate mechanism of death*". The possible cause of death was given as drowning. No disease factors were discovered.
(Height = 179 cm, Weight = 96 kg, BMI = 30)

Summary: Untrained; experienced; dived without wetsuit but with substantial weights in cold water; separation during descent; body washed ashore five days later; equipment never found; hypothermia possible factor; probable drowning.

Surface-supply breathing apparatus

CASE SS 03/01

The victim, a 25-year-old male, was diving with a friend from a boat about 500 m from shore. Sea conditions were described as perfect and the ocean floor visible about 5 m below. They were using a home-made surface-supply breathing apparatus (SSBA, 'hookah').

The victim was wearing a 5 mm short wetsuit and about 8 kg of weights. He had never dived before so his friend instructed him on how to release the weight belt if needed, and how to ascend to the surface. Initially, the friend remained on the boat and watched the victim while he swam on the surface breathing from the 'hookah'. Once he was satisfied that the victim appeared to be coping, the friend entered the water and, using the other hose, dived below the victim looking for crayfish. He had expected that his friend would remain on the surface at this time. After about five minutes trying to catch a crayfish, the friend looked up and could not see the victim. He noticed that the other hookah hose had sunk and followed it to find the victim lying face up and motionless on the seabed without the regulator in his mouth. After determining that the victim was unconscious, the friend brought him to the surface, attempted some in-water rescue breathing and eventually managed with difficulty to bring him aboard the boat.

The friend commenced BLS without a response. After calling the police and being told that assistance would be delayed, the friend drove the boat to shore, stopping every four minutes or so to apply BLS. Prolonged ALS on shore was unsuccessful.

The SSBA was 'home-made' and the air filter had been recently modified. It had reportedly been used by the buddy and another diver a week earlier with no apparent problems. When tested, the SSBA was found to deliver an air flow rate below that required under Australian Standards, and the air supplied had an excessively high water content. This would have made it difficult to breathe from, especially when two people were using it. The air was free from contaminants.

Autopsy: Toxicological analysis showed evidence of prior use of amphetamines and cannabis; however, the levels detected were not believed to be clinically significant. Carbon monoxide saturation was reported to be four per cent. Neurohistology was conducted and the pathologist stated that "*microdysgenesis is a microscopic cortical malformation considered to have the potential to act as a substrate for seizures. Although non-specific, the presence of white matter gliosis, subependymal gliotic nodules and subpial gliosis suggests there has been some previous old insult to the brain*".

It was suggested that the victim may have had an increased potential for seizures and that the scarring of the brain suggested that there may have been prior seizures of which the victim may not have been aware. It was stated that the victim's carboxyhaemoglobin level of 4% may partly or wholly have been the result of recent tobacco smoking, of which there was evidence. The cause of death was found to be drowning as a result of a seizure underwater.
(Height = 179 cm, Weight = 72 kg, BMI = 22.5)

Comment: No injuries to the tongue were noted. Although the pathologist suggested that the drowning may have resulted from an underwater seizure, there was no evidence to support this suggestion.

Summary: Untrained; first dive; using homemade 'hookah' which was not functioning correctly; separation; victim initially on surface and buddy underwater; found unconscious on sea bed; drowning (possibly as a result of a seizure).

Discussion

BREATH-HOLD DIVERS AND SNORKEL USERS

Hyperventilation prior to breath-hold diving is known to be associated with apnoeic hypoxia and loss of consciousness and has been reported to be associated with a substantial number of breath-hold fatalities in Australia in the past.[7,8] Despite this knowledge, the practice remains common and appears to have taken its toll once again. Anecdotal reports indicate that unconsciousness may occur without warning during breath-hold dives without hyperventilation, and there is evidence of this in the presence of sustained exercise.[9] Unless a buddy is immediately at hand to provide rescue, death is a likely result.

In this series, there were three deaths likely to have been associated with apnoeic hypoxia blackout. In one case (BH03/05) the victim was definitely seen to be hyperventilating prior to diving. One may simply have struggled for too long to free his spear gun on the seabed.

There was a clear difference between critical factors in deaths associated with breath-hold diving and those associated with the use of a snorkel as a swimming aid. The former were generally young and healthy and experienced in breath-hold diving, while the latter group tended to be older and lacking in experience and often carried a load of occult coronary artery disease.

ABSENCE FROM DIVING

A recurring theme in diving accident reports is experienced scuba divers getting into difficulties after an extended absence from diving. Diving is not like 'riding a bike'; diving requires re-familiarisation under controlled conditions and equipment requires appropriate inspection and servicing, especially after not being used for an extended period as corrosion and deterioration can occur. The victims SC03/01 and SC03/05 were both said to be experienced divers who had taken a break from diving.

Diver SC03/01 appears to have panicked when his mask flooded (as did the first-time diver SC03/02), something that regular divers should be less likely to do. The associated stress may have contributed to or precipitated the cardiac event that proved fatal. However, managing a flooded mask is an important skill that should never be taken for granted and should be practised regularly by all divers, especially those without recent experience.

LACK OF EXPERIENCE IN THE ENVIRONMENT OR CONDITIONS

Diving in different environments may require specific skills. Sometimes specialised training is required, on other occasions appropriate supervision will suffice, while on others a thorough briefing and orientation may be adequate. As an example, diving in caves or wrecks requires carefully controlled buoyancy and if there is a strong surge, the situation can be substantially more demanding. Although victim SC03/08 had received some basic training in wreck diving, it is not known how much relevant experience he had prior to this fatal cave dive.

Victim SC03/03 had only ever done one dive in the ocean prior to her fatal dive. Given that her training and most of her previous dives were conducted in a fresh water quarry, she would have had little or no exposure to currents, diving from a boat, wreck diving or exposure to marine life. Whether or not her death was accidental, it is unlikely that it would have occurred had she been appropriately supervised. In fact, the dive operator was charged with breaches of local diving workplace regulations for disregarding its own standards in permitting the inexperienced victim to dive without having a prior dive site orientation with one of its staff.

Dive planning should always include an allowance for the operation of 'Murphy's Law' – a long history of trouble-free practice of a procedure is no guarantee – 'familiarity breeds contempt'. Divemasters and instructors should always remember when giving instructions or a dive briefing that the listeners may be interpreting what one is saying against an entirely different background of experience.

SCUBA EXPERIENCE / RESORT DIVING

It is likely that very large numbers of scuba experience dives are conducted each year worldwide with relatively few reported accidents. However, two cases (SC03/02 and SC03/04) in this series involved divers who died while participating in such dives.

It is important to select dive sites, the diving conditions and instructor/student ratios carefully, given the often total lack of experience of participants. Instructors should remain very close to the divers at all times so that they can intervene without delay when necessary. However, even though the instructor may have immediate access to the novice and may act appropriately, not all problems can be managed successfully, as appears to be the situation with SC03/02. With case SC03/04, there were significant differences in the accounts given by the instructor, who claimed to have swum on his back so as to observe the novices and to have seen the victim ascending, and by the other divers, who denied this version of events completely.

One of the divers in the group in SC03/04 later complained that he had wanted to ascend but had not been shown how to adjust his buoyancy and therefore had difficulty in doing so. The group also reported that they were not told how to ditch their weight belts. Adjustment of buoyancy and the ditching of weight belts may not be necessary if the instructor is immediately at hand, but will occasionally be necessary if separation occurs, as in this case.

An interesting challenge with resort diving is to determine the minimum skills a diver should be taught in the limited time available under these conditions. Various scuba training agencies have standards that address this problem, and dive operators are required to meet these standards. In addition, there is currently a draft ISO standard for scuba experience diving. Most such standards do not include removal of weight belt and use of the BCD underwater as required skills.

COMMON SENSE

Safe diving requires common sense. It is difficult to imagine, for instance, how the victim SC03/09, who was reported to have been an experienced diver, would attempt a dive in 15^{O}C water without an exposure suit and with substantial weight on his weight belt; an obvious recipe for disaster. There are several other examples of extraordinary lack of common sense in this series of fatalities from 2003.

CARDIAC DEATHS

Cardiac-related issues were thought to have contributed to the deaths of six snorkel divers (50%) and four scuba divers (44%) in this series. Diving can add additional stressors in the form of exertion; heavy, and sometimes restrictive equipment; increased respiratory effort, salt-water aspiration and anxiety, among others. This can be a potent recipe for precipitation of a cardiac event in someone with pre-existing cardiovascular disease, whether diagnosed or not. Sometimes such deaths could have occurred with or without exertion in a variety of situations and just happened to occur while diving. We are becoming increasingly aware of the danger of cardiac arrhythmias, such as the long QT syndrome, in diving. Any history of syncope or drop attacks should be thoroughly investigated before a person is cleared to dive.

In cases BH03/02, BH03/04, BH03/08, SC03/01 and SC03/07, the victims were aware of pre-existing conditions, although possibly unaware of the potential implications with diving. However, with BH 03/06, BH03/07, BH03/09, SC03/04 and SC03/06 there was no reported evidence that the victims were aware of their existing cardiovascular disease. It is important that divers and physicians are made well aware of the increasing incidence of cardiac-related deaths in diving so that appropriate health monitoring strategies can be put in place. Since older recreational divers are not required to be assessed medically on a regular basis, and the diving industry appears unlikely to introduce this, such health surveillance could only be achieved through appropriate and effective education programmes or, if this is unsuccessful and it is considered to be a substantial enough problem, through legislation.

ALCOHOL

Alcohol and any form of diving do not mix. Whilst international drowning statistics incriminate alcohol as a contributing factor in many drownings, especially in young males, this appears uncommon in snorkelling and scuba diving. However, alcohol and drug screening is not routinely performed by pathologists as part of diving autopsies. For instance, in the 1980 to 2000 New Zealand series, only 72 of 173 snorkellers and scuba divers whose bodies were recovered had a blood alcohol level measured.[10] This was positive in five of 24 snorkellers and four of 48 scuba divers.

CORONER'S AUTOPSIES

The information obtained from autopsies of scuba fatalities is often incomplete, as many are performed incorrectly.[11] Despite the promulgation by the Royal College of Pathologists of Australasia of new and detailed guidelines on how to conduct diving fatality autopsies, these are frequently not followed and some pathologists are clearly unaware of the likely pathologies to look for. The same is still true in some areas of New Zealand.[10] There is a need for a significant improvement in the standard of conduct of coroner's autopsies in scuba fatalities in Australasia. In cases where the investigation reveals that the victim had a pre-existing medical condition, every effort should be made to obtain relevant information about this.

Conclusions

There were 22 reported diving-related fatalities during 2003, which include 12 deaths while snorkelling and/or breath-hold diving, nine while scuba diving and one while using surface-supply breathing apparatus (SSBA).

Causal factors associated with these deaths include cardiac disease, whether diagnosed or not; inexperience or lack of recent diving experience, diving in an unfamiliar diving environment and lack of common sense.

Factors that may reduce mortality in the future include improved medical screening of older divers; cessation of the practice of hyperventilation prior to breath-hold diving; closer supervision of inexperienced divers; out-of-practice divers or divers who are inexperienced in the particular environment; and closer communication between dive buddies.

In the investigation of diving fatalities, there is a need for more consistent documentation by investigating authorities such as the police, and improved standards for the performance of scuba diving fatality autopsies by pathologists.

Conflict of interest

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

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Analysis of a complex recreational scuba diving accident: French Pass, New Zealand, 2000

Graham McGeoch and F Michael Davis

Key words
Diving accidents, scuba accidents, diving deaths, decompression illness, legal and insurance, case reports

Abstract

(McGeoch G, Davis FM. Analysis of a complex scuba diving accident: French Pass, New Zealand, 2000. *Diving and Hyperbaric Medicine*. 2009;39:20-8.)
In March 2000, six students and an instructor dived using open-circuit scuba in a narrow pass and were swept by a strong current to a depth of 90 metres' sea water. Three died and four were injured, which makes the incident the worst diving accident in New Zealand history. The group was on an officially-sanctioned course with many factors contributing to the final tragic events. The dive is described and the medical response examined. The legal consequences are reported and their implications for diver training and employment are discussed.

Introduction

On 10 March 2000, seven divers (six divemaster students and an instructor) undertook a planned drift dive at French Pass in the Marlborough Sounds, New Zealand. French Pass is a channel between D'Urville Island and mainland South Island approximately 600 metre-wide at its narrowest ('The Gap', Figure 1). The current flows up to seven knots in either direction, depending on the tide. The area contains numerous rocks and depth varies rapidly and irregularly with a scour hole (Jacob's Hole) of up to 105 metres' sea water (msw) deep on the northern side (Figure 2).[1] There is a brief 20-minute period at high and low tides when currents through the Pass are less.[2] During this dive, three divers died, three suffered decompression illness (DCI) and one suffered barotrauma to the middle ears and face. The authors were involved in the subsequent management of the survivors, and one (GMcG) undertook a detailed investigation of the incident and its subsequent medical and legal ramifications. The results of this study are reported here.

Methods

The study was approved by the Upper South B Regional Ethics Committee with the request that all due care be taken to ensure that any published material protected the privacy of the individuals involved. The first author (GMcG) visited the area by land and boat and met with two survivors who could be located and who agreed to be interviewed. No relatives of the deceased were contacted. A comprehensive collection of resources was obtained, including legal documents and the coroner's reports, court proceedings, media reports, and interviews with various individuals, and access was obtained to the files and logbooks of one of the survivors and the Christchurch and Nelson Hospitals' patient records.[3–8] The two interviewed survivors have read and approved the manuscript.

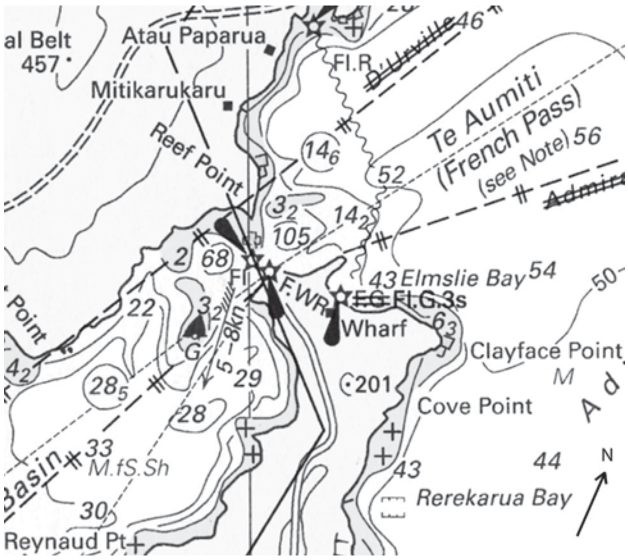
The French Pass dive

CHRONOLOGY OF EVENTS

- 1 February 2000: six students commenced a 14-week Professional Association of Diving Instructors (PADI) Divemaster course run by the Nelson Dive Centre (NDC) and funded by Work and Income New Zealand (WINZ) and approved by the New Zealand Qualifications Authority (NZQA).
- 9 March 2000: all but one of the six divers and their instructor attended an evening party until 0200 hr.
- 10 March 2000; 1300 hr: the group arrived at French Pass by boat. The two interviewed survivors say the intent was to dive when the current was running so that they would drift east along the southern wall of the pass into Elmslie Bay (Figure 2).
- 1400 hr: seven divers, using single-cylinder open-circuit scuba air, entered the water 20–50 metres from the Channel Point lighthouse on the northeast side (Figure 2). The group held on to loops on a 30 metre-long rope with a small float and a 'ski biscuit' on the surface end. Weather conditions were good, with light winds and the ebb tide running southwest to northeast. Unbeknown to them, the divers were carried rapidly into a whirlpool and sucked down into Jacob's Hole. The dive profile is shown in the printout of one of the diver's computers (Figure 3). For the first three minutes, the dive was at a depth of less than 12 msw. This was followed by an uncontrolled descent to 89 msw in three minutes. After briefly leveling out at about 85 msw they were swept by the current towards the surface over four minutes at a fairly constant rate.
- 1415 hr: the boatman discovered the inflatable tube of the ski biscuit, which he had been following, had detached and deflated and he was, therefore, not following the divers. Other boats rescued three students and the instructor about 1 km away from the starting

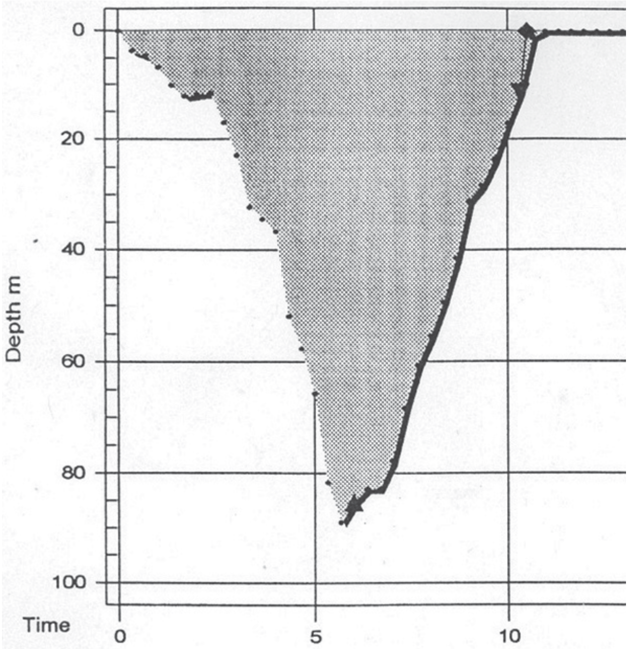
Figure 1
'The Gap', French Pass, from near Channel Point light looking northwest to D'Urville Island, tide flowing northeast to southwest. Entry point for the fatal dive would have been close to right foreground and divers swept northward into the main current.

Figure 2
Detail of Chart 6151 showing French Pass and Jacob's Hole, labelled 105 msw; North shown at bottom right (with permission Land Information New Zealand; not to be used for navigation)



- point. One deceased student was found tangled in the diving line. A further deceased person was removed from the water. One student was missing.
- The survivors were evacuated by helicopter to Nelson Hospital. No indication for recompression other than missed decompression was elicited and all but one (see below) were discharged from hospital that day.
- 11 March 2000: one diver presented with symptoms suggesting decompression sickness (DCS). All four surviving divers were then transferred by pressurized air ambulance to the regional hyperbaric unit in Christchurch and underwent an extended Royal Navy treatment table 62 (RN 62 ext) hyperbaric oxygen treatment.
- 12 March 2000: the three divers with suspected DCS were retreated once or twice with a Royal Adelaide Hospital treatment table 18.60.30. Following these treatments, all appeared to be asymptomatic and were discharged back to Nelson.

Figure 3
Computer printout from one of the divers showing the dive profile with time (min) against depth (msw)



Case summaries

All divers had passed a recreational dive medical. The divers are listed in the order they dived from the surface downwards, with their outcomes.

- Male, aged 37; Student C; neurological and musculoskeletal DCS with full resolution
- Male, aged 41; deceased; cause of death given as drowning secondary to cerebral arterial gas embolism (CAGE) from pulmonary barotrauma; alcohol and tetrahydrocannabinol in blood
- Male, aged 21; deceased; body not found; assumed cause of death drowning secondary to massive AGE
- Male, aged 23; Student B; minor aural and facial barotrauma only
- Female, aged 24; Student A; nitrogen narcosis, near-drowning, neurological and musculoskeletal DCS, aural barotrauma and probable global hypoxic brain injury with moderate sequelae; rescued by Student B
- Female, aged 27; deceased; upper mediastinal gas;

cause of death given as drowning secondary to AGE from pulmonary barotrauma. The instructor saw her with her regulator out and unconscious on the bottom and brought her to the surface where she appeared to vomit but never recovered consciousness.
- Male: aged 36; the instructor; equivocal DCS (right shoulder pain), full physical recovery

Two of the survivors (Students A and B) were interviewed by one of the authors (GMcG) in 2007. These two case histories demonstrate very different outcomes from the same extreme dive. One diver survived virtually unscathed whilst the other nearly died and has been left with moderate sequelae.

STUDENT A

This 24-year-old woman had dived 33 times. The evening before, she had drunk about six cans of beer with a meal at the party. She had not smoked marijuana. On the dive, she stated there was no time to ditch her weight belt or inflate her buoyancy compensator (BCD). It then became very dark and she hit the bottom. She thought her regulator was not working properly, spat it out and recalls inhaling water. She recalls feeling very narcotized and “feeling like hell”. Student B reported that she floated off the line at about 50 msw depth on the way up from 88 msw and looked as though she had lost consciousness, losing her regulator. He gave assistance by bringing her back to the line and carrying her to the surface. The next thing she remembers is regaining consciousness on the surface, coughing and spluttering. She had three-quarters of her air left, whereas the other survivors were nearly out of air.

Following helicopter evacuation to Nelson Hospital, her main symptom was pain in the ears. After phone discussion with the duty hyperbaric physician (GMcG) in Christchurch, she was admitted for observation. A transient rash developed that evening, and overnight she also developed a headache, arthralgia and myalgia in the hands and feet and occasionally in the arms, altered sensation over the scalp, a full feeling in the face and ears, central chest discomfort and a productive cough. When these symptoms were reported the following morning, arrangements were made to transfer her for recompression treatment.

On arrival in Christchurch she still had leg pains, poor balance, ear pain, facial discomfort and a persistent, productive cough. Neurological examination was normal except for her inability to perform a sharpened Romberg’s test. Chest X-ray was normal; an audiogram showed a high -frequency (6 and 8 KHz) hearing loss on the right. The diagnoses made were of near drowning secondary to loss of consciousness at depth, DCI probably due to a combination of AGE and decompression sickness, and middle ear and sinus barotrauma with possible inner ear barotrauma with residual high-frequency hearing loss. She was treated with an RN 62 ext, followed by two more hyperbaric treatments on the following days, after which, apart from her right ear problem and mild chest soreness, she appeared to have made a full recovery.

On follow up, however, Student A had lost her *raison d’être,* which was to become a dive professional, and was severely traumatised by the experience and the loss of her group of companions. She found that her memory was impaired and it was difficult to learn new tasks at work. Eventually psychiatric assessment in 2006 concluded that she was suffering from an adjustment disorder with mixed anxiety and depressed mood, and that there was possible mild cerebral damage accounting for her sensory and memory problems. When interviewed in 2007, poor performance on serial 7s and on recall of an address five minutes later was noted. She has a minor residual high-frequency hearing loss which is troublesome in noisy environments, and describes some altered (dysaesthetic) sensation in both thighs.

STUDENT B

Student B was the only student diving regularly prior to joining the dive course, with Advanced Diver and Nitrox Diver certifications. He reported a history of asthma treated with intermittent inhaled bronchodilators. He was very fit and confident in the water. He confirmed that they were not planning to dive at slack water. He remembered the descent as very fast once it started. He communicated with the instructor, who was below him, and signalled to abort the dive. He then went back up the line, passing Student A, who was then about five metres below him. He graphically describes biting down hard on his regulator and telling himself not to let it come out. He describes feeling very narcotized, “Hell narked up; very woolly,” and blacked out briefly on the bottom. He came round enough to notice that Student A had no regulator in her mouth and no bubbles were coming from her. He left the line and grabbed hold of the left side of her BCD. He tried to push his ‘octopus’ regulator into her mouth, but her teeth were clamped shut. They were coming up fast while bumping on rocks. Student A’s body was shuddering on the way up but she was unresponsive on the surface and not moving. He shouted and shook her; she vomited seawater and started breathing then regained consciousness. Student B says that he had 40 bar gauge pressure left in his tank. He noticed they were a long way from land. Eventually, people on the beach heard them shouting and recovered them by boat.

He felt clear-headed and well after the dive, and felt that people did not seem to believe they had been to 90 msw and did not appreciate the significance of this. He was discharged from hospital the same day. The following day, he went to the NDC where he met Student C who was clearly unwell. He persuaded him to return to Nelson Hospital and then went home where he was rung by Student A who told him to return to hospital for transfer to Christchurch. On examination, he had moderate bilateral middle ear barotrauma and subconjunctival haemorrhages, but was otherwise asymptomatic. Although asymptomatic of DCS, he underwent a single, uneventful RN 62 ext with the other divers as a precaution, given the profound depth of the dive.

Following the incident, Student B was treated with inhaled fluticazone for his asthma. He felt that he was unaffected by the accident but never completed his dive instructor's course. He was anxious during penetration dives on wrecks following the incident and became very upset when involved coincidentally in another fatal diving accident.

Legal aspects

The issue of legal responsibility for the events at French Pass has caused considerable debate in New Zealand. The police investigation concluded that there was insufficient evidence for criminal prosecution under the Crimes Act,[9] and that lesser charges than manslaughter would be difficult to prove when there was clearly no intent to injure by the instructor, the boatman or the NDC (McCoy W, personal communication, 2000). The Police summary of the case states "[the instructor] *claims that upon assessing the water conditions and the tide he deemed it entirely appropriate to put in the party where he did and did not think they were at any risk. He himself had previously conducted a dive course at that location, and been taken through on his instructor course by* [his instructor] *at that location*."

In the absence of criminal responsibility, the burden of obtaining some accountability fell to the Department of Labour (DoL) Occupational Safety and Health Division (OSH). The case was heard in the District Court at Nelson in April 2001 with the Nelson Dive Centre and the instructor as defendants. They were prosecuted under the Health and Safety in Employment Regulations 1995,[10] and faced six charges of "*being an employer, it failed to take all practicable steps to ensure that no action of an employee, namely X, while at work harmed any other person, namely Y, in respect of a training dive in French Pass*." These charges were proven.[4]

They were also charged as follows, "*It, being a person who controlled a place of work, did fail to take all practicable steps to ensure that hazards that arose in the place of work did not harm Y who had paid NDC to undertake an activity there*." This was not proven because the regulation applies to buildings or equipment and was not thought to apply to the open ocean.[4]

There was considerable legal argument during the trial as to whether the instructor was an employee or an independent contractor. The key issue was the control test, the identification of an employer's right to control how the work is done. It was determined that both integration and control indicated the instructor was an employee of NDC.

The next issue was whether the NDC took all practicable steps to ensure that no action of the instructor while at work harmed any other person in respect of the training dive at French Pass. The Court examined the experience of the instructor and an NDC director on previous dives in French Pass. They had been swept away from their intended drift path and into 'The Gap' on a previous dive. The instructor had also dived at the Pass with a previous group of students. He described this dive as "extreme" and the group were "tossed and turned in whirlpools." The NDC director was made aware of this dive and the problems that arose, although he subsequently denied knowledge of other groups getting into difficulty.[4] The Court concluded that the instructor selected the site for the 10 March dive fully aware that at least a turbulent dive could be expected by the students. Another instructor warned him the day before the accident that he would be "crazy" to train divers in French Pass. The Court heard the instructor was relatively inexperienced, qualified but without a Certificate of Competency and had made a similar mistake before. In spite of this, no steps were taken by NDC to stop the instructor diving in the Pass. The Court thus concluded that the defendant failed to take all practicable steps to ensure that no action of the instructor, its employee, at work harmed the student divers.

NDC was also found guilty of failing to ensure their employee had a Certificate of Competency to work as a dive instructor. The NDC was fined and ordered to pay reparations totalling NZ$75,000 and the instructor fined NZ$15,000. The judge made it clear that he considered the NDC was more culpable than the instructor.[4] NDC was declared insolvent and went into liquidation and is reported to have not paid its fines.[8] The survivors say that they have not received reparation from NDC. In contrast, the instructor paid his dues promptly.

The two students interviewed are still paying off their student loans. Nelson MP, Nick Smith, commented "*It just adds insult to injury that the students caught up in the tragedy did not receive the tertiary education they paid for and end up saddled with thousands of dollars of debt. The Government approved the dodgy course, the Government should write off the loans for these students who never received the tertiary education for which they paid. Not only was the course useless and uncompleted, it was downright dangerous*."[8]

Discussion

CONDUCT OF THE DIVE

The US Navy Standard Air Decompression Table for a dive to 300 feet (91.4 msw) for a bottom time of 10 minutes gives a total decompression time of 37 min.[11] Once taken to that depth by the current, the divers were unable to ascend safely even if the current had not swept them back towards the surface, because they had insufficient air to complete the required decompression. They would have had no idea about the duration or depths of decompression stops required and were unable to maintain depth in the fast current. They were also in no fit state to conduct decompression stops as

Table 1
The compliance of the dive with the PADI Drift Diver course requirements

Drift Diver course requirements	Compliance	Comments
PADI Open Water Diver	yes	limited experience
Age >12	yes	
Student to instructor ratio	yes	maximum 8:1; this dive 6:1
Confined water training	no	discretionary
Maximum depth 18 msw	no	PADI does not specify water depth, only dive depth
Equipment	yes	all checked after the dive and no issues found
Diving with surface reference float	no	inadequate; see text
Surface supervision	no	only single boatman in the boat
Planning and entry to water	no	intensity of current was not considered
Drift dive descent	no	PADI clearly describes descent to bottom, not free-water drift dive which is more hazardous
Constantly manipulate BCD to maintain neutral buoyancy	no	see text
Perform a normal ascent as a group	no	rate greater than recommended and uncontrolled; group fragmented
Safety stop at 5 msw for 3 minutes	no	uncontrolled ascents

they were more concerned with rescuing themselves and their injured and dying friends. Thus this dive carried a high risk of DCS.

The dive should have been conducted in accordance with the PADI Drift Diver Specialty Course Instructor Outline, from which it deviated considerably (Table 1).[12] The boatman reported that the instructor told the divers not to let go of the loops in the rope; this was confirmed by Students A and B. None of the students appears to have let go until they lost consciousness, preventing earlier individual remedial action such as inflating their buoyancy compensation devices or dropping their weight belts. The exact site of the dive for the state of the tide caused the divers to be swept into Jacob's Hole, the largest and deepest whirlpool in the Pass. The instructor had dived the site before only with the tide running in the opposite direction (as seen in Figure 1). The timing was intentional because the instructor wanted the students to have the thrill he had experienced diving in the area, which suggests he did not appreciate the significance of the timing in relation to tidal flow.

MEDICAL ASPECTS

Fitness to dive on the day

The students and instructor had no absolute contra-indications to diving. One diver had asthma but was already a moderately experienced diver; he was the one who survived without significant injury and performed a deep-water (50 msw plus) rescue saving the life of one of his buddies.

The issue of whether these were suitable candidates for training as diving professionals is more difficult. Both hyperbaric units in New Zealand noted an increase in cases of DCI around this time, contributed mainly by students on WINZ-funded courses (Figure 4). Professional divers ideally need to have good medical, social and psychological fitness and skills combined with some experience of the marine environment. Without these aptitudes, decisions will be made that increase risk. It appears many of the candidates for these courses were encouraged to join them by WINZ as a means of removing them from reliance on unemployment benefits. Diving was not an occupation that many of them would have considered without such assistance. Many students would have been unable or unwilling to finance the course themselves if student loans and WINZ living allowances had not been available. This means that some candidates were potentially less personally motivated and already had

Figure 4
The numbers of divers with decompression illness treated at Christchurch Hospital, 1995–2006; there were 14 divers on funded divemaster courses in 2000–2002, but none since

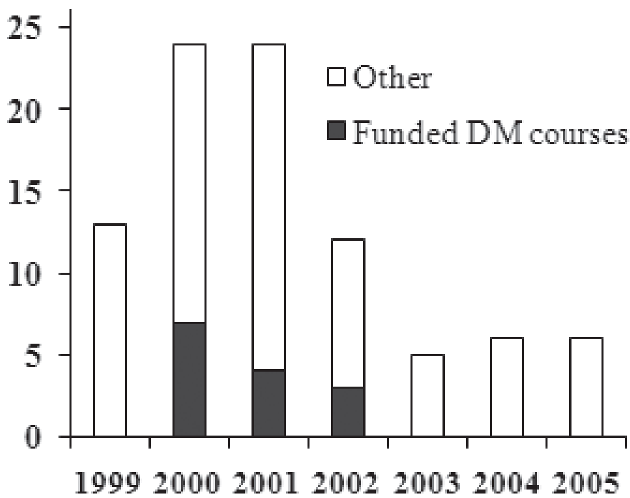


Table 2
Physiological and medical risks of a 90 msw dive with rapid descent and ascent

Oxygen toxicity
Acute carbon dioxide retention
Nitrogen narcosis
Hypoxia
Salt-water aspiration and drowning
ENT barotrauma
Pulmonary barotrauma
Cerebral arterial gas embolism
Decompression sickness

proven themselves less able in life skills. We have gained the impression the survivors of this incident were the stronger and more able divers, supporting the contention that aptitude is an important factor in determining diver risk.

Irrespective of their previous fitness and suitability for diving, were they at their peak on that day? According to Student A's logbook, they had been diving on 15 of the previous 23 days. They had all completed about 30 dives in various sites and conditions. The previous day had involved a drive of some hours and three shallow but cold dives in freshwater springs and caves. They then drank some alcohol; some smoked marijuana and had a short, disturbed night's sleep. Alcohol and marijuana were detected in one of the deceased but no blood was taken from the survivors. Thus fatigue may have played a part, combined with some residual drug effects. Why did seven adults jump into an area of ocean that is so obviously very hazardous? The power of peer pressure, belief in the leader and naivety are likely explanations.[13]

THE MEDICAL RISKS OF THE DIVE

The pathophysiological risks of such a rapid bounce dive to 90 msw on air are numerous (Table 2). The maximum partial pressure of oxygen experienced by the divers was about 202 kPa breathing air; the risk of acute oxygen toxicity for a dive of this short duration would be low. There is early transient acute carbon dioxide (CO_2) retention during a deep dive with a rapid compression, causing dyspnoea and exacerbating nitrogen narcosis.[14,15] The main mechanism is hypoventilation due to the increased work of breathing from increased gas density and diving regulator resistance. CO_2 retention may also sensitize the myocardium to arrhythmias such as those induced by the diving reflex and by enhanced catecholamine release from severe anxiety.

The effects of compressed air at 1,013 kPa are stupefaction, severe impairment of practical activity and judgement, mental abnormalities, memory defects and almost total loss of intellectual and perceptive faculties. Nitrogen narcosis is most severe early in a dive, especially with rapid compression as occurred here, followed by rapid recovery on decompression, as described by the survivors.[14] The sequence of nitrogen narcosis and CO_2 retention leading to loss of consciousness would then result in salt-water aspiration and laryngeal spasm. Laryngeal spasm followed by a rapid ascent may have resulted in pulmonary overpressure and the massive AGE apparently observed at autopsy. An alternative pathophysiological sequence may have been drowning following nitrogen narcosis and the air observed post mortem could be an artefact. Symptoms of salt-water aspiration were observed in Student A, who was the only survivor to lose her regulator.

Air consumption was high given the short duration of the dive. None of the divers (survivors or deceased) were reported to have been out of air but all except Student A used three-quarters of their air supply within 12 minutes. Student A used only a quarter of her air supply suggesting that she lost her regulator fairly early in the dive and suffered cerebral hypoxia, but survived because of her rescue by Student B. Her long-term symptoms of memory loss and difficulty concentrating and following instructions are readily explained on this basis.

Two of the survivors suffered from tympanic membrane barotrauma with Student A requiring myringotomies for her hyperbaric treatments. Pneumothorax was not observed, but AGE may have occurred in the deceased and contributed to Student A's condition. DCS was present in two and probably a third of the survivors. One completed the dive with minor barotrauma only, demonstrating the variability in susceptibility between individuals.

MISSED DECOMPRESSION AND DELAYED DIAGNOSIS OF DCS

Recreational divers frequently miss decompression stops because of lack of or improper use of depth and time monitors, carelessness, equipment failure, lack of air supply and changes in environmental conditions. Most lapses are minor and result in no symptoms, but some will result in DCS. Hyperbaric units rarely receive requests for treatment of recreational divers who have missed decompression but are asymptomatic. This event was the first for the Christchurch Unit and advice was given pragmatically and not based on an established protocol. GMcG was informed about the incident following evacuation to Nelson Hospital, which is 250 km by air from Christchurch. The view of the attending doctors in Nelson was that none of the survivors had DCI and so transfer was not requested. Pressurized air ambulance with specialist crew on the day would have raised funding issues had transfer been requested, since DCS injury did not appear at that time to have occurred.

Student B's medical records from Nelson indicate a brief but adequate assessment. Where Student A was concerned, the assumption was that her symptoms were due to aural barotrauma, salt-water aspiration and near drowning. A specialist physician completed an adequate neurological examination. It was only that evening that she developed a skin rash. This alone is not an indication for recompression. In hindsight, all the divers should have been admitted overnight for observation, oxygen and oral hydration and undergone a full neurological examination initially and prior to discharge. When initially assessed in Nelson, the survivors did not appear to the assessing medical staff to meet the criteria for DCI but rather to have missed decompression. On this basis, it was a reasonable decision not to evacuate them immediately. However, once symptoms appeared, the decision to evacuate and treat was also correct.

Phone advice and the consequent duty of care accepted by the doctor providing the advice is a contentious issue. Generalists, both in the hospital and in the community setting, rely on remote specialist advice via various media; an increasing trend in medicine. The availability of standard protocols for managing uncommon presentations in remote settings may assist physicians with many of these problems. Doctors have been concerned that guidelines may be used to deskill them and expose them to risk if they are not followed. However, the use of guidelines for remote advice protects both the specialist and the generalist.

AUTOPSY FOR DIVING ACCIDENTS

A senior specialist pathologist conducted the two autopsies about 21 hours after death. CT scans showed widespread gas in the cerebral arteries and systemic vessels. CT is a very sensitive way of detecting gas in the body. This was interpreted as indicating widespread air embolism. However, gas in the systemic circulation is not specific for CAGE and occurs in many diving fatalities.[16,17] The direct cause of death was given as drowning with the antecedent cause as massive air embolism and the underlying cause as pulmonary barotrauma. For this sequence to be correct, the CAGE would have occurred at depth with loss of consciousness during ascent causing the diver to lose their regulator and drown. CAGE usually occurs in the surface 20 msw during rapid ascent with loss of consciousness on the surface. This was not the observed sequence. Based on the evidence, it is the authors' view that it is more likely the deceased suffered the same pathological sequence as the survivors clearly describe – severe nitrogen narcosis and impairment or loss of consciousness with or without loss of the scuba regulator and salt-water aspiration. This sequence might lead to panic with breath-holding or laryngeal spasm, which might have caused CAGE. In summary, the true cause of death depends on the interpretation of the gas seen on CT. CAGE is unproven, and in our view an alternative cause of death of severe nitrogen narcosis and drowning is possible.

THE LATE EFFECTS OF SCUBA DIVING ACCIDENTS

The neurological consequences of DCS are well known but there is little literature on the long-term follow up of survivors of recreational diving accidents, particularly relating to psychological injury.[18] The survivors described above have both suffered psychological consequences and one is still moderately impaired from her previous level of functioning. The aetiology in her case is most likely hypoxic brain injury secondary to near drowning, post-traumatic adjustment and residual symptoms from DCS. It has not been possible to differentiate the contributions of each of these causes. Psychological support for her was slow in coming.

THE ROLE OF EACH ORGANIZATION

DoL regulates occupational diving in New Zealand. The requirements are documented in the *Guidelines for occupational diving* which were in final development but not fully introduced in 2000.[19] Any person who wishes to work as a diver is required to gain a Certificate of Competency under the Health and Safety in Employment Regulations 1995. The diver requires a medical clearance from the Diving Hyperbaric Medicine Services that involves a five-yearly medical examination and an annual questionnaire. They also require suitable qualifications and references for their prospective branch of diving. A Certificate of Competency is required to be an instructor or tutor in recreational diving and this was the goal of the students involved in the incident. At the time, the majority of divemasters and instructors had not applied for certification.

The six divemaster students were all receiving a training allowance from WINZ, and had also received student loans of NZ$7,500 each. Dive shops providing courses to PADI standards require approval by NZQA. NZQA contracted a private training establishment, Adventure Sports Institute of New Zealand (ASINZ), to take responsibility for ensuring courses met these standards. NZQA advised that they believed this was happening and that ASINZ had the necessary policies and procedures in place. ASINZ also advised the Coroner in rather general terms that they had done everything required, but acknowledged ASINZ was not ensuring that all instructional staff had a Certificate of Competency.

RECREATIONAL DIVING INSTRUCTION AS AN EMPLOYMENT SCHEME

It has always been hard to manage recreational diving training in New Zealand. Instructors, for many years, were enthusiastic amateurs working through shops for some extra money and as a hobby. This was beginning to prove difficult given the new OSH regulations. Shops needed to employ instructors and provide them with full-time employment. The divemaster courses were fully funded at the start of the course by student loans and were thus a guaranteed source of employment for staff. The funds were received even if the student did not turn up or dropped out of the training. From the material available, it is our opinion that WINZ at that time appeared to regard recreational diving as a useful industry for young people, without appropriate mechanisms in place to assess their suitability.

In turn, many dive shops regarded these programmes as a 'cash cow' and were not particularly selective. Some operators even offered inducements to students such as free equipment. The students required a medical examination, but not a DoL one, and this could be with any general medical practitioner, irrespective of whether they had any training or experience in diving medicine. Most students probably did not discuss their aspirations to become occupational divers with their doctors, many of whom would not have the diving medicine or occupational health experience to recognize the different standards required for occupational divers.

PADI guidelines for their courses were fully documented in 2000. However, the framework for risk management had not evolved, so that the responsibilities were unclear at each level from student to the NZQA. PADI was not supervising and auditing the standard of their operators closely and hence the chain of accountability was broken. NZQA accredited the Course as being of suitable educational quality but clearly did not ensure that monitoring was effective. The shops were (and still are) required to be accredited with NZQA. As a training institution, their protocols have to be approved but this was new to all parties in 2000.

In conclusion, some students were enrolled on these courses with no institutional checks and balances to ensure they were physically fit to dive daily, psychologically able to cope with the stresses, socially and intellectually capable of a leadership and management role or with sufficient life experience to manage risk. There was inadequate institutional monitoring of standards of instructors, instruction and safety. There were financial advantages to be gained by dive shops in this environment to use poorly trained and inexperienced staff and to take short cuts in supervising these staff and students. The stage was thus set for a disaster to occur.

TRAINING CHANGES

In March 2000, NZQA introduced an audit of private training establishments, and ASINZ was audited in March 2001. This showed significant non-compliance with the standard of registration. Following the prosecution, NDC lost its membership of PADI in June 2001 and was expelled from ASINZ. In September 2001, NZQA conducted a further audit of ASINZ that showed considerable improvement. The auditors said that ASINZ was monitoring the quality of diver training at its delivery sites very closely and had initiated new procedures to further assure student safety.

WINZ is part of the Ministry of Social Development, and required courses to be NZQA-approved. However, WINZ case managers were not provided with guidance about selecting appropriate clients to consider diving as a career. The large numbers of students referred by WINZ suggests there was considerable enthusiasm from case managers who probably thought this was an easy way of moving clients into an expanding industry. Unfortunately, the recreational diving industry was also incapable of selecting suitable candidates or adequately supervising less able students. It is still possible for students to receive assistance from WINZ for diving courses.

THE AFTERMATH

After a tragedy, those involved frequently want to know if anything has changed and whether their loss might help prevent others from suffering the same. The consequences for two of the survivors have been detailed above. The pain of the seven orphaned children and the families of the bereaved can only be imagined. The instructor has paid his fine and seems to have accepted his share of responsibility, whereas the directors of the Nelson Dive Centre appear not to have done so.

DCI incidence

During the four years 1996–1999, 40 divers with decompression illness were treated in Christchurch. In the two years 2000 and 2001, 48 divers presented, including 11 on various student-loan, or WINZ-funded, NZQA-approved courses (Figure 4). A similar pattern was noted by the Slark Hyperbaric Medicine Unit in Auckland (Murphy B, personal communication, 2003). No cases have been noted to be on student-loan schemes since 2002, although these courses have continued to be funded.

Medical lessons

The treatment of the survivors from a medical perspective was adequate. However, their care could have been improved by more detailed neurological examination, closer observation in hospital and better communications between on-site hospital staff and the regional hyperbaric unit.[20] The standard procedure in most of New Zealand is to evacuate diving accidents to the nearest base hospital. This has the advantage of rapid administration of first aid and resuscitation by medical personnel, but has the disadvantage of sending the diver to a hospital without specific diving medicine expertise. Of course, this issue applies to many specialist services across the health sector in many countries.

Conclusions

This tragedy changed the delivery of recreational diving training in New Zealand. It demonstrated a failure of the institutional controls on instructors and on the courses delivered. This allowed a dive shop to use an inexperienced, uncertified instructor to train a group of students of varying suitability. Supervision of the instructor appeared to be such that he took a group of hung-over, sleep-deprived students to one of the most hazardous dive sites on the NZ coast. The psychological inertia in the group meant that none was willing or able to refuse to dive or accurately assess the degree of risk involved. The conduct of the dive, in failing to apply the PADI protocols correctly, contributed to the ensuing mortality and morbidity.

This review has documented some observations differing from previous coronial and legal proceedings.

- The divers say they intended to dive when the current was running and were not concerned about tide times.
- The arrangement of the drift line and inadequate surface floatation for it may have contributed to the accident.
- The female survivor probably suffered a clinically significant global hypoxic brain injury.
- The cause of death may have been drowning due to loss of consciousness secondary to nitrogen narcosis *ab initio* rather than CAGE.
- The instruction to the divers not to let go of the rope under any circumstances was important as it stopped useful (and previously successful) remedial action.

Acknowledgements

Particular thanks go to the two brave survivors who freely revisited their memories and provided their own personal files. Messrs Brian Franks, Geoff Cooper, Brian Green and Martin MacDonald advised on various aspects of the incident and the legal processes.

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Erratum

Douglas Walker, who was the Editor of the *SPUMS Journal* at the time, points out that the cartoon on page 188 of the December 2008 issue was attributed incorrectly.
"*The cartoonist was Peter Horrigan and his obituary was on the cover of the Journal following his death. He was the cartoonist on the Manly Daily for years and kindly donated his talents to translating ideas I put to him into cartoons.*"

Using a Delphi technique to rank potential causes of scuba diving incidents

Peter Buzzacott, Michael Rosenberg and Terri Pikora

Key words
Diving accidents, scuba accidents, ascent, buoyancy, risk factors, survey

Abstract

(Buzzacott P, Rosenberg M, Pikora T. Using a Delphi technique to rank potential causes of scuba diving incidents. *Diving and Hyperbaric Medicine*. 2009;39:29-32.)
Scuba diving experts suggested and ranked potential causes of three known risk factors for scuba diving incidents: running out of air, losing buoyancy control and making rapid ascents. Three types of scuba diving expert participated: medical experts, divemasters and expert divers. In three rounds, consensus was reached for 28 (58%) of 48 suggested causes. Inexperience was ranked highly for all three risk factors, as was anxiety/stress and diver failure (to monitor contents gauge or release air on ascent). Poor skill levels and inadequate training were also often suggested. Overall, the expert panel suggested potential causes that were more often human or equipment related, than environmental.

Introduction

Among recreational divers, the three leading causes of injury and death are drowning/near drowning, barotraumas due to expanding air during ascent, and decompression illness (DCI).[1–8] Running out of air, a loss of buoyancy control and making a rapid ascent have been found to be associated with these types of diving morbidity and mortality.[1,9–12] These risk factors are also known to occur concurrently.[12–14]

What remains to be investigated are the reasons why divers lose control of their buoyancy, make rapid ascents or run out of air. Nor is it known whether these injury risk factors share common causes. Before research can be conducted to investigate the potential strength of association between three risk factors and their potential causes, likely causes need to be identified. This paper presents the results of a Delphi study conducted between February and June 2007 using a panel of experienced recreational divers, diver supervisor/instructors and diving medicine/research experts.

DELPHI ANALYSIS

Developed in the 1950s, this technique is a useful method for reaching consensus of expert opinion regarding a complex or imprecise issue.[15] In its 'ideal' form, an expert panel is formed whilst anonymity is maintained and each expert contributes to an initial summary of expert opinion. This summary is then circulated to the panel and each expert makes revisions based on both their own opinion and bearing in mind the weight of opinion of the panel.[16] A second summary is circulated, usually with a higher level of agreement than the first and, once again, each expert makes revisions. After three or more rounds, a pre-defined consensus of opinion is reached for some aspects of the summary, while for the remainder the experts should be expected to reach 'terminal disagreement' where the likelihood of further agreement is diminished.[17]

Methods

INSTRUMENT DESIGN

A questionnaire comprising thirteen questions formed the basis of the first-round survey. This consisted of four questions addressing characteristics of respondents such as occupation and number of dives made, followed by nine questions related to running out of air (three questions), losing buoyancy control (three questions) and making rapid ascents (three questions). The first of each trio was an open-ended question asking why some divers might experience each of these risk factors, the next asked which single reason was the most common cause of each risk factor and the final question asked whether this had ever happened to the respondent. The study was approved by the Human Research Ethics Committee of the University of Western Australia.

The questionnaire was assessed for face and content validity, and was pilot tested by sixteen divers ranging in experience from novice to instructor. Minor revisions were made to the invitation to participate and the wording of the questions. Potential participants were identified based on their profession. Medical experts included researchers and hyperbaric clinicians identified from published research who were known to have treated injured divers and/or engaged in diving-related research. Expert divers, identified by reviewing the popular diving press, had published numerous diving feature articles, travelled extensively to popular dive destinations and were known to have made 1,000 dives or more. Expert divemasters and instructors were nominated by staff at the largest dive businesses within Western Australia. Each had worked as a professional divemaster or instructor for ten years or more. A search of diving industry journals identified two additional instructors who had received industry awards for teaching recreational scuba diving. Most potential participants had experience in at least one additional category other than that for which they were considered expert, e.g., some medical experts were also instructors and most instructors were accomplished divers.

Anticipating an initial response rate of 75%, 29 potential participants were each sent, by e-mail, an invitation to join the study. A copy of the first-round questionnaire was attached to each invitation. Prior agreement to participate was not sought. E-mail was chosen as the preferred method of communication because of its speed and cost effectiveness over traditional mail.[18] At the end of the first round all suggested possible causes were listed alphabetically and in the second round participants were asked to rank the five most common causes for each risk factor. In the third round possible causes not chosen at least once in the second round were removed from the list. The remaining causes were placed in order of how often each possible cause was chosen as significant and, based on this, participants were asked to re-consider and to re-rank the five most common potential causes of each risk factor.

Consensus was pre-defined to at least 90% agreement between participants upon whether a potential cause was likely, or not likely, to be commonly associated with each risk factor. Finally, potential causes were classified as relating to the diver (human), dive gear (equipment) or conditions at the dive site (environment). Classification was made using existing criteria, with the exception of equipment misuse, which was considered in this study to be equipment related.[5,19,20]

STATISTICS

Data were managed using Excel and analysed using SAS ver 9.1. Differences in mean number of dives made by each group in the previous year were tested for significance using the Wilcoxon rank sum test. Differences between groups (n = 3) in the mean number of potential causes suggested were tested for significance using ANOVA, with pooled variance. Reported correlations between rankings of potential causes are Spearman rank correlation coefficients. Differences between expert groups in correlation between second- and third-round rankings were tested for significance using Fisher's z transformation.[21] Significance in all tests was accepted at 0.05.

Results

Of 29 experts contacted, one declined to participate, three returned only one of the last two rounds and 25 (86%) completed both second and third questionnaires. Participation was evenly distributed across the expert groups, with nine from each group taking part in the third round. Participants reported having made a total of 2,736 dives (median = 90) during the previous year. Medical experts reported making fewer dives during the previous year (median = 18) compared with either divemasters (median = 100) or divers (median = 100).

Table 1
Suggested possible causes of divers running out of air (see text for explanation)

Round	**First**	**Second**	**Third**
	Nº times		
Possible cause	**suggested**	**Rank[a]**	**Rank[a]**
Failing to monitor gauge	16	1	1[b]
Inexperience	12	2	2[b]
Overexertion/strong current	6	3	3
Inadequate training	8	4	4
Poor dive planning	4	5	5
Panic/anxiety/stress	7	8	6
Diving deeper than usual	4	7	7
Trying to match their buddy	4	6	8
Overweighting	3	9	9.5[b]
Task-loading	3	14[b]	9.5[b]
Faulty equipment	7	10.5[b]	12[b]
Narcosis	3	10.5[b]	12[b]
Low starting pressure	3	14[b]	12[b]
Entrapment	2	14[b]	16[b]
Tired or cold	1	14[b]	16[b]
Unplanned decompression	1	14[b]	16[b]
Drugs/medication	1	17.5[b]	16[b]
Using a smaller cylinder	1	17.5[b]	16[b]
Correlation with 3rd round	0.90	0.94	1.0

[a] Ranked by number of times in top five
[b] Consensus reached by ≥ 90%

In the first round, participants suggested 18 possible causes of divers running out of air, 14 possible causes of divers losing buoyancy control and 16 possible causes of rapid ascent. Medical experts suggested more potential causes overall (n = 40) than divemasters or divers (n = 31 and 32 respectively). The mean number suggested by medical experts (4.7, SD 1.3) was significantly higher ($P < 0.01$) than by divemasters (3.5, SD +/- 0.8) or divers (3.6, SD +/- 1.2). Suggested potential causes are provided in Tables 1, 2 and 3. Movement toward consensus is evidenced by the increasing consistency with which each possible cause was suggested during successive rounds. By round three, consensus was reached for 28 (58%) of the 48 suggested possible causes.

Correlation coefficients were calculated between second- and third-round choices for each participant's five most significant potential causes, to gauge how far each group moved towards consensus. Overall intra-rater correlation coefficient (r) for divemasters was 0.47, for divers 0.65 and for medical experts 0.75; these differences were significant. Divemasters were more likely than divers to move towards consensus ($z = 2.88$, $P = 0.004$), whereas medical experts were less likely to change their ranking than either divers ($z = 2.22$, $P = 0.026$) or divemasters ($z = 5.19$, $P < 0.003$).

Lastly, potential causes selected at least once in the third

Table 2
Suggested possible causes of divers losing buoyancy control

Possible cause	First round: Nº times suggested	Second round: Rank[a]	Third round: Rank[a]
Inexperience	13	1[b]	1[b]
Failure to release air on ascent	4	4	2.5
Poor training/skills	6	3	2.5
Incorrect weighting	9	2	4
Panic/anxiety/stress	8	6	5
Unfamiliar equipment	6	5	6
Incorrect body position	5	10	7.5
Incorrect use of BCD	2	8	7.5
Loss of weight system	6	7	9
Wetsuit compression	1	10	10[b]
Carrying heavy objects	2	10	12[b]
Current or surge	2	13	12[b]
Faulty BCD	9	12	12[b]
Upwelling of water	2	14[b]	14[b]
Correlation with 3rd round	0.56	0.95	1.0

[a] Ranked by number of times in top five
[b] Consensus reached by ≥90%

Table 3
Suggested possible causes of divers making rapid ascents

Possible cause	First round: Nº times suggested	Second round: Rank[a]	Third round: Rank[a]
Panic/anxiety/stress	20	1[b]	2[b]
Failure to release air on ascent	11	3	2[b]
Inexperience	12	4	2[b]
Running out of air	12	2	4
Incorrect use of BCD	4	5	5
Ignorance of safe ascent rate	3	9	6.5
Poor body position on ascent	8	7	6.5
Fail to monitor depth gauge	2	7	8
Loss of weight system	5	7	9
Equipment failure	3	10	10[b]
Bad visibility	1	11.5	13.5[b]
Upwelling of water	1	11.5	13.5[b]
Entanglement	1	14[b]	13.5[b]
Lifting a heavy weight	1	14[b]	13.5[b]
No computer	1	14[b]	13.5[b]
Narcosis at depth	1	16[b]	13.5[b]
Correlation with 3rd round	0.93	0.94	1.0

[a] Ranked by number of times in top five
[b] Consensus reached by ≥90%

Table 4. Classification of remaining possible causes, by risk factor

Risk factor	Human	Equipment	Environment
Running out of air (N = 8)	Inexperience Inadequate training Poor dive planning Panic/anxiety/stress Trying to match buddy	Failure to monitor gauge	Overexertion/strong current Diving deeper than usual
Losing buoyancy control (N = 9)	Inexperience Poor training/skill level Panic/anxiety/stress Incorrect body position	Fail to release air on ascent Incorrect weighting Unfamiliar equipment Incorrect use of BCD Loss of weight system	
Making a rapid ascent (N = 9)	Panic/anxiety/stress Inexperience Ignorance of safe ascent rate Poor body position Loss of weight system	Fail to release air on ascent Running out of air Incorrect use of BCD Fail to monitor depth gauge	
Overall (N = 26)	14	10	2

round were classified as human, equipment or environmental, (Table 4). The overall distribution suggests the three most common risk factors for diving morbidity and mortality are thought to be associated with either human error or equipment issues, and environmental conditions are thought to assume a less significant role in diving incidents.

Discussion

Although medical experts reported making substantially fewer dives during the previous year, they initially suggested significantly more possible causes for each risk factor and then changed their ranking of the importance of potential causes to a significantly lesser degree than the other expert groups. Given this group's probable exposure to published research relating to diving incidents, this difference is not surprising. Despite this apparent heterogeneity between types of expert, consensus was reached that diver inexperience was the most common cause of losing buoyancy control, the equal most common cause of rapid ascents and the second most common cause of running out of air. This is in keeping with results of previous studies that reported air embolism occurred more often in people who dove less frequently and that most severe air embolisms occurred among inexperienced divers.[22,23] Inexperience has also often been cited as important within diving fatality analyses.[6,7] In our study diver failure to check the contents gauge or release air during ascent ranked high, as did panic/anxiety/stress. Inadequate training and poor skill level were also suggested by the experts, implying that increased training and practice might reduce diver stress, improve skill-level and reduce diver error. The presence of such an association remains to be proven.

Although a high level of consensus was reached in this study, the actual causes of each risk factor remain undetermined. To address this, a prospective study is underway to determine which of these potential causes are significantly associated with running out of air, losing buoyancy control and/or making a rapid ascent. Though it is customary to define consensus as an arbitrary level of agreement, the ranking of potential causes, including even those for which consensus was not reached, may occasionally prove more useful, for example in the development of a survey. In such cases, the Delphi technique may even prove useful for investigating other issues related to diving injuries and deaths.

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The world as it is

Emergency recompression: clinical audit of service delivery at a national level

John AS Ross and Martin DJ Sayer

Key words
Clinical audit, decompression sickness, decompression illness, recompression, hyperbaric oxygen therapy, outcome

Abstract

(Ross JAS, Sayer MDJ. Emergency recompression: clinical audit of service delivery at a national level. *Diving and Hyperbaric Medicine*. 2009;39:33-7.)
Clinical audit is an essential element to the maintenance or improvement of delivery of any medical service. During the development phase of a National Recompression Registration Service for Scotland, clinical audit was initiated to provide a standardised tool to monitor the quality of outcome with respect to the severity of presentation. A functional audit process was an essential consideration for planned future measurement of treatment efficacy at local (single hyperbaric unit) and national (multiple hyperbaric units) scales. The audit process was designed to be undemanding, robust and informative, irrespective of the experience of treatment centre and of the clinician in charge of treatment. The clinical records from 104 cases of divers with decompression illness were used to derive and evaluate measures of severity and clinical outcome that could be used for audit and quality assurance. The various measures of disease severity were examined against clinical outcome and days spent in care after admission to a hyperbaric unit. An initial version of the clinical audit format that was developed from this process is presented.

Introduction

The fiscal responsibility for the recompression service for the treatment of decompression illness in Scotland, based at Aberdeen Royal Infirmary, passed from the Department of Energy to the Scottish Home and Health Department in the mid 1990s. In 1996, it became the subject of a contract between the Infirmary and the National Health Service (NHS) in Scotland. With this contract came a responsibility for the clinical audit of the treatment of diving-related illness throughout Scotland. At that time, there was no accepted method of clinical audit available for decompression illness and a system had to be developed.

Clinical audit has a plethora of definitions that are not reviewed in detail here. Examples of the important elements of clinical audit are presented well by Johnston et al, who defined it as "*a valuable assistance to any programme which aims to improve the quality of health care and its delivery*".[1] Burnett and Winyard acknowledged the importance of clinical audit as a tool to enable clinicians to improve their care, while including how essential it is that it enables an evaluation of how health-care intervention achieves what is intended in the most beneficial way.[2]

The present account outlines the development of an audit process targeted at providing an ongoing, periodic assessment of the efficacy of recompression treatment within the Scottish service as a whole. The primary aim at the time of developing the audit process was to establish simple measures that would permit quantitative service-wide analyses of disease severity against clinical outcome irrespective of the numbers of inputting clinicians and their respective levels of specialist knowledge. A secondary aim was, by defining the severity of illness presenting at pressure chambers, to define the level of care that needed to be delivered by Scottish hyperbaric units.

Methods

The present study adheres to the procedures of implied consent operated by the UK NHS for clinical audit and its development. An opinion was sought from the Chairman of the North of Scotland Research Ethics Service who formally indicated that ethical approval was not necessary for the conduct of clinical audit. The clinical records of all 104 consecutive cases of decompression illness treated in four Scottish recompression chambers from October 1991 to December 1995 were available and were used to develop the basic audit tool. After examination of all the records, a questionnaire was developed to record the data that were available in the clinical record. By restricting data gathering to the level at which clinicians spontaneously recorded them in case notes, it was thought that the data-gathering tool would have a high level of acceptability in the future. The manifestation-based system used to gather data regarding the clinical condition of the patient was broadly taken from that of Francis and Smith.[3] The data-collection format is shown in full in Appendix 1.

The severity of patient condition was quantified on presentation, when cases were first notified to the medical or emergency services, on admission to the hyperbaric unit and on discharge from acute care (Table 1). The stability of the patient's condition was assessed and scored on admission to the hyperbaric unit as recovered (score 1), improving (score

2), stable (score 3) or deteriorating (score 4). The response to the first recompression treatment was also quantified (Table 1). Scoring patient condition in this manner was vulnerable to an unavoidable observer bias. Accordingly, the severity of the patient's condition was also quantified in terms of the number of days spent in acute care after the accident.

DATA ANALYSIS

The data (104 consecutive cases of decompression illness) were analysed at differing temporal points throughout the treatment process (condition on referral, condition on admission, response to first treatment, and condition on discharge) following the measurement criteria summarised in Table 1; calendar days spent in care were also assessed. Although the form allowed reporting of multiple symptoms and signs under these headings, the scores for condition on referral, condition on admission and condition on discharge were taken as the highest of a ranked set of symptoms and signs. In other words, a patient with nausea and vomiting and ataxia on referral would score 5 for nausea and vertigo and a patient presenting with motor weakness, sensory disturbance and pain would score 4 for motor weakness.

The data analysis planned was descriptive only in this pilot study. Three-dimensional plots were constructed to visualise the relationships between measures of severity (condition on referral and condition on admission) and measures of outcome (days in acute care and condition on referral).

Results

Clinical outcome was favourable in 88% of cases (62% complete resolution, and 26% with mild pain or sensory symptoms; n = 104). Six per cent were left with a mild motor or ataxic problem, four per cent with a more severe problem of this kind with or without a urinary catheter, and three per cent had a cerebral deficit problem on discharge (n = 104). The median time to treatment from the onset of symptoms was 5.8 hours (25–75% range: 3.8–11.0 hours). The most important factor in treatment delay was in the time taken for the case to present after the onset of symptoms (median: 2.0 hours; 25–75% range: 0.9–7.0 hours).

Referral presentations of ataxia and milder were associated with relatively mild outcomes. Severer outcomes were typical of motor and cerebral symptoms. Although nausea and vertigo as presenting symptoms were not associated with prolonged stay in care and might merit a lower score than a motor deficit, there was a limited association with a cerebral deficit outcome (Figures 1 and 2).

On admission to the hyperbaric unit, a similar picture was seen, although the significance of ataxia was greater on referral since there was an association between this clinical sign and motor or ataxia problems on discharge and with a cerebral deficit outcome requiring 10–12 days in care (Figures 3 and 4). When the clinical progress on admission was considered with condition on referral, it was clear that, as in Figure 4, the longer stays in care were associated with deteriorating cerebral and motor presentations (Figure 5).

Discussion

It was established that it is possible, using a simple approach to data collection and severity stratification, to produce informative data on the presentation, severity and outcome of decompression illness. As a result, from 1 January 1996, chambers treating decompression illness in Scotland returned an audit form along the line of the one described

Table 1

Examples of the translation of descriptive data onto ranked ordinal scoring scales for symptoms on referral, condition on admission, response to primary treatment and condition on discharge. All vertical ranked scores should be viewed in isolation; similar horizontal scores do not infer any similarity in severity of condition.

Ranked ordinal score	Symptoms on referral	Condition on admission	Response to initial recompression treatment	Condition on discharge
0	None	None	No initial signs or symptoms and no clinical change	Completely resolved
1	Pain only	Pain	Complete resolution in condition	Slight pain or sensory residua
2	Sensory	Sensory	Major improvement in condition	Residual motor involvement/ataxia
3	Ataxia	Ataxia	Moderate improvement in condition	Severe residual motor involvement/ataxia
4	Motor involvement	Motor involvement	Slight or no change in condition	Urinary catheter
5	Nausea or vertigo	Bladder/rectal involvement		Cerebral residua
6	Cerebral	Nausea/vertigo or cerebral		Dead

(Appendix 1), and a copy of the patient discharge letter to Aberdeen for clinical audit processes. By 1998, sufficient data had been collected that indicated the level of care required in chambers treating decompression illness for the NHS in Scotland. This, in turn, led the Central Services Agency to fund a quality assurance programme for the chambers involved. In 1999, all compression chambers in Scotland that provided emergency recompression of divers were invited to apply to be part of a national (Scottish*) registration service. Funded by the National Services Division within the Common Service Agency of the NHS in Scotland, the objectives of the registration service were to assure levels of baseline quality of care for patients receiving recompression therapy. This took the form of initial site-based assessments of the standards of medical, nursing and technical provision with periodic re-evaluation. However, in addition, a significant purpose of the service was to assess the quality of recompression-related health care through a process of clinical audit.

There is a significant literature dedicated to clinical care. However, no reports have made direct reference to clinical audit with respect to the emergency treatment of divers with symptoms of decompression illness. In this account, we do not address the actual delivery of treatment in terms of medical, nursing or technical quality, even though that was

* **Footnote:** Scotland is, at the time of writing, an integral part of the United Kingdom although having devolved powers including some related to the funding of health services. The UK National Health Service (NHS) is separated between the following "national" regions: England and Wales; Scotland; Northern Ireland. The rationale and financial approaches of the NHS in Scotland may (and do) differ from other national healthcare bodies.

Figure 1
Condition on referral and discharge in relation to patient numbers (% of symptom category)

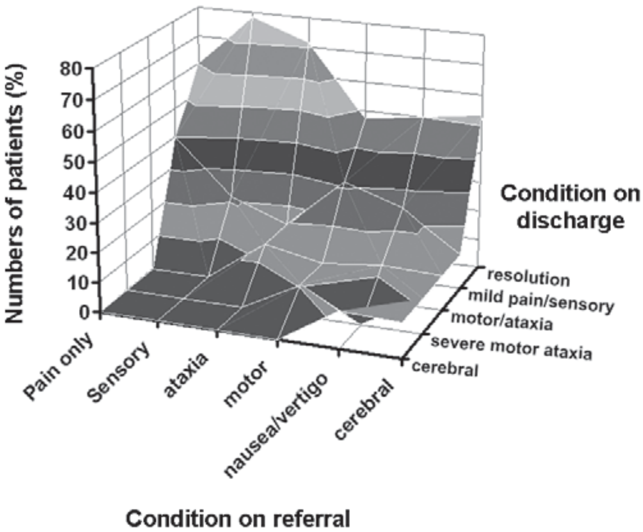


Figure 2
Condition on referral and discharge in relation to days spent in care

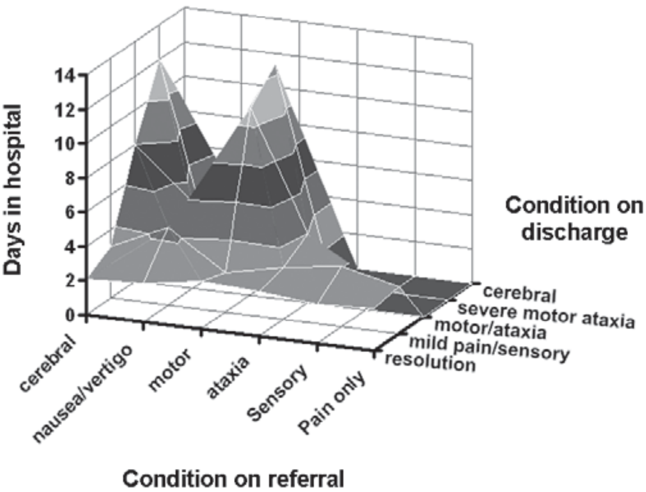


Figure 3
Condition on admission and discharge in relation to patient numbers (% of symptom/sign category)

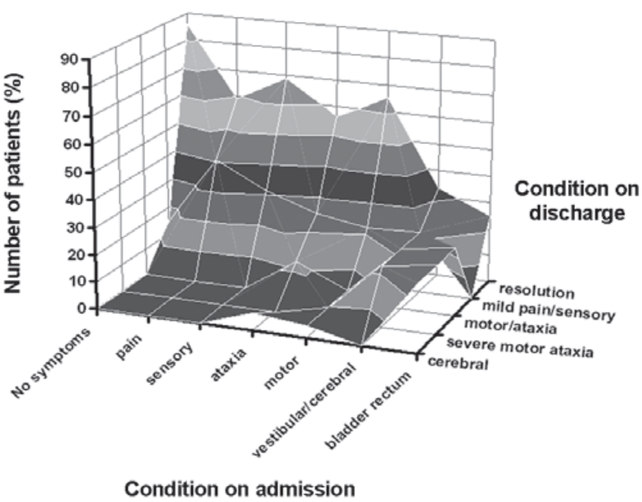


Figure 4
Condition on admission and discharge in relation to days spent in care

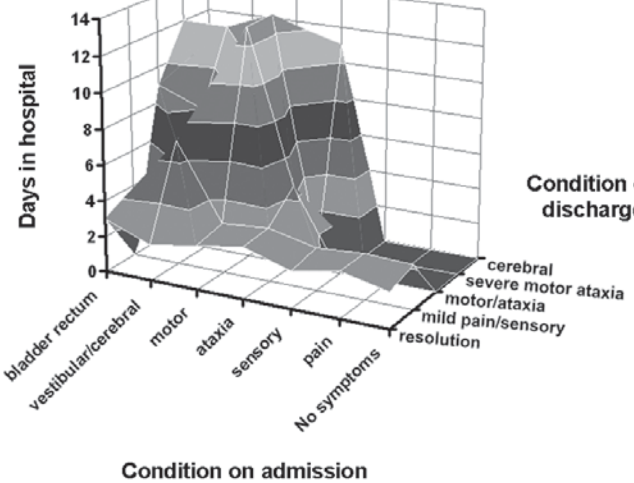
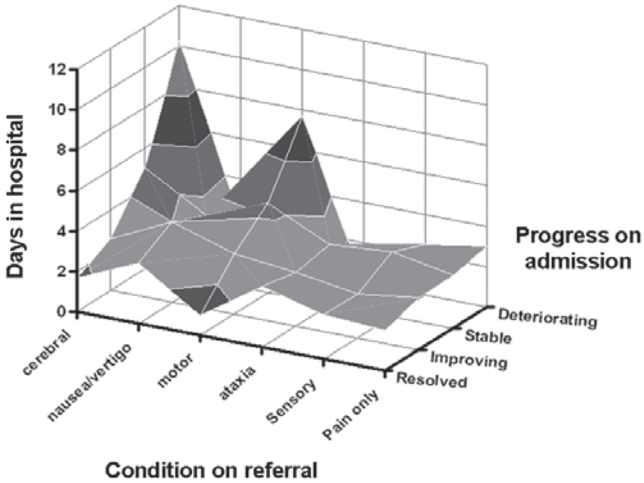


Figure 5
Condition on referral and progress on admission in relation to days spent in care



part of the basic evaluation process. Initially we examine how we have designed and applied a method that measures recompression treatment efficacy on a national basis.

Any audit of a clinical process will, at some point, rely on a form of measurable assessment of entry-level condition against that of discharge. Quantifiable scales of the degree of severity of decompression illness that have been applied in the past are reviewed by Mitchell.[4] As outlined by Mitchell, most previous scoring systems have been proposed for quantifying condition on presentation with a view to predicting outcome. From its inception, it was the main objective of the present study that clinical audit would provide a standardised tool for monitoring the quality of outcome with respect to the severity of presentation with a view to measuring treatment efficacy. However, this had to be the case for the totality of a national service, irrespective of the experience of treating centre and of that of the clinician in charge of treatment. The design of our audit process, therefore, had to be both undemanding and robust while, at the same time, being informative. To this end, complex scoring regimes were overlooked in preference for using a limited number of descriptive terms.

The present account outlines the background to the development of a process of audit and quality assurance for the emergency recompression of divers that can be applied at a national (or at least a supra-regional) level. The audit form has changed somewhat since its inception and now gathers details on the dive history and on muscle weakness associated with upper and lower limb presentations. The basic severity and outcome measures, however, remain as presented here. Future work is in the prospective application of this instrument and the evaluation of the data it produces. The results from this initial work may lead to recategorisation of the degree of severity associated with the various measures of clinical status. For example, it may be necessary to down-grade the category of nausea/vertigo to be less severe than that of motor problems.

Since its inception, the audit tool has been used to produce data indicating to the NHS in Scotland that the outcome of treatment for cases of decompression illness was generally favourable and that a quality assurance programme was associated with a demonstrable improvement in short-term clinical outcome.[5] It has also been used to identify professional divers in Scotland as an at risk group in terms of poor outcome of recompression treatment and to indicate that statutory reporting of decompression illness was of limited value.[6] Most importantly, audit data generally indicated that there was no benefit in recompressing severe cases of decompression illness as rapidly as possible in the nearest hyperbaric chamber if the unit was poorly staffed and equipped. This conclusion has been used to inform possible changes in the statutory management of decompression illness in professional divers in the UK, as well as to underpin the decision to withdraw support from two recompression facilities in Scotland that were unable to deliver an adequate level of care for NHS patients with decompression illness. Both units subsequently stopped accepting patients who were effectively treated elsewhere.

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Appendix 1 – All data retrieved from the clinical record for audit purposes

Commercial diver / Sport diver (delete as appropriate)
Patient Name ______________________
Date of Birth ______________________
Unit Number ______________________
Patient Address (Use patient addressograph if possible)
____
____
____
Post Code ____________
Name of patient's GP ______________________
Address ______________________
____
____
Post Code ____________

Source of Referral
Relapse ____
Self referred ____
Hospital Unit Name ______________ Location ______________
GP referred Name ______________ Location ______________
Emergency services ______________________

End of last dive
Date ___/___/___ Time ___:____ am/pm
Onset of symptoms
Date ___/___/___ Time ___:____ am/pm
Presentation to medical services
Date ___/___/___ Time ___:____ am/pm
Admission to ARI/HMU
Date ___/___/___ Time ___:____ am/pm
Start of primary treatment
Date ___/___/___ Time ___:____ am/pm
End of primary treatment
Date ___/___/___ Time ___:____ am/pm
Discharge from hospital ___/___/__
Letter to GP sent ___/___/__
Final diagnoses ______________________
____

Working Diagnosis on Referral
CAGE _____
DCI Type I _____ Type II _____
Partial drowning _____
Ommitted decompression _____
Barorauma _____
Non-diving _____

Initial symptoms
No signs or symptoms _____
Pain only _____
Sensory involvement _____
Motor involvement _____
Ataxia _____
Nausea/vertigo _____
Cerebral involvement _____

Clinical progression on admission
Resolved _____
Improving _____
Stable _____
Deteriorating _____

Therapy before admission
Oxygen _____
intravenous fluids _____
steroids _____
Other (detail) ______________________

Presentation at hospital/HMU
Pain site ______________________
Skin involvement .... Y / N
Respiratory involvement ..... Y / N
Neurological involvement .... Y / N
Sensory _____
Motor _____
Bladder/rectum _____
Vestibular _____
Cerebral _____

Primary Treatment
Table 6 no extensions ____
extension at 18 m ____
extension at 9 m ____
Table 4 ____ Table 7 ____ Cx 30 ____
He/O_2 saturation ____ HBO ____

Complication of treatment
Ears ___ Pulmonary ___ CNS ___
Other (detail) ______________________

Response to Primary Treatment
No initial signs or symptoms and no clinical change ___
Complete resolution of signs and symptoms ___
Major improvement in signs and symptoms ___
Moderate improvement in signs and symptoms ___
Slight or no change in condition ___
Relapse after treatment ___
(for treatment of relapse start another form)

Inspired oxygen monitored during treatment Y/N

Investigations
PFO Positive / Negative
Psychometry Positive / Negative
Other: (detail) ______________________
____

HBO sessions given after primary treatment Y/N

Condition on Discharge
Complete resolution ___
Mild pain or sensory residua ___
Residual motor involvement/ataxia ___
Urinary catheter ___
Cerebral residua ___

Follow-up
none required ___
at home ___
return visit required ___
follow-up appointment made Y/N

Technical articles

Oxygen sensor signal validation for the safety of the rebreather diver

Arne Sieber, Antonio L'Abbate and Remo Bedini

Key words
Rebreathers/closed circuit, oxygen, monitoring device, equipment

Abstract

(Sieber A, L'Abbate A, Bedini R. Oxygen sensor signal validation for the safety of the rebreather diver. *Diving and Hyperbaric Medicine*. 2008;38:38-45.)
In electronically controlled, closed-circuit rebreather diving systems, the partial pressure of oxygen inside the breathing loop is controlled with three oxygen sensors, a microcontroller and a solenoid valve – critical components that may fail. State-of-the-art detection of sensor failure, based on a voting algorithm, may fail under circumstances where two or more sensors show the same but incorrect values. The present paper details a novel rebreather controller that offers true sensor-signal validation, thus allowing efficient and reliable detection of sensor failure. The core components of this validation system are two additional solenoids, which allow an injection of oxygen or diluent gas directly across the sensor membrane.

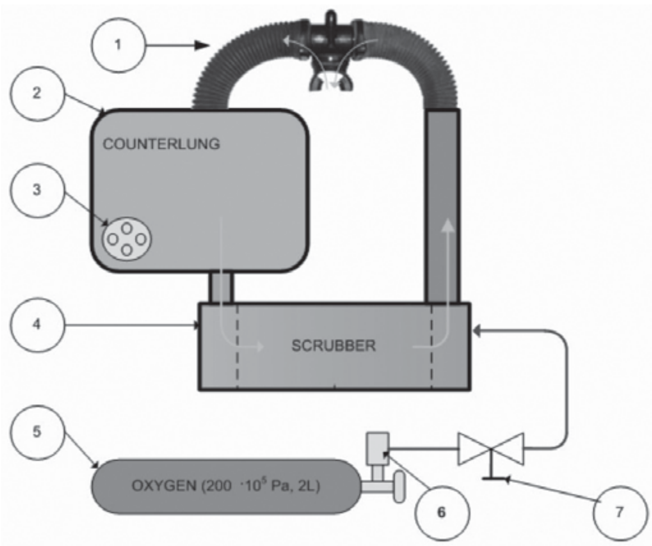
Introduction

REBREATHER SYSTEMS

Closed-circuit rebreather (CCR) diving with its many advantages in comparison to open-circuit diving is becoming increasingly popular.[1] In an oxygen (O_2) rebreather (Figure 1) the diver exhales into a bag – the so called 'counter-lung'.[2] A scrubber removes carbon dioxide (CO_2) and fresh gas is added to replace metabolized oxygen (O_2). This recycled gas is then inhaled by the diver again. In the case of a pure O_2 rebreather, the circuit contains mainly O_2. Thus the partial pressure of O_2 (ppO_2) inside the circuit is dependent on the ambient pressure (Dalton's Law). Such a rebreather has the advantages of maximizing the efficiency of gas usage, and provides bubble-free, silent diving and warm, humid breathing gas. The presently recommended ppO_2 limits for life-sustaining breathing gas range from 0.1 bar (10.1 kPa) to 1.6 bar (162 kPa).* A ppO_2 above this upper limit may lead to acute oxygen toxicity, manifested as an epileptiform convulsion, which is likely to be fatal underwater. A ppO_2 below 0.1 bar (10.1 kPa) will lead to unconsciousness.[3,4] The maximum ppO_2 limit recommended varies from 1.4–1.6 bar, and sets the depth limit for pure O_2 and mixed-gas rebreathers. Rebreathers are classified into either semi-closed-circuit rebreathers (SCR) or manually or electronically controlled closed-circuit rebreathers (mCCR or eCCR).[5,6] In an SCR, O_2-enriched gas enters the breathing loop via a constant flow injector (commonly an orifice, typically 6–12 bar $L.min^{-1}$) to substitute the metabolized O_2 (Figure 1). Excess gas in the circuit is then vented through an overpressure valve. The maximum depth for an SCR is mainly limited by the percentage of O_2 in the supply gas.

In a CCR, the ppO_2 is usually kept at a constant level, only the metabolized O_2 is substituted. In mixed-gas diving, the breathing gas in a CCR contains nitrogen (N_2) or helium (He) or, for deeper dives, a He-N_2 mixture. To maintain the ppO_2 at a constant level, a control loop is needed.[7,8] Therefore, electrochemical oxygen sensors, whose output signals are proportional to the ppO_2, are used as sensing elements. In a mCCR, the diver reads the ppO_2 from a display, then, as necessary, adjusts the O_2 injection needle valve and/or adds O_2 manually. In an eCCR this control task is usually performed by a microcontroller and a solenoid valve.

Figure 1
Schematics of an oxygen rebreather
1: mouthpiece, 2: counterlung, 3: overpressure valve, 4: CO_2 scrubber, 5: oxygen cylinder, 6: pressure regulator, 7: manual valve



Footnote: * In this report, pressure is expressed as bar pressure (1 bar = 0.1013 MPa, 101.3 kPa)

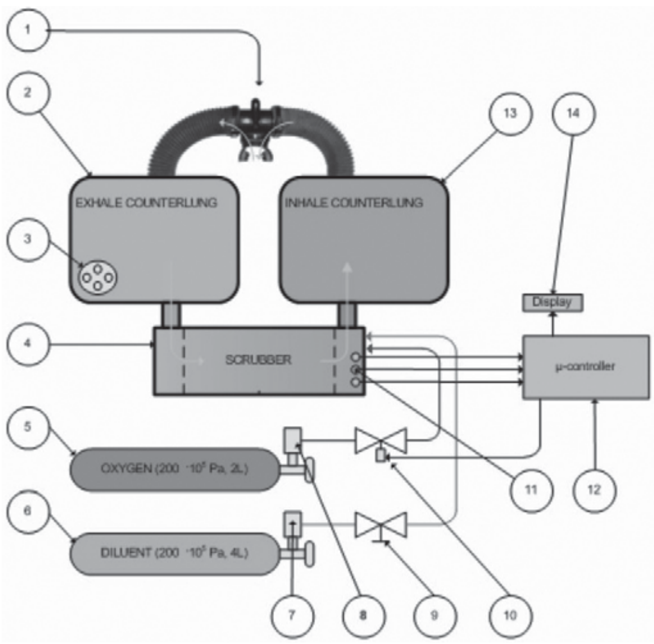
Both types of closed rebreather systems have many advantages:

- Gas efficiency: Open-circuit scuba diving has a low gas utilisation efficiency from less than 5 % on the surface, to below 0.5 % at 100 metres' sea water (msw) depth. In CCRs, because the breathing gas is recycled and, under optimal conditions, only the metabolised O_2 is replaced, gas efficiency may approach 100 %, enabling the design of comparatively small, lightweight systems where gas costs and supply are no longer the limiting factors.
- Silence: CCRs allow bubble-free, silent diving; only during ascent gas is vented from the circuit.
- Warm, humidified breathing gas: Gas from open-circuit scuba is dry and, because of expansion of the gas in the regulator, cold. Cold breathing gas cools the diver and, in very cold water, may lead to regulator malfunction due to freezing. In a rebreather, the breathing gas is usually warm and humid, as the chemical CO_2 absorption produces water and heat as by-products. However, in cold water, scrubber efficiency can also be impaired.

REBREATHER SAFETY

To ensure the safety of the diver, rebreathers sold within the European Union have to be CE-marked (European Normative EN14143:2003),[9] and are classified as Category III Personal Protective Equipment. They must be certified by an independent, certified Notified Body.[10]

Figure 2
Schematics of an electronic closed-circuit rebreather
1: mouthpiece, 2: exhale counterlung, 3: overpressure valve, 4: CO_2 scrubber, 5: oxygen cylinder, 6: diluent cylinder, 7, 8: pressure regulators, 9: manual diluent valve, 10: solenoid, 11: ppO_2 sensors, 12: microprocessor, 13: inhale counterlung, 14: display



Unfortunately there is already a long list of rebreather diving incidents and fatalities.[1,11,12] The most commonly identified systems failures in these deaths are:

- ppO_2 outside of life-sustaining limits
- high CO_2 levels
- water leakage into the breathing circuit.

High CO_2 levels can be avoided by good scrubber design and conservative scrubber management. The latest developments use pre-packed scrubbers, to avoid poor scrubber filling methods that may cause channeling, an important cause of raised CO_2 levels in the breathing circuit. Water leaking into the circuit reacts with the scrubber chemicals, causing the so called 'caustic cocktail'. Some CCRs avoid this by incorporating hydrophobic membranes in the inlet and outlet of the scrubber, that prevent water from entering or leaving.

Figure 2 details the ppO_2 control in an eCCR. A solenoid stuck in either the open or closed positions is a typical failure of the O_2 injection system. A properly trained diver will be able to handle this and other emergency situations. The state of the art for the electronic components is to use redundant design; typically the diver carries two or three independent ppO_2 meters and several displays, the ppO_2 inside the loop depending on the accuracy and reliability of the sensor signals.

O_2 SENSORS

In current rebreathers, galvanic O_2 sensors are used. The core element of a galvanic O_2 sensor is an electrochemical cell ('fuel cell') consisting of two electrodes of dissimilar metals (cathode – a noble metal behind a diffusion barrier, usually of Teflon; anode – lead) in contact with a liquid or semisolid basic electrolyte, usually potassium hydroxide. When the sensor is exposed to the breathing gas, O_2 diffuses through the Teflon membrane and is chemically reduced at the surface of the cathode to hydroxyl ions. The hydroxyl ions then flow toward the lead anode, where an oxidation reaction occurs generating an electrical current proportional to the ppO_2.

In most cases, a resistor is incorporated in the electrical circuit, thus the output from the sensor is measured in mV. Many sensors incorporate temperature compensation in the electronics. Typical specifications for an O_2 sensor for diving purposes are:

- Range: 0–100% O_2, 0–2 bar O_2
- Signal output: 8–13mV @ 0.21 bar O_2 (linear slope: 40–75 mV per bar pressure)
- Response 90%: 6 s

In the reaction with O_2, the anode is consumed, which is the limiting factor determining the lifetime of the sensor, typically 12–24 months.

O_2 SENSOR FAILURES

Typical O_2 sensor failures are:

- non linearity
- current limitation (the output signal of the sensor is limited, thus will remain constant at a certain ppO_2)
- slow signal response
- other sensor failures (mechanical or electrical damage).

The most common failure mode is not achieving the correct electrical output for a given ppO_2. This is due either to exhaustion of the anode or loss of water from the electrolyte solution, resulting in a low reading. The most serious failure is not giving the correct output above a given ppO_2. Exhaustion of the anode surface results in an increase in the response time and then what is called current limitation, voltage limitation, or ceiling fault. Sensors can fail temporarily if the sensor membrane is exposed directly to water. This results in a dramatic increase in the response time and sensor readings that are too low. This problem can be avoided by good design, such as where the sensors are mounted top down, so that water cannot collect on the sensor membrane. Damage of the sensor membrane due to impact shocks may lead to electrolyte leakage, which usually results in an increased current output.

Failure of the electronic components may lead to several problems. Oxygen sensors generate an electrical charge, which is drained via a resistive load; in the case of a failed resistor this charge will build up until current leakage is sufficient to dissipate the charge generated: this can be as high as 100V. With a thermistor failure, the output may vary by up to 2% per degree Celsius. In the case of a shortcut of the resistor, the sensor will produce no output. Other sensor failures that may occur temporarily are current changes caused by fast decompression and He and CO_2 susceptibility.

Non-linearity and current limitation are the most serious failures for a rebreather diver; for example, a current-limited cell may report a ppO_2 of 1.2 bar correctly, but a ppO_2 above this will not be correctly indicated. This is despite calibration with 100% O_2 on the surface showing normal values. This causes injection of more O_2, resulting in a potentially dangerous elevation of ppO_2 inside the circuit outside of life-sustaining limits. For these reasons, multiple, typically three, O_2 sensors are used together with a 'voting algorithm'.[13,14] Here, the sensor signals are continuously compared with each other. If one sensor signal differs from the others, that sensor signal is 'voted out'. In such a case, the two remaining sensors are used for further control of the system and the user is notified with an alarm signal. For example, in the Hammerhead™ CCR electronic (Juergensen Marine, USA) a sensor is voted out if its signal deviates by more than 15% from the average value of the other two sensors. As the voting algorithm is based on a comparison of sensor signals, it will fail when two or more sensors give the same but incorrect signals; this cannot be reliably detected with the voting algorithm. Unfortunately similar concurrent sensor failures do occur, especially when sensors from the same manufacturer and same production lot are used. Rebreather divers have tended to replace all the sensors at the same time with the same type of sensor. This practice is now changing so that sensors from different production lots and/or manufacturers are used and additional checks are performed. Pre-dive preparation currently includes a single-point normobaric calibration with 100% O_2 or air. Since during diving a ppO_2 above 1.0 bar will occur, this is not optimal. Some rebreather divers now pressure test sensors at 1.6 bar to check linearity.

The present work details an alternative to the voting algorithm, in which a novel sensor signal validation concept allows reliable detection of sensor failure and automatic sensor calibration without any interaction by the user.

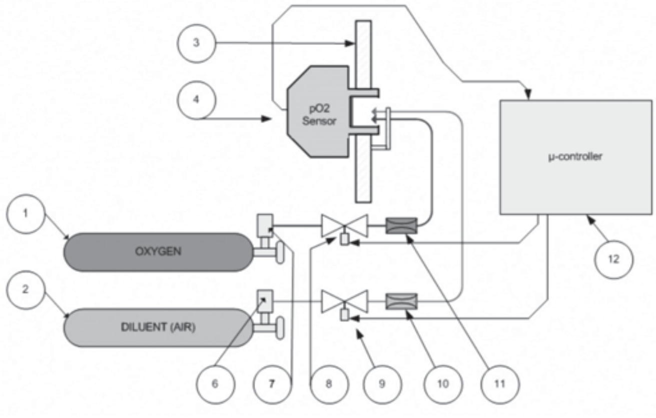
Methods

OXYGEN SENSOR SIGNAL VALIDATION

The principle of the sensor signal validation technique is based on injection of a gas with a known O_2 fraction across the O_2 sensor membrane. As the actual depth is known from the readings of the pressure sensor, the ppO_2 of the injected gas can be calculated. The injected gas flushes the sensor membrane, so that the ppO_2 of the injected gas is read, not that of the breathing gas in the circuit. The sensor readings can then be compared to the theoretically calculated values, confirming whether or not the sensor is working correctly. Any O_2 sensor suitable for diving applications may be used with this sensor validation method.

Figure 3 shows the practical setup of the sensor signal validation apparatus to allow flushing the sensor membrane with O_2 or with diluent. Two solenoids are incorporated for

Figure 3
The principle schematics of the ppO_2 sensor signal validation system
1: oxygen cylinder, 2: diluent cylinder, 3: sensor support, 4: ppO_2 sensor, 5: support for O_2 and diluent injection, 6, 7: pressure regulators, 8, 9: solenoids, 10, 11: flow restriction orifices, 12: microprocessor



the flow control. In some previous CCR units, a similar device to flush the sensor membrane manually with diluent could be found, but frequent cell failures have been reported with this technique. This is likely to be a result of the injection of gas at intermediate pressure (8–10 bar above ambient) directly onto the sensor membrane, possibly shooting moisture drops on the orifice at the sensor at high velocity. To avoid this problem in the new system, orifices with an internal diameter of 140 µm are mounted on the exit of the solenoids reducing the gas velocity at the output and limiting the gas flow to approximately 2 bar $L.min^{-1}$.

Sensor signal validation with diluent is carried out every 120 s (default setting, range 60–255 s). In addition to that, in a depth range of 0–10 msw the same procedure can be carried out with O_2. This allows detection of non-linearity and/or current limitation of the sensor when combined with periodic checks with diluent allowing calibration of the sensor at a ppO_2 greater than 1 bar. By analysis of the signal response the t_{90} response time can be calculated, which also allows recognition of slow response times. The typical duration of flushing the sensor membrane is 6 s, which results in 0.2 bar L of injected gas. Considering a total circuit volume of about 6 L, the signal validation procedure with air causes a decrease of ppO_2 inside the circuit of approximately 0.01 bar; with 100 % O_2, it will lead to an increase of the ppO_2 of 0.016 bar.

The ppO_2 control in the first prototype was designed to keep the oxygen fraction (FO_2) in the circuit constant at 0.50 to a maximum depth of 14 msw. Below that depth, the ppO_2 has a set point of 1.2 bar. If a failure is detected, the diver is notified via an alarm. The diver should then change to an independent bailout system and abort the dive. Theoretically safe operation can be achieved with just one sensor with this sensor signal validation system. However, for redundancy purposes, the first prototypes included two O_2 sensors along with the electronics and the solenoids housed inside the scrubber (Figure 4). In the case of one sensor failure, the dive can be continued. In the case of a failure of both sensors, the diver has to switch to bail out.

ELECTRONICS

Hardware

The core component of the electronics is an 8-bit RISC microcontroller (ATmega 32™, 32kByte flash ROM, 2 Kbyte RAM, Atmel™). A 4x20 characters display (EA DIP 204-4™, Electronic Assembly™, Germany) is connected via a serial peripheral interface (SPI) bus. To enable a detailed post-dive analysis a slot for SD memory cards was incorporated. Three N-FET transistors (NDS355) serve as solenoid drivers.

The microprocessors' internal 10-bit AD-converters are used for sensor signal readout. The programmable gain of 10 and 2000 is sufficient to allow a direct connection of the two sensors (electrochemical pO_2 sensors used in rebreathers typically have a linear output with a slope of approximately 8–13 mV @ 0.21 bar ppO_2). To measure the ambient pressure/depth, two digital pressure sensors (MS5541™, Intersema™, Switzerland) are incorporated. The MS5541 is factory-calibrated for a pressure range of 0–14 bar and has a 15-bit resolution. The maximum working pressure is 33 bar (not specified), and continuous temperature compensation is built in. The sensor is read out via the SPI bus. A rechargeable battery pack (6V, 900mAh, NiMH) is used as power supply for the solenoids. For the electronic components, two low-drop voltage regulators (Texas Instruments) are used for the generation of 3.3 V and 5 V levels.

A second display is used for redundancy purposes.[15] This display has analog inputs and can be connected to the O_2 sensors in parallel with the primary electronics. The core component is again an 8-bit RISC microprocessor (ATmega644p™, 64 Kbyte flash ROM, 4 Kbyte RAM, Atmel). A digital interface line is included, which allows receiving data from the primary electronics (the controller) via a serial interface (either USART or I2C). A graphics display with 128x64 characters is placed behind a concave lens (f = 60 mm, designed for a virtual image distance of 1 m), which allows the display to be mounted directly on the mouthpiece of the rebreather. The two displays show the sensor signal ppO_2 values, depth, central nervous system (CNS) oxygen toxicity percentage, oxygen tolerance units (OTU), diving time and decompression information.

Software

As programming platform, the Atmel AVR Studio 4™, together with the GNU C compiler WinAVR http://winavr.sourceforge.net, was used under Windows XP®. All sensor data are stored on the SD card in spreadsheet format. FAT 16

Figure 4
The two O_2 sensors combined with the electronics and solenoids mounted inside the scrubber in the prototype eCCR; the tubing through which diluent or 100% oxygen can be flushed to perform calibration can be seen

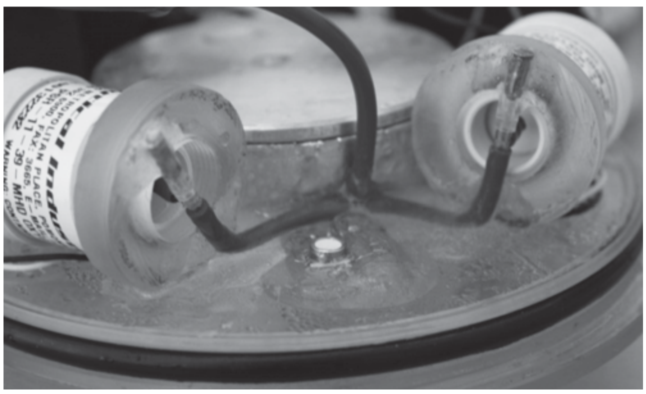
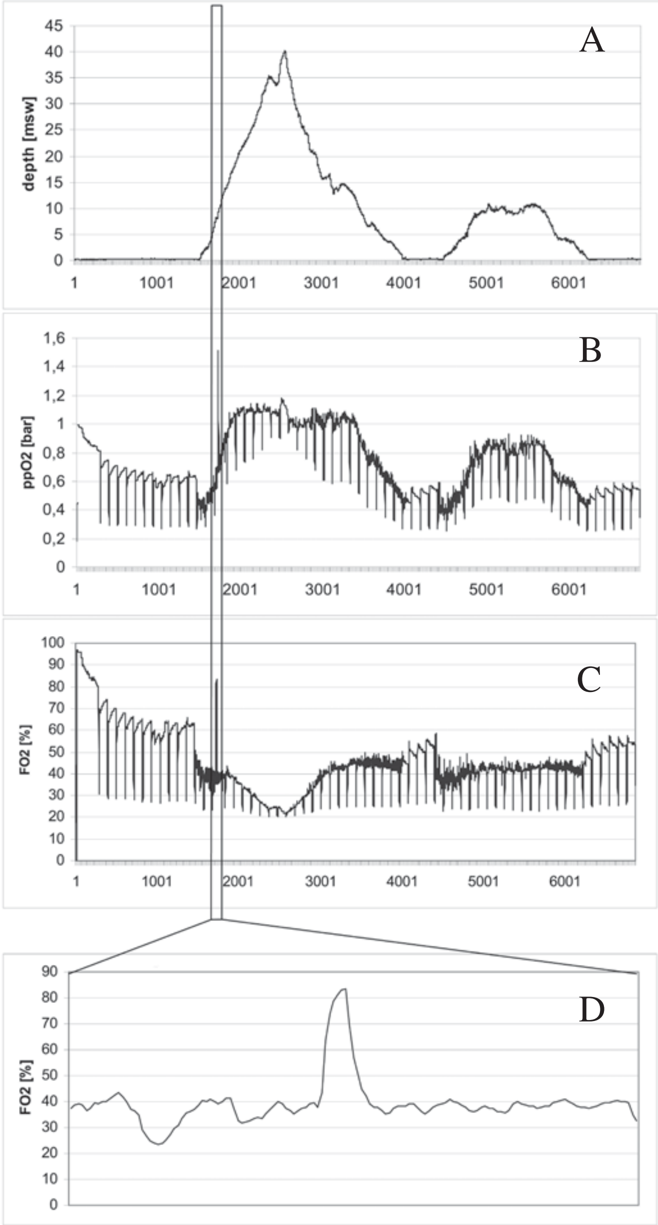


Figure 5
Data from a 100-min open-water test dive to a maximum depth of 40 msw; A: depth profile; B: ppO_2 sensor signals from two sensors; C: calculated FO_2; D: one validation cycle with 100% oxygen at 10 msw



or FAT 32 formatted SD memory cards can be used. For each dive a new file is created. Additional data, such as battery voltage, oxygen injection, oxygen consumption and error messages, are stored. These data can then be displayed with suitable programmes, such as MS Excel® (Figure 5).

Every 120 s, the sensor signal validation procedure, with diluent as the validation gas, is carried out, which results in the spikes in the readings of the ppO_2 sensors (Figure 5B-D shows the signal of one sensor). During the validation cycle the calculated FO_2 must drop to a value less than 0.25; if not, an alarm signal is generated. At a depth between 6 and 10 msw once during a dive, the sensors are checked with 100% O_2 (Figure 5D). Additional validations at depths less than 10 msw may be carried out. Error messages are created if a ppO_2 sensor signal is outside the limits set (see earlier), if the sensor signals differ by more than 0.01 bar from each other, if the battery voltage is below 6.0V and if the calculated O_2 consumption of the diver is less than 0.3 or more than 3 bar $L.min^{-1}$.

As the validation procedure is carried out with two different gases, it is possible to detect incorrect calibration, non linearity and slow sensor response. Because the response time of O_2 sensors is typically about 6 s (t_{90}), at the end of the validation cycle, the sensors will read, at 10 msw depth, a ppO_2 in the range of 1.6–1.9 bar rather than 2.0 bar. During the 6 s, the sensor signal output is measured every second. As the signal response has a single exponential character (the signal response time is mainly limited by diffusion of O_2 through the Teflon membrane), it is possible to forward calculate the final value. To pass the test at 10 msw, the sensors have to read a minimum 1.6 bar ppO_2 at the end of the O_2 injection and the forward calculated signal has to correspond to an O_2 fraction of greater than 90%. If the test is failed, an alarm is created and the dive should be aborted. If, despite the alarm, the dive is continued on closed circuit, for safety reasons the maximum ppO_2 set point is automatically changed to 1.0 bar. The forward calculation is applied only during the checks with 100% O_2, not for calibration or measurement purposes.

Several pre-checks have to be performed before diving with a CCR. To facilitate this, a six-step semi-automated test sequence has been implemented:

1. The user is asked to evacuate the loop of gas.
2. As soon as a pressure drop of −15 mbar is registered, the user is asked to close the mouthpiece.
3. To test for circuit leaks, the negative pressure must not fall to less than −10 mbar within the following 60 s, otherwise the test is failed.
4. After a successful negative pressure test, the loop is inflated with 100% O_2 until an overpressure of 15 mbar is registered. For the inflation, the solenoid valve opens cyclically every second for 200 ms; the cycles are counted. A correctly operating solenoid takes 45 +/− 1 cycles to inflate the counter lungs with a volume of 5 L; 42–48 counted cycles are needed to pass the test.
5. The O_2 sensors are calibrated; readings must be higher than 40 mV to pass the calibration test.
6. In step 4, the loop is inflated to +15 mbar; this pressure must not drop more than 5 mbar in 60 s to pass the test.

After successfully passing all six steps, the unit is ready to dive. If the unit is dived without a correctly passed test an alarm is created and, if the diver is still at a depth less than 6 msw, O_2 sensor calibration is immediately carried out by injection of O_2 for 15–20 s directly onto the sensor membrane. If the diver is already deeper than 6 msw, no calibration will be carried out but the maximum ppO_2

setpoint is automatically limited to 1 bar.

TESTING OF THE SENSOR SIGNAL VALIDATION ALGORITHM

For validation of the algorithm implemented on the microcontroller, a PC-based dive simulator was designed. A sensor signal simulator was developed which could be connected to the PC's printer port. Its core component is a six-channel digital potentiometer (Analog Devices™, AD5206™). Each potentiometer has a nominal value of 10 kΩ and 8-bit resolution. One of the potentiometers is connected in series with a 10 kΩ resistor to a stabilized 5 V direct-current supply for the generation of an output voltage of 0–2.5 V. For simulation of dives, the firmware of the microcontroller was slightly modified. Instead of processing the signal of the digital pressure sensors, depth information is gained from an analog to digital converter channel, by converting input voltages from 0–2.5 V to 0–100 msw depth equivalents. To simulate O_2 sensor signals in the range of 0–128 mV with a resolution of 0.5 mV, three of the potentiometers were each connected in series with a 390 kΩ resistor to the 5 V supply. The microcontroller's output usually driving the solenoids is connected to digital IO pins of a multifunction input/output board (National Instruments™, NI USB-6008™).

A graphical user interface which allows programming of the output voltages of the potentiometers at discrete time steps was developed under National Instruments LabView 7.1™. Simulation of depth profiles together with O_2 sensor signals is possible with different scenarios, such as defective O_2 sensors, being simulated with ease. Signal responses of the sensors to signal validation were pre-programmed to simulate correct function, slow response, current limitation and non linearity.

Two prototypes CCRs were designed and manufactured with the following specifications (Figure 6):

- outer dimension: 45 x 25 x 18 cm
- scrubber holds 1.8 kg of soda lime
- maximum recommended depth 40 msw (unit for recreational purposes)
- 1 oxygen cylinder: 1.5 L, 200 bar working pressure
- 1 diluent cylinder: 1.5 L, 200 bar working pressure
- total weight including cylinders: 12 kg
- maximum dive time: 180 min
- positive buoyancy: 40 N
- two O_2 sensors: PSR-11-39MD (Analytical Industries)

The implemented algorithm for sensor signal validation returns a binary validation result: either a 'correctly' or 'incorrectly' working sensor. If one of the criteria is failed, an alarm is activated.

- Validation with diluent: at the end of the validation cycle, the sensor has to read a ppO_2 corresponding to a FO_2 of less than 25%.

Figure 6
The prototype eCCR being prepared for a dive

- Validation with O_2: at the end of the validation cycle, the sensor has to read a ppO_2 corresponding to a FO_2 of at least 80%. The forward calculated sensor signal for the FO_2 has to be higher than 90%.

The sensor signal validation system was first tested in simulated dives in the laboratory, for which O_2 sensors were not required. These tests simulated O_2 sensor behaviour during normal operations to detect non-linearity, current limitation, slow response times and incorrect calibration. All the simulated sensor failures were correctly detected, validating the correct implementation of the algorithm.

TESTING THE eCCR PROTOTYPES

After laboratory testing, the function of the prototypes was tested in a hyperbaric chamber at a maximum pressure of 405 kPa and a dive duration of 40 min. The main aim of this test was the validation of the principal correct operation of the ppO_2 control and the sensor signal validation method. The second aim was to ensure that the flow rate was high enough to substitute all the gas in front of the sensor membrane with either O_2 or diluent to achieve a defined FO_2. A flow rate of 2 bar $L.min^{-1}$ turned out to be optimal in the current design. No system failures occurred.

Six test dives were also performed in a 10.5 metres' fresh water (mfw) research pool (Divesystem, Massa Marittima, Italy). Tests were carried out with three old sensors known to be current-limited. The faulty sensors calibrated correctly at surface, showed a correct response to the validation with diluent, but failed the validation at 10 mfw depth where their output signal reached just 1.4 bar (threshold was 1.6 bar). The failures were correctly detected.

Fifty-two open-water dives with the two prototype eCCRs were then carried out by three test divers (average depth 28 msw, range 11–52 msw). During all these dives, sensors with an age of less than one year were used. The ppO_2 control worked flawlessly; no dive had to be bailed out on open circuit. During one dive, the handset cracked and the display inside was flooded and failed. The handset cable leading to the main controller is hermetically sealed, thus no water could reach the main electronics. The dive was successfully continued with the dive data still displayed on the head-up display. In one dive, the sensor connector became loose, resulting in a floating sensor reading. The validation with diluent successfully detected this failure and the dive was continued. An example 100-min dive to a maximum depth of 40 msw is shown in Figure 5; no sensor failures occurred and sensor signal validation cycles with O_2 and diluent (air) were successfully carried out. The present concept of ppO_2 sensor signal validation has now been incorporated into a new eCCR, the Poseidon Discovery™ MK6 rebreather.

Discussion

Like the state-of-the-art voting algorithm, the sensor signal validation method described allows reliable detection of single sensor failures. In addition to this, and unlike the voting algorithm, failures where more than one sensor shows incorrect readings can be reliably recognized. The thresholds for passing the validation procedures were found empirically. The detection of all simulated sensor signal failures proved the correct implementation of the algorithm.

As the method is based on flushing a sensor membrane with a gas with a known O_2 fraction, an interesting case is when the FO_2 in the loop is close to the FO_2 in the diluent. During validation with diluent, no sensor signal changes should occur. Safe operation of a CCR requires a diluent with a FO_2 lower than the FO_2 in the loop, thus such a case should not occur during normal operation. In the first prototype, this scenario was not investigated.

O_2 sensors have to be replaced every 1–1.5 years. By using just one or two sensors instead of three, the yearly maintenance costs are reduced without compromising safety. However, this is offset by the need for additional hardware (two solenoids plus electronics), resulting in higher production costs.

Current limitation does not appear suddenly; it is a result of the aging of the sensor. Depending on the thresholds in the O_2 validation procedure, such a sensor will, sooner or later, be recognized as faulty. Further investigation is needed with a larger batch of O_2 sensors in order to validate and adjust the thresholds for such detection to find a good compromise between conservativeness and cost effectiveness.

Conclusions

The present paper describes a novel system for sensor signal validation and reliable sensor failure detection based on flushing the sensor membranes with a gas with a known fraction/ppO_2. Injection of 100% O_2 directly onto the sensor on the surface is used for initial calibration. Then in water up to 10 msw depth, 100% O_2 is used again to expose the sensors to a ppO_2 of up to 2.0 bar. Both current limitation and non-linearity are detected with this two-point calibration; these sensor failures do not occur temporarily, thus a single check early in the dive is sufficient. Recording the response signal of the sensor to O_2 injection also allows estimation of the sensor signal response time.

In principle, this concept allows safe operation of an eCCR with a single O_2 sensor, where, in the case of a failure, the diver must bail out of the dive. This is acceptable for a recreational unit intended for use for non-decompression dives. For more advanced diving, a second O_2 sensor should be used.

CCR diving requires continuous training and technical understanding of the equipment so that the diver is able to detect and safely handle malfunctions of the system The validation system described in this paper facilitates rebreather handling, as the system itself is able to carry out pre-dive O_2 sensor calibration and sensor signal checks semi-automatically. Reliable automation of safety checks in an eCCR is an important step to enabling recreational divers to dive more safely using these breathing systems.

Acknowledgements

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Malfunction of the Siaretron 1000 Iper™ hyperbaric ventilator

Pieter A Bothma, Andreas Brodbeck and Uday Bapat

Key words
Ventilators, equipment, hypoxia, barotrauma, safety, hyperbaric facilities

Abstract
(Bothma PA, Brodbeck A, Bapat U. Malfunction of the Siaretron 1000 Iper™ hyperbaric ventilator. *Diving and Hyperbaric Medicine*. 2009;39:45-7.)
Introduction: Patient ventilators for use in the hyperbaric chamber need to be of special design; any malfunction could have disastrous consequences. We report two serious problems with a recently purchased Siaretron 1000 Iper™ ventilator.
Methods: The ventilator was tested with a Biotek VT-Plus™ gas flow analyzer, which also measures O_2 concentration. The changes in fraction of inspiratory oxygen (FiO_2) were verified with a Teledyne Electronic Devices™ O_2 analyzer.
Results: In volume control ventilation (VCV) mode: excessively large tidal volumes were delivered when the fraction of inspiratory oxygen (FiO_2) was changed.
In pressure control ventilation (PCV) mode: changing the FiO_2 setting did not change the FiO_2 delivered by the ventilator. The ventilator also exhibited an irregular flow pattern in PCV.
Conclusions: These problems may cause serious diagnostic and clinical consequences if not identified as equipment malfunction issues. A malfunction of the integrated memory in the microchip on the main board was said to cause the PCV malfunction. The manufacturer replaced the main board, which corrected the problem. The solution offered for the VCV problem was to change FiO_2 in steps of 0.1 per breath, which eliminates the tidal volume surges. We feel it is extremely important that all users of the Siaretron 1000 Iper™ are made aware of these problems as they are not described in the user manual or elsewhere.

Introduction

The design of equipment for critically ill patients in the hyperbaric environment tests engineers and manufacturers to the limit.[1,2] For a long time, existing transport or intensive care ventilators (or modified versions thereof) have been used with reasonable success. These are all affected variously by the hyperbaric environment and many are no longer supported technically and or spare parts are no longer available.[3] One such earlier generation ventilator, the Iper 60VF, has been developed further and is one of only two CE (Conformité Européenne or European Conformity) certified hyperbaric ventilators on the market as the Siaretron 1000 Iper™ (Figure 1).[4] It is described as "*an electropneumatic ventilator which has automatic compensation of the volume delivered up to pressure of 7 ATA measured by a special absolute pressure transducer. The ventilator can operate in IPPV, PSV, SIMV and CPAP modes and it has alarms for high and low airway pressure. The user can set the oxygen concentration (between 21% and 99%) as well as I:E ratio. The ventilator is supplied by the air and oxygen having pressure at 3.5 bar higher than pressure in the chamber. The electronic circuit is powered by low voltage batteries (2x6V) granting autonomy of about 3 hours*".[5]

As this ventilator has received a lot of interest internationally, we report here initial experiences with a recently purchased unit that did not perform satisfactorily. We recognised there were problems when an Ohmeda 5410™ volume monitor was used during testing prior to putting the ventilator into service. It was noticed that the tidal volume increased by up to 100% when changing FiO_2 from 1.0 to 0.21. It was realized that more thorough testing was required.

Methods

We tested the ventilator with a Siemens™ test lung 190, 1L and then with a Biotek VT-Plus™ gas flow analyzer. This apparatus also measures O_2 concentration after an automatic calibration in room air and 100% O_2. In addition, a Teledyne Electronic Devices™ O_2 analyzer (calibrated manually at FiO_2 0.21 and 1.0) was incorporated into the circuit to confirm the findings (see Results). All measurements were done at atmospheric pressure as none of this equipment is certified as safe under hyperbaric conditions.

Results

VOLUME CONTROL VENTILATION (VCV)

It was found that, on changing the FiO_2 setting, the ventilator delivered one or two large tidal volume breaths. The magnitude of this increase varied from 30% to 100% above the set volume and occurred both when increasing and decreasing the FiO_2. This could lead to volutrauma or barotrauma unless the high airway pressure limit has been set to safe levels, which in our practice is 20% above baseline.

PRESSURE CONTROL VENTILATION (PCV)

Changing FiO_2

Changing the FiO_2 setting did not change the FiO_2 delivered by the ventilator while in PCV mode. Attempting to decrease it was extremely slow, lasting 5 to 10 minutes to decrease from 1.0 to 0.9 and inadequate to be of practical use. Changing the FiO_2 setting from 0.21 to 1.0 did not change the delivered FiO_2 at all. Both these malfunctions pose serious clinical problems, with the latter obviously a major risk to the patient.

Because we were initially concerned that the O_2 analysis was erroneous, the circuit was interrupted to add the Teledyne O_2 analyzer. On reconnecting the circuit, the FiO_2 immediately changed in the appropriate fashion. This was reproduced repeatedly, i.e., with the circuit closed the FiO_2 would not change, but interrupting the circuit for a few seconds would correct the problem.

Irregular flow pattern

It was also found that the flow pattern in PCV was irregular, and particularly bad with the FiO_2 in the 0.21 to 0.5 range. A saw-tooth pattern was seen throughout the ventilator cycle, but most prominent during the plateau phase. We termed this 'sobbing' ventilation: when connected to the test lung it resembled the breathing pattern of a sobbing child. In VCV the pattern was smooth and acceptable.

We tested a second unit of the same model ventilator from another UK-based hyperbaric unit and found the same problems, except a slightly less irregular, 'sobbing' flow pattern was observed.

Discussion

RESOLUTION OF PCV PROBLEMS

The ventilator was returned to the manufacturer and we reported the problem to the Medicines and Healthcare products Regulatory Agency (MHRA) in the UK. A malfunction of the integrated memory in the microchip on the main board was diagnosed and the main board was replaced. On its return, the ventilator was re-tested as before. Both the problems in PCV had been eliminated.

The failure of FiO_2 to revert back to 1.0 at the end of an air break could lead to hypoxia in certain patients with impaired oxygenation, and or negate the beneficial effects of hyperbaric oxygen therapy. If this problem is not identified, the resulting decreased oxygenation could be ascribed to patient factors with increasing positive end expiratory pressure (PEEP) being introduced or a pneumothorax being suspected.

RESOLUTION OF VCV PROBLEMS

The manufacturing company, Siare, based in Italy, advised us not to change the FiO_2 setting in steps of more than 0.1.

Figure 1
Siaretron 1000 Iper™ ventilator

We have found that changing FiO_2 in steps of 0.1 (and even 0.2) per breath, is well tolerated by the ventilator and avoids surges in tidal volume. Thus, switches in FiO_2 should be achieved over four to eight breaths to avoid this problem. Hopefully the company will have a better solution in time.

In the meantime, training is very important to make all staff aware of the importance of setting the high airway pressure limit to 20% above baseline pressure and of changing FiO_2 in steps of 0.1 or 0.2 at most. Careful monitoring of ventilation should also be used, as for example in the measurement of end tidal carbon dioxide, spirometry, or transcutaneous pO_2 and pCO_2 and, of course, monitoring of the cardiovascular system. We have attached a laminated warning notice to the ventilator.

We made enquiries from colleagues elsewhere, known to use this model of ventilator, but nobody had noticed similar problems. Given that a loaned second unit demonstrated the same problems, this may not be an isolated finding. All hyperbaric facilities using the Siaretron, (or indeed, any other make or model of mechanical patient ventilator) should fully test their ventilator(s) before placing one into clinical service.

Further testing under hyperbaric conditions is required.

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The new journal e-mail address is: <editor@dhmjournal.com>

Letter to the Editor

Australian scuba diving fatalities and decompression sickness: erratum and further analysis

Dear Editor,

I am writing to clarify some points made in my recent article on Australian scuba diving fatalities and decompression sickness in *Diving and Hyperbaric Medicine*.[1] First, I wish to point out a publishing error in Table 4. The rate for DAN America Members was 11–18 deaths per 100,000 Members and not per 100,000 dives as shown in Table 4. A corrected version of these data is shown in Table 1.

When assessing the risk of death of divers in Australia, I used the combined results of two different survey modes, one for Australian residents and the other for overseas visitors, to yield a total number of dives for Australia. Although this was the only way I could see of trying to roughly estimate a general rate for Australia, I am aware, and should have stated in the Discussion, that this method can sometimes provide unreliable results due to the different methods of data collection. A more reliable result, albeit not a general rate, can be achieved by calculating the incident rate separately for residents and visitors rather than combining them. This would have given estimates of 0.7 deaths per 100,000 dives for residents (95% CI 0.3, 1.5) and 0.4 per 100,000 dives for visitors (95% CI 0.1, 1.2), rather than the combined 0.57 per 100,000 dives reported.

As pointed out to me by some colleagues at DAN America, given that some of the visitors may have dived elsewhere during the period and died in a dive accident outside Australia, it would have been more appropriate, when reporting a per person rate, not to combine visitors with Australian divers and to use deaths per visitor rather than deaths per diver for the international data. The same observation applies to the data previously reported from Stoney Cove, where the authors reported a rate per diver rather than a rate per visitor.[2] In this case, the estimates would better have been reported as 8.5 per 100,000 resident divers (95% CI 4.2, 17.5) and 1.5 per 100,000 *visitors* (95% CI 0.5, 4.3).

Where I separately estimated the individual fatality rates for Queensland and Victoria based on surveys in those States, I should have pointed out in the Discussion that inaccuracies can be introduced as different methods were used to determine the denominators. To better compare the relative rates between places, it is useful to view the 95% confidence intervals as shown in Table 1. As can be seen, when one considers the potential variation in these rates, there is no discernable difference.

I am grateful to my colleagues at DAN America, Petar Denoble and Richard Vann, for their input.

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Key words
Diving deaths, scuba diving, data, epidemiology, letters (to the Editor), erratum

Table 1
Global risk estimates for scuba diving fatalities

Group analysed	Deaths per 100,000 dives	95% CI	Deaths per 100,000 divers or visitors	95% CI
Australian residents	0.7	0.3, 1.5	8.5	4.2, 17.5
Australian visitors	0.4	0.1, 1.2	1.5	0.5, 4.3
DAN America members	–	–	11–18	–
UK divers	0.8	0.5, 1.3	–	–
Okinawa divers	1.3	0.3, 7.2	–	–
Stoney Cove visitors	–	–	2.9	1.4, 6.0

Editor's note:
We apologise to Mr Lippmann for the incorrect representation of some of the data in Table 4 of his paper.

Erratum

The following statement was missing from the bottom of Table 1 of the Diving accident guidelines of the German Society for Diving and Hyperbaric Medicine: summary version (*Diving and Hyperbaric Medicine*. 2008;38:151.):
* These symptoms can also be indicative of DCS type II or AGE

Book review

Hyperbaric medicine practice, 3rd edition

Kindwall EP, Whelan HT, editors

Hard cover, 606 pages
ISBN 978-1-4160-3406-3
Philadelphia, PA: Saunders Elsevier; 2008
Price: US$189.00 plus postage
Copies may be ordered through Best Publishing Company, 2355 North Steves Boulevard, PO Box 30100, Flagstaff, AZ, USA 86003-0100
<www.bestpub.com>
Phone: +1-928-527-1055
Fax: +1-928-526-0370

My reluctance to read a textbook cover-to-cover persists virtually unabated from medical school and my procrastination genes still function quite admirably (they, after all, have a tertiary education too). Having said this, I found myself quite surprisingly engaged when the occasion arose to open the whopping 1,076 pages comprising the third edition of *Hyperbaric Medicine Practice* by Kindwall and Whelan. As my first complete perusal through a hyperbaric medicine (HBM) textbook ever, it was without doubt an eye-opening and learning experience.

The book is infinitely readable. While styles vary, as is inevitable when chapters have a variety of authors, for the most part the language flows harmoniously, the rhythm follows the inoffensive tempo of lounge music and the lyrics are clear, concise and easy to follow. This book would almost certainly suit the first-time reader to HBM. It does not delve too deeply into the intricacies of physics, physiology or decompression theory, yet it paints a detailed landscape of who we are and why we do what we do as hyperbaric practitioners. As the name suggests, this certainly is a ‘practical’ guide to delivering a medical service.

The book is well bound but physically heavy, as is attested to by the dirty look from the customs official as I tried to slip it innocuously into my carry-on baggage. The pages have a sheeny reflecting quality that can be annoying in some lights. The typeface is large enough to be comfortable and graphs and tables are produced in a reader-friendly format. Subject subheadings tend to get a little lost on occasions, but each chapter is furnished with an overview page, which is helpful here. Typographical errors are rare, probably fewer than one per chapter. On occasion they even provide some amusement as “several” [severed] limbs are reattached and cardiologists spell-check their way to providing “stints” rather than ‘stents’ for their patients.

The book is organised into three sections: hyperbaric oxygen – general considerations, disorders approved for hyperbaric treatment, and hyperbaric oxygen used in ‘off-label’ disorders and investigational areas. A wide swathe of sub-specialty experts have been gathered in to author chapters, on occasion the most recognised publisher in the field is found summarising their own work. Authors, in general, tend to take one of two approaches to their subject matter, either they cover the topic in a general broad format or they present sequential summaries of the published work within the field. While the latter approach gives a more comprehensive view of ongoing research, the overall picture can sometimes lack cohesion. In comparison, the broad format can leave the educated reader with the feeling that perhaps some detail or evidence is missing. In several chapters, the blend between these approaches hits exactly the right note; in others, authors do a remarkable job with the paucity of clinical and research evidence that exists.

The first section of the book is a blatant reminder that this publication is specifically targeted to an American audience. Units are Imperial rather than decimal or SI units, and drug names and dressing types unfamiliar, though we have doubtless used them otherwise branded. While it is fascinating to compare the bureaucracy between nations, the qualification specifics and codes of practice bear little relevance to an Australasian (or European) audience. An entire chapter on the economics of HBM concentrating on the USA medical insurance industry, reminds us that our Australian health system, despite its obvious flaws, is still something to be proud of.

The chapters on complications from hyperbaric therapy cover preventative strategies well but could perhaps be supplemented with more on incidence, management and outcomes. The highlights of this section include overviews on children in the hyperbaric environment and approaching chronic wounds. The guide to managing a critically ill patient in a monoplace chamber is so comprehensively written that, should some English-speaking alien culture invade a cataclysmic earth to find only a copy of this chapter, one monoplace chamber and a critically ill necrotising fasciitis patient, at least one human would survive to tell the tale (provided, of course, the aliens had sufficient intensive care clinical management skills, as the authors so thoughtfully emphasise!).

The second section of the book does a very good job of covering conditions for which hyperbaric oxygen use is sanctioned and funded within the American system. This includes our usual suspects – decompression illness, gas embolism, gas gangrene and other necrotising soft-tissue infections, radiation damage, diabetic ulcers, acute traumatic ischaemias, and also some conditions not seen or treated routinely in Australasia – burns, intracranial abscess, sternal wound dehiscence, and skin grafts and flaps. The third section covers some more controversial indications such as stroke, multiple sclerosis, cerebral palsy, acute myocardial infarction, femoral head necrosis and traumatic brain injury. It is gratifying here to see a rational and balanced analysis of the relevant research, especially in the face of the non-evidence-based practice that haunts the reputation of our field. The historical account given in the chapter on Hansen's disease is nothing short of fascinating both from a clinical and sociological perspective.

I will admit to being a little disappointed with some aspects of this book. The reference formatting is diabolical. There is no uniformity between approaches with some authors listing references alphabetically, some in order of usage and others obviously just tacking a few recent references onto the ends of their previously well-settled lists. In many chapters, the most recent reference quoted is 10 to 20 years old and this begs the question as to how much revision has been done between this and previous editions.

While references cited are often extensive they are by no means comprehensive. Using the chapter on decompression illness as an example, it becomes obvious there is a difference of opinion between the UHMS and SPUMS fraternities. Not one single reference from the *SPUMS Journal* can be found. The use of NSAIDs is not mentioned and lignocaine is simply written off as having insufficient evidence to support it. However, on the next page the author goes on to recommend use of glycerol and digitalis from single patient anecdotes, driving home the message that at some points this text slips from evidence-based medicine into opinion-based practice. While there is no debate that experiential medicine has worth, the exclusion of the only randomised controlled and blinded trial in the treatment of decompression sickness (of NSAIDs) does sit as a reminder to us of the need to promote our journal and research onto the international (or should I say American) stage.

Provided that the reader is willing to expand his knowledge with other texts and reviews, I would have no trouble in recommending this textbook, especially to the initiate in the field of hyperbaric medicine.

Karen Richardson
Registrar in hyperbaric medicine, The Alfred Hospital, Melbourne

SPUMS notices and news

South Pacific Underwater Medicine Society Diploma of Diving and Hyperbaric Medicine

Requirements for candidates (updated October 2008)

In order for the Diploma of Diving and Hyperbaric Medicine to be awarded by the Society, the candidate must comply with the following conditions:

1 The candidate must be medically qualified, and be a current financial member of the Society of at least two years' standing.
2 The candidate must supply evidence of satisfactory completion of an examined two-week full-time course in Diving and Hyperbaric Medicine at an approved facility. The list of approved facilities providing two-week courses may be found on the SPUMS website.
3 The candidate must have completed the equivalent (as determined by the Education Officer) of at least six months' full-time clinical training in an approved Hyperbaric Medicine Unit.
4 The candidate must submit a written proposal for research in a relevant area of underwater or hyperbaric medicine, in a standard format, for approval *before* commencing their research project.
5 The candidate must produce, to the satisfaction of the Academic Board, a written report on the approved research project, in the form of a scientific paper suitable for publication. Accompanying this written report should be a request to be considered for the SPUMS Diploma and supporting documentation for 1–4 above.
6 In the absence of documentation otherwise, it will be assumed that the paper is submitted for publication in *Diving and Hyperbaric Medicine*. As such the structure of the paper needs to broadly comply with the instructions to authors – full version, published in *Diving and Hyperbaric Medicine* 2008; 38(2): 117-9.
7 The paper may be submitted to journals other than *Diving and Hyperbaric Medicine*; however, even if published in another journal, the completed paper must be submitted to the Education Officer for assessment as a Diploma paper. If the paper has been accepted for publication or published in another journal, then evidence of this should be provided.
8 The Diploma paper will be assessed, and changes may be requested, before it is regarded to be of the standard required for award of the Diploma. Once completed to the reviewers' satisfaction, papers not already accepted or published in other journals will be forwarded to the Editor of *Diving and Hyperbaric Medicine* for consideration. At this point the Diploma will be awarded, provided all other requirements are satisfied. Diploma projects submitted to *Diving and Hyperbaric Medicine* for consideration of publication will be subject to the Journal's own peer review process.

Additional information – prospective approval of projects is required

The candidate must contact the Education Officer in writing (e-mail is acceptable) to advise of their intended candidacy, and to discuss the proposed subject matter of their research. A written research proposal must be submitted before commencing the research project.

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

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

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

The Academic Board reserves the right to modify any of these requirements from time to time. As of October 2008, the SPUMS Academic Board consists of:
Associate Professor David Smart, Education Officer
Associate Professor Mike Davis
Dr Simon Mitchell.

All enquiries and applications to the Education Officer:
Associate Professor David Smart
GPO Box 463, Hobart, Tasmania 7001
E-mail: *<david.smart@dhhs.tas.gov.au>*

Key words
Qualifications, underwater medicine, hyperbaric oxygen, research, medical society

Notice of SPUMS Annual General Meeting 2009

The AGM for SPUMS 2009 will be held at Snorkelers Cove Resort, Iririki Island, Vanuatu, at 1730hr, Wednesday 27 May 2008.

Agenda

Apologies:
Minutes of the previous meeting:
Minutes of the previous meeting will be posted on the notice board at Snorkelers Cove Resort and were published in *Diving and Hyperbaric Medicine.* 2008; 38 (4): 224-7.
Matters arising from the minutes:
Annual reports:
President's report
Secretary's report
Educations Officer's report
Annual financial statement and Treasurer's report
Journal Editor's report
Presidents' Committee report
Subscription fees for 2010:
Proposed by the Treasurer, seconded by the Secretary: To remain unchanged from the 2009 fees:
Full members AUD $150 (internet transaction); AUD $170 (manual/paper-based transaction). Associated/retired/medical student members AUD $80 (internet transaction); AUD $100 (manual/paper-based transaction).
Call for expressions of interest for position:
Public Officer (must be a Victorian resident)
Election of office bearers:
Treasurer
Committee Members (2)
Appointment of the Auditor 2009:
Proposed by the Treasurer, seconded by the Secretary: Barrett, Baxter and Bye, 60 Albert Road, South Melbourne 3205
Business of which notice has been given:
The SPUMS diving medical: recent review and implementation
The SPUMS Membership promotion package

Nominations for office bearers and expressions of interest for the Public Officer position are to be forwarded to the Secretary by **17 May 2009**.
Notice for other business must be received in writing to the Secretary by **31 April 2009**.

Education Officer's report, March 2009

I am pleased to report in 2008 the following SPUMS members successfully completed their SPUMS diplomas:

Sean Hopson – Intravenous infusions in hyperbaric chambers: effect of compression on syringe function
Dan Rainolds – Blinding the blinded – assessment of the effectiveness of a sham treatment in a multiplace hyperbaric chamber trial
Karen Richardson – Diving expedition medicine: the Coral Cay experience
Mark Edsell – The use of hyperbaric oxygen therapy in the treatment of skin ulcers due to calcific uraemic arteriolopathy: experience from an Australian hyperbaric unit
Graham McGeoch – Analysis of a complex scuba diving accident – French Pass 2000
David Cooper – Hyperbaric chamber attendant safety. Doppler analysis demonstrates low levels of decompression stress in multiplace chamber attendants

The SPUMS Diploma continues to stimulate high quality and diverse research in diving and hyperbaric medicine. Congratulations to the above successful candidates.

Associate Professor David Smart

Key words
Qualifications, medical society, underwater medicine, hyperbaric oxygen, research

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Minutes of the SPUMS Committee Meeting 28th May 2008 at Liamo Resort, Kimbe Bay, Papua New Guinea

Opened: 1914 hr

Present: M Bennett (President), G Williams (Treasurer), C Acott (Immediate Past President), S Lockley (Secretary), V Haller (Public Officer), M Davis (Editor DHM Journal), R Walker (Previous Committee Member/Past President)

Apologies: D Smart (Chairperson ANZHMG), S Sharkey (Committee Member), S Squires (Committee Member), G Hawkins (Committee Member)

1 Minutes of previous meeting
Minutes accepted for Executive Committee Meeting, Holiday Inn Melbourne Airport, held 04 Nov 07 (Proposed: C Acott, Seconded: G Williams)

2 Matters arising from previous minutes
2.1 No specific issues were followed up from previous minutes, except for those addressed in the individual reports.

3 ASM 2009
3.1 Further discussion regarding location. Dr D Smart not present; however, further information required regarding safety concerns and travel restrictions if meeting in Fiji. Action: Dr M Bennett to discuss further with Dr D Smart and Dr R Walker regarding specific safety issues and threat level.

3.2 Letter from Dr M Davis to Dr S Sharkey raising personal concerns in regard to Fiji as 2009 ASM location. Action: Locate correspondence.

4 ASM 2010

4.1 Location and ASM not discussed. Dr G Hawkins not present.

4.2 Discussed possibility of combined meeting with Asia Hyperbaric and Diving Medical Association, in South East Asia. Action: To discuss further at next Committee Meeting.

5 ASM 2011

Recommended to add ASM 2011 to the agenda for next Committee Meeting.

6 Treasurer's report

6.1 Request made by Dr M Davis that Financial Statement goes into AGM Minutes.

6.2 Report given by Dr G Williams. Signatories on bank account need to be changed. Current signatories are: Dr G Williams; Dr V Haller; Dr C Acott and Dr S Sharkey. Proposed that Dr C Acott be replaced by Dr S Lockley on list of account signatories. Committee agreed.

6.3 Proposed that credit cards will be acquired for SPUMS expenditures over the next months, and will be held by Dr G Williams, Dr M Davis and Dr S Lockley. This was agreed to by the Committee.

6.4 Reported that EUBS has not yet paid for March journal. Account mailed only one week prior to sending out journal. Action: Dr G Williams to determine on RTA if funds have been deposited by EFT to SPUMS account.

7 Journal report

7.1 Main report as presented at AGM.

7.2 Proposed Editorial Board to be approached and includes Drs D Smart and M Bennett.

7.3 Dr M Davis continues to work on a four-year-old contract. Legal aspects need to be investigated and include work cover and superannuation if position is to be altered.

7.4 Noted that formalisation of the relationship between the Editorial Board and SPUMS needs to occur.

7.5 Commercial advertising policy needs to be developed. It was proposed that the journal needs to have advertising for income generation. Action: Dr M Davis to provide information to Dr S Lockley in this regard.

7.6 Dr M Davis needs to download Adobe programmes on to his own computer for Journal and SPUMS work at a cost of approx $1,000 to allow ongoing editing. This was approved by the Committee.

7.7 A replacement editorial assistant will need to be identified and employed as the previous editorial assistant, Sarah Webb, has resigned.

7.8 Special thanks given to Sarah Webb for much appreciated work as editorial assistant, by Dr M Davis.

8 Education Officer's report:

Dr F Sharp (outgoing Education Officer) was not present to discuss composition of Education Committee. This will require follow up by Dr D Smart, incoming Education Officer. Ongoing.

9 Correspondence

No correspondence was discussed.

10 Other business

10.1 Dr P Mueller (representing the German Society) presented a proposal requesting that the German Society Diving Medicine Diploma be granted formal recognition by SPUMS so that doctors who are members of EUBS holding a German Society Diploma can perform diving medicals that are recognized within Australia.

10.1.1 Discussed what guidelines would be utilized.

10.1.2 Committee discussed the need to reassess European courses to determine what equates to Level 1 and Level 2 trained diving doctors.

10.1.3 Discussed potential for European doctors to be added to the SPUMS Diving Doctor list providing they have completed the appropriate courses and are a member of EUBS or SPUMS.

10.1.4 The German Society has also offered to participate in the online diving database. Proposed that a joint venture allowing EUBS and SPUMS members to access a combined database would increase access to resources for all members.

Action: Dr G Hawkins and Dr M Davis to liaise to arrange sharing access to database. New item to be added to agenda of next committee meeting to address reevaluation and accreditation of all Diving Medicine Courses currently endorsed by SPUMS.

10.2 Constitution

The constitution is to be circulated to all committee members and agreement to be reached regarding accepted constitution, over the next months.

10.3 ASM convenor manual update.

The outgoing president Dr C Acott, will update the Convenor's Manual with new ideas from 2008 ASM.

10.4 New members.

Member survey/research required to identify potential new members and explore demographics of current membership. Action: Proposed to add this as an agenda item to next AGM.

10.5 SPUMS Diploma requirements and accreditation.

Request by Dr M Bennett that this be added as an agenda item for discussion at the next committee meeting.

10.6 Proposed amendment to SPUMS Medical

10.6.1 Proposed by Dr M Bennett that the Committee meet in 3 to 5 months to discuss draft of guidelines.

10.6.2 Additional experts ("invited guests") were proposed as attendees and include Dr R Walker, Dr S Mitchell, Dr P Thomas (Respiratory Physician), Dr C Meehan, Dr M Cohen (Diabetes Specialist) and Dr Andy Veale (Respiratory Physician).

10.6.3 Initially draft of medical to be sent to all committee members. Secretary to liaise with all relevant parties to arrange time for a follow-up meeting. Draft of medical also to be circulated to "invited guests" prior to the proposed meeting.

10.6.4 Initial meeting to be followed by meeting with lawyer to provide advice on formalization of guidelines and implementation. Advice from medical insurers will also need to be sought.

10.6.5 Discussed the issue that stakeholders will need to be appropriately informed of the new guidelines once these have been implemented.

11 Next meeting

The next committee meeting is planned for the end of the year (September/October).

Closed: 2044 hr

ANZCA Certificate in Diving and Hyperbaric Medicine

Eligible candidates are invited to present for the examination for the Certificate in Diving and Hyperbaric Medicine of the Australian and New Zealand College of Anaesthetists.

Eligibility criteria are:

1 Fellowship of a Specialist College in Australia or New Zealand. This includes all specialties, and the Royal Australian College of General Practitioners.

2 Completion of training courses in Diving Medicine and in Hyperbaric Medicine of at least 4 weeks' total duration. For example, one of:
  - a ANZHMG course at Prince of Wales Hospital Sydney, **and** Royal Adelaide Hospital or HMAS Penguin diving medical officers course **OR**
  - b Auckland University Diploma in Diving and Hyperbaric Medicine.

3 **EITHER:**
  - a Completion of the Diploma of the South Pacific Underwater Medicine Society, including 6 months' full-time equivalent experience in a hyperbaric unit and successful completion of a thesis or research project approved by the Assessor, SPUMS
  - b **and** Completion of a further 12 months' full-time equivalent clinical experience in a hospital-based hyperbaric unit which is approved for training in Diving and Hyperbaric Medicine by the ANZCA.

  OR:
  - c Completion of 18 months' full-time equivalent experience in a hospital-based hyperbaric unit which is approved for training in Diving and Hyperbaric Medicine by the ANZCA
  - d **and** Completion of a formal project in accordance with ANZCA Professional Document TE11 "Formal Project Guidelines". The formal project must be constructed around a topic which is relevant to the practice of Diving and Hyperbaric Medicine, and must be approved by the ANZCA Assessor prior to commencement.

4 Completion of a workbook documenting the details of clinical exposure attained during the training period.

5 Candidates who do not hold an Australian or New Zealand specialist qualification in Anaesthesia, Intensive Care or Emergency Medicine are required to demonstrate airway skills competency as specified by ANZCA in the document "Airway skills requirement for training in Diving and Hyperbaric Medicine".

All details are available on the ANZCA website at:
<www.anzca.edu.au/edutraining/DHM/index.htm>

Dr Margaret Walker, FANZCA
Chair, ANZCA/ASA Special Interest Group in Diving and Hyperbaric Medicine

SPUMS

37th Annual Scientific Meeting

24–30 May 2009

Snorkelers Cove Resort, Iririki Island, Vanuatu

Themes

Diving, Flying and Space Exploration
Future synergies in Diving Accident Management
Ear Injuries and ENT Workshop
Moderator for workshop: Michael Taplin, Senior ENT Surgeon, Sydney
The ENT workshop will cover ENT diagnostic dilemmas in divers, practical case examples of ear injuries, principles and practical use of Tympanometry.

Keynote Speaker

Professor Bruce Spiess MD, FAHA

Bruce Spiess is Professor and Chief of Cardiothoracic Anesthesia and Director of Research in the Department of Anesthesiology at Virginia Commonwealth University. As Director of the Virginia Commonwealth University Reanimation Engineering Shock Center (VCURES), he is researching perfluorocarbons as blood substitutes and their potential in treating decompression illness and gas embolism. Professor Spiess also conducts research into decompression sickness and submarine escape with the United States Navy, and is working with NASA on decompression sickness in astronauts.

Abstracts

The deadline for Abstracts has been extended until 27 April 2009.
Abstracts should be submitted as a Word file of up to 250 words (excluding references – four only) and with only one figure.
Papers should preferably reflect the theme of the conference: diving, flying (including aeromedical retrieval), space exploration, future synergies in diving accident management, systems of care and treatment.

CPD Credits Obtained for ANZCA and applied for with ACEM and RACGP

Snorkelers Cove Resort

Snorkelers Cove Resort on beautiful Iririki Island is just minutes by ferry from Port Vila and offers a range of contemporary deluxe hotel accommodation, beach activities and dining options and a Leisure Precinct with one of the largest freshwater pools in the Pacific, children's wading pool, Sunset Bar and Cafe, exercise room, games room and two tennis courts.

Register now for the conference and view the preliminary programme online at:
http://www.spums.org.au/2009_annual_scientific_meeting

If you wish to present a paper please contact the Convenor

SPUMS 2009 Convenor

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All travel, accommodation and diving enquiries to: <allways@bigpond.com.au>

EUBS European Underwater and Baromedical Society

Combined with the

British Hyperbaric Association Annual Scientific Meeting

Venue:
King's College Conference Centre, University of Aberdeen

Hosts:
University of Aberdeen and Aberdeen Royal Infirmary Hyperbaric Medicine Unit

Key topics will include:

- Health technology assessment and hyperbaric oxygen therapy
- Diving research and treatment of decompression illness
- Treatment of ORN and diabetic foot

Accommodation:
A number of rooms have been reserved. Please book early.
The accommodation booking service is provided by Aberdeen Convention Bureau.

Contact details:
EUBS 2009
c/o Environmental & Occupational Medicine
Liberty Safe Work Research Centre,
Foresterhill Road, Aberdeen, AB25 2ZP
Phone: +44-(0)1224-558188
Fax: +44-(0)1224-551826
E-mail: <hyperbaric@abdn.ac.uk>
Website: <www.hyperchamber.com/EUBS2009>

EUBS European Underwater and Baromedical Society

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The EUBS website is at
www.eubs.org
Members are encouraged to log in

EUBS website update

The year 2008 has been an important year for the EUBS and its membership services. Not only has the joint scientific journal, *Diving and Hyperbaric Medicine*, taken a flying start and seems to be evolving extremely positively, but also internet-based membership resources have been tackled.

Since November last year, the EUBS website (www.eubs.org) has undergone a major upgrade. While keeping the general appearance, a personalised 'members only' section has been added. Online membership application and payment is now conveniently available, and as much as possible the membership secretary's work has been automated (sending of renewal notices, updating of payment history, membership application forwarding, etc.).

In order to maximise the usefulness of the website, and to provide the membership with as much in the way of useful services as possible, it is vital that all EUBS members update their personal information in this section. Logging in requires a password. If you have already provided an e-mail address, the password will be mailed to you automatically by the website's database engine; just fill in your e-mail address at the "I have forgotten my password" prompt. If you have never given us your e-mail address, you will need to send a mail to Tricia Wooding (patriciawooding@btinternet.com) in order to obtain your password.

Members also benefit from free, unlimited access to the GTUEM database of hyperbaric and diving medicine scientific articles, which includes the complete collection of previous EUBS Annual Meeting Proceedings, in digital format – found nowhere else! A dedicated, easy to use, discussion forum is available to registered members; the ideal place to exchange ideas, get answers to burning questions and make new professional contacts.

The EUBS website will be further expanded in the future. In the pipeline are: electronic publishing of accepted (mini) papers of each year's Annual Scientific Meeting, announcements of courses and vacancies in diving medicine and hyperbaric centres in Europe and abroad, and more.

Remember, the EUBS website is, together with this journal, your instrument to enhanced professional contacts. In these times of increased pressure on hyperbaric scientists to produce good-quality research and provide evidence-based medical practice, these professional and personal contacts will prove to be valuable assets in increasing knowledge and acceptance of our specialty. Over one third of EUBS members have already logged in and updated their professional details. Please help us improve the service even more, by sending us your ideas and announcements. They will be published both on the website and in DHM.

Peter Germonpré, EUBS Webmaster

Scott Haldane Foundation Diving Medicine Education

In collaboration with the Dutch Society for Diving Medicine
Diving Medicine Courses, first semester 2009
19 June Advanced Course: Evidence-based diving medicine. Driebergen, The Netherlands

For further information and registration:
Website: <www.scotthaldane.nl>
E-mail: <info@scotthaldane.nl>

5th Karolinska Postgraduate Course in Clinical Hyperbaric Oxygen Therapy

Date: May 7, 2009
Venue: Stockholm, Sweden
The course will cover past, present and future clinical trials with a focus on 'evidence-based medicine'
Speakers include: Stephen Thom, Neil Hampson, Lin Weaver, Simon Mitchell, Jon Buras, Ian Millar, Dirk Bakker, Michael Bennett, Daniel Mathieu, Tom Hunt, Christer Hammarlund and Dick Clarke
Registration & Information:
<www.oxygeninfection.se>
Contact person: <folke.lind@karolinska.se>

Oxygen and infection

ESCMID European Society of Clinical Microbiology and Infectious Diseases

European Committee for Hyperbaric Medicine

Dates: May 8-9, 2008
Venue: Stockholm, Sweden
A European Committee for Hyperbaric Medicine Conference, endorsed by the European Society of Clinical Microbiology and Infectious Diseases, to review the role of oxygen in infectious diseases from basic science to clinical practice. The effects of anoxia, hypoxia, normoxia and hyperoxia on microbes, antibiotics, leukocyte bacterial killing and inflammation will be examined.
Registration & Information:
<www.oxygeninfection.se>
Contact person: <folke.lind@karolinska.se>

Historical Diving Society SE Asia Pacific

DIVING HISTORICAL SOCIETY AUSTRALIA, SE ASIA

P O Box 347, Dingley Village, Victoria, 3172, Australia
Email:
<deswill@dingley.net>
Website:
<www.classicdiver.org>

Undersea & Hyperbaric Medical Society
Annual Scientific Meeting 2009

Dates: 25 to 27 June 2009
Venue: Crowne Plaza Los Cabos-Grand Faro Resort
Blvd San Jose s/n, Zona Hoteler
San Jose del Cabo, 23400 Mexico
Pre-course: Ultrasound and decompression research workshop, 24 June
UHMS is accredited to provide continuing medical education for physicians
Kronheim Lecturer: Dr Sylvia Earle

For further information:
E-mail: <uhms@uhms.org>
Website: <www.uhms.org>

Asian Hyperbaric & Diving Medical Association

5th Annual Meeting – preliminary announcement
Dates: 25 to 27 September 2009
Venue: Goa, India
Further details (academic programme, registration fees and hotel tariffs) to follow soon
For further information:
E-mail: <ahdma.goa@gmail.com>

Note: This conference overlaps the 10th International Maritime Health Conference, 23–26 September. Details available on their website: <www.ismh10.com>

The Hyperbaric Research Prize

The Hyperbaric Research Prize encourages the scientific advancement of hyperbaric medicine and will be awarded annually whenever a suitable nominee is identified. It will recognise a scholarly published work or body of work(s) either as original research or as a significant advancement in the understanding of earlier published science. The scope of this work includes doctoral and post-doctoral dissertations. The Hyperbaric Research Prize is international in scope. However, the research must be available in English.

The Hyperbaric Research Prize takes the form of commissioned art piece and US$10,000 honorarium.

For detailed information please contact:
Baromedical Research Foundation
5 Medical Park, Columbia, SC 29203, USA
Phone: +1-803-434-7101
Fax: +1-803-434-4354
E-mail: <samir.desai@palmettohealth.org>

2008 ROYAL AUSTRALIAN NAVY MEDICAL OFFICERS' UNDERWATER MEDICINE COURSE

Dates: 10 to 21 November 2009
Venue: HMAS Penguin, Sydney
Cost: tbc

The Medical Officers' Underwater Medicine Course seeks to provide the medical practitioner with an understanding of the range of potential medical problems faced by divers. Considerable emphasis is placed on the contra-indications to diving and the diving medical, together with the pathophysiology, diagnosis and management of the more common diving-related illnesses.
For information and application forms contact:
The Officer in Charge, Submarine & Underwater Medicine Unit, HMAS PENGUIN,
Middle Head Road, Mosman, 2088 NSW, Australia
Phone: +61-(0)2-9960-0572
Fax: +61-(0)2-9960-4435
E-mail: <Scott.Squires@defence.gov.au>

ROYAL ADELAIDE HOSPITAL DIVER MEDICAL TECHNICIAN (DMT) & DIVING MEDICAL OFFICER COURSES 2009

Full DMT Courses:
2 – 20 March
16 November – 4 December
DMT Refreshers
27 April – 1 May
26 – 30 October
Medical Officers Course
Basic Course: 22 – 26 June
Advanced Course: 29 June – 3 July
For more information contact:
Lorna Mirabelli
Senior Administrative Assistant
Hyperbaric Medicine Unit, Royal Adelaide Hospital
Phone: +61-(0)8-8222-5116
Fax: +61-(0)8-8232-4207
E-mail: <Lmirabel@mail.rah.sa.gov.au>

Situations vacant

The Alfred Hospital, Australia
Registrar/Fellow in Diving and Hyperbaric Medicine

Applications are sought for 2009/2010 appointments as full-time Registrar in Hyperbaric Medicine at The Alfred Hospital in Melbourne, Australia. Usual fellowship durations are 6–12 months.
For detailed information contact:
Dr Ian Millar, Unit Director
***Phone:** +61-(0)3-9076-2269*
***E-mail:** <i.millar@alfred.org.au>*

Instructions to authors

(revised March 2009)

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

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

Requirements for manuscripts

Documents should be submitted electronically on disk or as attachments to e-mail. The preferred format is Microsoft® Office Word 2003. Paper submissions will also be accepted. All articles should include a title page, giving the title of the paper and the full names and qualifications of the authors, and the positions they held when doing the work being reported. Identify one author as correspondent, with their full postal address, telephone and fax numbers, and e-mail address supplied. The text should generally be subdivided into the following sections: an Abstract of no more than 250 words, Introduction, Methods, Results, Discussion, Conclusion(s), Acknowledgements and References. Acknowledgements should be brief. Legends for tables and figures should appear at the end of the text file after the references.

The text should be double-spaced, using both upper and lower case. Headings should conform to the current format in *Diving and Hyperbaric Medicine*. All pages should be numbered. Underlining should not be used. Measurements are to be in SI units (mmHg are acceptable for blood pressure measurements) and normal ranges should be included. Abbreviations may be used once they have been shown in brackets after the complete expression, e.g., decompression illness (DCI) can thereafter be referred to as DCI.

The preferred length for original articles is up to 3,000 words. Including more than five authors requires justification, as does more than 30 references. Case reports should not exceed 1,500 words, with a maximum of 15 references. Abstracts are required for all articles. Letters to the Editor should not exceed 500 words with a maximum of five references. Legends for figures and tables should generally be less than 40 words in length.

Illustrations, figures and tables must NOT be embedded in the wordprocessor document, only their position indicated. No captions or symbol definitions should appear in the body of the table or image.
Table data may be presented either as normal text with tab-separated columns (preferred) or in table format. No gridlines, borders or shading should be used.
Illustrations and figures should be submitted as separate electronic files in TIFF, high resolution JPG or BMP format. If figures are created in Excel, submit the complete Excel file. Large files (> 10 Mb) should be submitted on disk.
Photographs should be glossy, black-and-white or colour. Colour is available only when it is essential and may be at the authors' expense. Indicate magnification for photomicrographs.

References

The Journal reference style is the 'Vancouver' style (Uniform requirements for manuscripts submitted to biomedical journals, updated May 2007. Website for details: <http://www.nlm.nih.gov/bsd/uniform_requirements.html>). References must appear in the text as superscript numbers at the end of the sentence after the full stop.[1,2] The references are numbered in order of quoting. Index Medicus abbreviations for journal names are to be used (<http://www.nlm.nih.gov/tsd/serials/lji.html>). Examples of the exact format for a paper and a book are given below:

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

Place a full stop after the journal name and at the end of the reference. Titles of books and journals should be in italics. Accuracy of the references is the responsibility of authors.

Any manuscript not complying with the above requirements will be returned to the author before being considered for publication.

Consent

Studies on human subjects must comply with the Helsinki Declaration of 1975 and those using animals must comply with National Health and Medical Research Council Guidelines or their equivalent. A statement affirming Ethics Committee (Institutional Review Board) approval should be included in the text. A copy of that approval should be available if requested.

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Full 'Instructions to authors' can be found on the EUBS and SPUMS websites (revised March 2009).

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+81-3-3812-4999 (Japan)

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0800-020111 (in South Africa, toll-free)
+27-10-209-8112 (international, call collect)

EUROPE
+39-06-4211-8685 (24-hour hotline)

UNITED KINGDOM
+44-07740-251-635

USA
+1-919-684-8111
+52-5-629-9800 (America-Mexico))

LATIN AMERICA
+1-919-684-9111 (may be called collect; Spanish and Portuguese)

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

DAN Asia-Pacific DIVE ACCIDENT REPORTING PROJECT

This project is an ongoing investigation seeking to document all types and severities of diving-related accidents. Information, all of which is treated as being confidential in regard to identifying details, is utilised in reports on fatal and non-fatal cases.
Such reports can be used by interested people or organisations to increase diving safety through better awareness of critical factors.
Information may be sent (in confidence unless otherwise agreed) to:
DAN Research
Divers Alert Network Asia-Pacific
PO Box 384, Ashburton VIC 3147, Australia
Enquiries to: <research@danasiapacific.org>

DIVING INCIDENT MONITORING STUDY (DIMS)

DIMS is an ongoing study of diving incidents. An incident is any error or occurrence which could, or did, reduce the safety margin for a diver on a particular dive. Please report anonymously any incident occurring in your dive party. Most incidents cause no harm but reporting them will give valuable information about which incidents are common and which tend to lead to diver injury. Using this information to alter diver behaviour will make diving safer.
Diving Incident Report Forms (Recreational or Cave and Technical)
can be downloaded from the DAN-AP website: <www.danasiapacific.org>
They should be returned to:
DIMS, 30 Park Ave, Rosslyn Park, South Australia 5072, Australia.

CONTENTS

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