

Health status and diving practices of a technical diving expedition

Andrew Fock

Key words

Technical diving, safety, health surveillance, decompression, air, mixed gas, trimix, nitrox, oxygen

Abstract

(Fock A. Health status and diving practices of a technical diving expedition. *Diving and Hyperbaric Medicine*. 2006; 36: 179-85.)

The author participated in a technical diving expedition to the South China Sea primarily to dive several deep World War Two wrecks. During the expedition, diving practices and diver health were observed, and a diver health survey was completed by six of the seven divers at the end of each diving day. This survey showed a slight worsening of health scores during the first half of the expedition, which then returned to baseline levels. However, no diver reached a health score of a level (six) associated with clinical decompression sickness (DCS) in a previous study. No clinical DCS was detected or treated; however, a high level of pre-existing musculoskeletal complaints prevalent in this group made clinical diagnosis difficult for marginal symptoms. A high proportion (50%) of divers reported symptoms consistent with pulmonary and ocular oxygen toxicity. The use of closed-circuit rebreathers for 74 dives in the depth range of 50 to 70 metres' sea water, with total dive time 100.4 hours, was associated with few technical problems for a suitably trained and experienced group of technical divers.

Introduction

Technical diving has been defined as recreational diving to depths beyond recreational limits and using gases other than air and is generally recognised as a high-risk activity.¹ Originating from techniques developed by the cave-diving fraternity, technical diving has continued to evolve and now incorporates equipment such as closed-circuit rebreathers (CCRs). The ready access to this type of sophisticated equipment and to computer software to calculate suitable decompression schedules has allowed recreational divers to explore depths and areas previously only dreamed of. This exploration has come at a cost, and technical divers are an over-represented group in decompression illness (DCI) statistics. This study aimed to provide an insight for diving physicians (who potentially have to deal with emergencies relating to these activities) into the diving practices and health impact of deep, mixed-gas, repetitive diving.

Methods

This observational study was conducted during an eight-day expedition to the South China Sea in accordance with the Australian National Statement on ethical conduct in Research Involving Humans (June 1999). Informed written consent was sought from the seven divers participating in the expedition; only one diver did not consent, and no reason for this refusal was sought or given.

DIVING PERSONNEL

Divers were all non-smoking Caucasian males, average age 47.5 years (range 43 to 54 years). Average body mass index was 29 kg.m⁻² (range 25 to 32). The cumulative diving

experience was 146 years (average 24 years, range 12–38 years). Experience on CCRs varied from one to eight years. Four divers had previously been treated for decompression sickness (DCS). Five divers described pre-existing chronic musculoskeletal injuries, mostly located in the upper limbs. Five divers consumed alcohol on most evenings, whilst one abstained completely during the expedition. No diver was seen to be intoxicated at any time. All divers hydrated actively before diving.

DIVER HEALTH SURVEY

The Diver Health Status (DHS) questionnaire developed by Doolette was used to assess the daily wellbeing of the divers.² The questionnaire comprises nine standardised questions. These cover five symptoms of DCS (paraesthesia, rash, balance, fatigue and pain), five health status indicators (vitality, pain, physical functioning, role limitation, and health perception) and the onset of symptoms, as well as a free response.³ Each item is scored from 0 to 3, and the resultant summed DHS ranges from 0 to 30. This health survey has been validated against both a commercial diving group and a technical cave-diving group.²⁻⁴ A questionnaire was filled out each evening by the divers, usually after dinner (i.e., about four hours post dive), directly into an Access® database (Office 2003®, Microsoft Corporation).² The participants also completed a post-expedition survey by e-mail. These data were transferred to and stored as an Excel® (Office 2003®, Microsoft Corporation) spreadsheet. The DHS scores were not calculated and analysed until after the expedition so as not to influence diving practices. Only a simple descriptive analysis was performed, without attempting to link scores to diving/decompression profiles.

DIVING PROCEDURES

All dives were conducted from a 22-metre dive boat based out of Singapore. On-board facilities included continual blending of nitrox and trimix gas mixes and pure oxygen (O₂), an electric hoist to lift divers back onto the boat and a 50-inch diameter twin-lock hyperbaric chamber, which had never been used in an emergency.

Diving was conducted over an eight-day period with usually two dives per day, except on the last day when only one dive was performed so as to allow a suitable surface interval before flying (Table 1). All dives, with the exception of this last dive, were to depths of greater than 50 metres' sea water (msw). The number of dives performed was at the discretion of the individual diver, only one diver performing all 15 dives (average 13, range 9–15). A surface interval of three hours was usual between dives on the same day. For dives to depths close to 70 msw, some divers elected to extend the surface interval to four hours.

Little formal dive planning was performed and no formal dive log was kept by the boat operator. A dive briefing was conducted before the first dive on each of six wreck sites. Two divers generally dived as a buddy pair. A further two, one being the diver who did not participate in the study, dived as a pair for some dives only. The remainder dived solo. Divers who operated in buddy pairs agreed on bottom time and bailout gases prior to diving, but, in general, formal written dive plans were not carried.

DIVING CONDITIONS

Daily air temperature varied between 30 and 35 °C, with 80% to 90% relative humidity. Surface water temperature

was 30.5 °C and surface visibility approximately 20–30 m on most sites. A thermocline was present on the deeper wrecks with a drop in temperature to approximately 25 °C and visibility to about 5–10 m. Surface sea states were calm on all but one day. Currents up to two knots were experienced on most dives from about 30 msw to the surface. Divers clipped themselves to the decompression station (Figure 1), but the deeper stops during ascent along the shot line from the wreck to the station often involved considerable effort holding onto the line. Large numbers of jellyfish swept through the decompression station with the risk of envenomation.

DIVING EQUIPMENT

All divers used CCRs produced by Ambient Pressure Diving (APD), UK, five *Inspiration* rebreathers and one the smaller *Evolution* rebreather. A detailed description of the functioning of these units is beyond the scope of this article but interested readers are referred to Jeffrey Bozanic's book on the subject.⁵ Three rebreathers used the new 'Vision[®]' electronics, which incorporate an integrated decompression computer and a temperature monitor to assess the scrubber performance. The oldest unit on the trip had been heavily modified with the original scrubber head replaced with an after-market Hammerhead[®] unit (Juergenson Marine, Addison, PA, USA). This unit incorporated pre-production handsets for the Dive Rite Optima[®] rebreather, one of which contained an integrated dive computer. Several of the other CCRs had received minor modifications, such as mouthpieces with integrated open-circuit function, an extra oxygen (O₂) second stage, etc.

All divers carried delayed surface marker buoys which could be deployed during decompression. Two divers also

Table 1. Dive demographics

Day	Dive	Average depth	Average bottom time (h:mm)	Average dive duration (h:mm)	Man dives	Total bottom time (h:mm)	Total dive duration (h:mm)
1	1	56	0:25	1:13	6	2:34	7:19
	2	56	0:29	1:15	5	2:27	6:16
2	1	54	0:28	1:11	6	2:52	7:07
	2	55	0:34	1:33	6	3:28	9:21
3	1	53	0:36	1:33	5	3:03	7:48
	2	55	0:40	1:44	5	3:21	8:43
4	1	54	0:44	1:57	5	3:40	9:46
	2	55	0:35	1:35	3	1:46	4:46
5	1	64	0:30	1:22	6	3:00	8:14
	2	66	0:25	1:19	5	2:05	6:35
6	1	49	0:34	1:15	5	2:52	6:17
	2	52	0:42	1:26	4	2:48	5:47
7	1	53	0:23	1:04	4	1:34	4:16
	2	52	0:24	0:56	4	1:36	3:46
8	1	44	0:24	0:55	5	2:00	4:35
AVERAGE		54	0:31	1:21	TOTAL 74	39:08	100:40

carried personal emergency position radio beacons. Total weight of the diver's equipment was approximately 40–47 kg depending on configuration and the number of bailout cylinders.

GAS MANAGEMENT

Bottom gas for all dives was trimix 15/50 (O₂ 15%, helium 50%, nitrogen 35%). This was produced by a continual blending process and then stored in bank cylinders. A Haskel booster pump was used to guarantee that all diving cylinders were filled to 200 bar. All gas compositions were verified by the author using a helium/O₂ analyser (Analox®, UK). All fills were found to be within 1% of the desired values.

All divers carried an off-board 6-litre (water capacity) cylinder for 'bailout' in case of a total CCR failure. This cylinder contained either trimix (15/50) or air depending on the CCR configuration. Three divers carried an additional 6-litre bailout cylinder of trimix (15/50) for the deeper dives, for the longer planned dives and for dives involving wreck penetrations.

DECOMPRESSION PLANNING

The VR3® (Delta P Technology Ltd, Dorset, UK) mixed-gas dive computer was used by all the divers. On three of the CCRs, this was connected into the CCR loop with a fourth redundant oxygen cell for real-time monitoring of

partial pressure of oxygen (PPO₂). One diver used a Sunto Viper dive computer as a back-up bottom timer. One diver carried back-up decompression tables. Three divers had fully redundant, mixed-gas decompression computers (Vision electronics, APD, Cornwall, UK).

Although divers relied on their computers to provide the decompression profile, most had a fair idea of the required total dive time and final stop time for a given bottom time, based on previous experience. Two divers formally used the dive-planning function of the VR3 to predict their decompression requirements, although the results were generally not written down. Bottom time was usually planned on estimated decompression obligation rather than gas requirements. For divers carrying redundant dive computers, the decompression profile was dictated by the more conservative computer.

All VR3s utilised the Buhlmann ZHL-16 algorithm with deep stops as per the method described by Pyle.^{6,7} Most divers used the 0% conservatism setting on the VR3 for all dives. One diver added a 10% conservatism factor to the algorithm for all dives, and one diver changed his setting from 0% to 10% after two days "to give more conservatism". Three divers used the inbuilt decompression computer in the *Vision* electronics, which incorporate the readings from the three CCR O₂ cells to calculate decompression requirements. This computer also utilises the Buhlmann ZHL-16 decompression method. Conservatism is altered by selecting the 'gradient factors' (allowed maximum super-saturation limits) for the deep and shallow parts of the dive.⁸ One diver used the decompression computer incorporated into his Hammerhead electronics. This unit used the same decompression algorithm and method as the *Vision* decompression computer. Both the VR3s and the *Vision* tracked pulmonary O₂ toxicity units (OTU) and central nervous system (CNS) O₂ toxicity based on the methods described by Hamilton et al.⁹

All divers used a PPO₂ set point of 1.3 ATA at depth and for ascent. Three divers manually increased the PPO₂ when at 6 msw to between 1.5 and 1.6 ATA (i.e., 100% O₂). Three divers utilised the surface-supplied, open-circuit O₂ at the 6 msw stop. There was considerable variation in practice as to whether the divers told their dive computers that they had changed their PPO₂ during the final decompression stop, some opting not to do so in order to gain a measure of decompression conservatism. Two divers limited their time on 100% O₂ to 20-minute periods, performing five-minute 'low O₂ breaks' between oxygen periods.

Three divers changed the diluent from trimix to air at between 30 and 40 msw during ascent by flushing their units so as to accelerate their decompression. The other divers remained on the trimix mixture except if they changed to 100% O₂ (by using either the open-circuit O₂ or the CCR as an O₂ rebreather). No problems were encountered with the practice of diluent switching.

Figure 1

An underwater decompression trapeze with bars at depths of 4.5 and 6 metres' sea water was slung underneath the boat during all dive operations. Surface-supplied oxygen was provided on the decompression station.

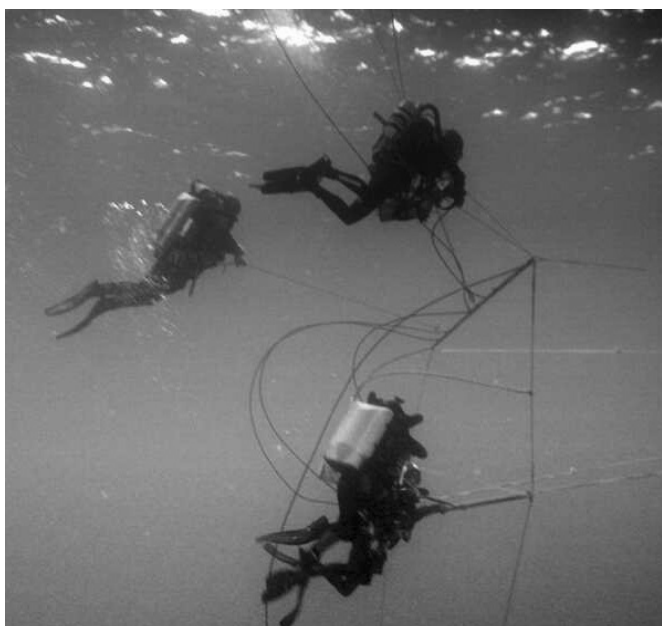
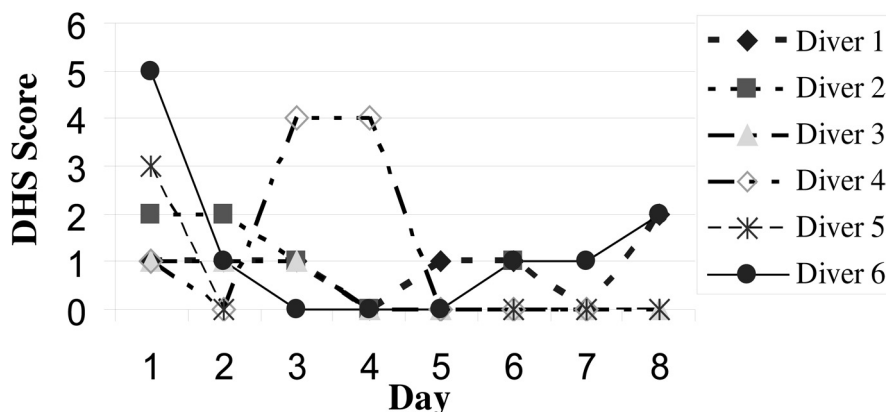


Figure 2
Diver health scores (DHS – Diver Health Status; diver 3 obscured by other data)



BAILOUT PLANNING

In general, insufficient open-circuit gas was carried to allow an independent return to the surface in the event of catastrophic CCR failure. Planning revolved around having sufficient gas to return to the shot line and reach the decompression station. Given that the 6-litre cylinders could be expected to last approximately 12 minutes at 56 msw, in many cases this plan would seem rather stretched! For divers who dived as buddy pairs, it was assumed that the chances of a dual catastrophic CCR failure were low, and that bailout gas would be shared in the event of an emergency. These divers also carried two bailout cylinders for deeper and longer dives. However, it was argued by some of the divers that, for penetration dives, the use of two sling cylinders increases the risks of entrapment and would impede their ability to swim. However, two divers with the dual bailout cylinder configuration swam the entire length of one wreck and back (some 500 m) at depths between 55 msw and 69 msw without physical distress.

SCRUBBER MANAGEMENT

Sodasorb® 4-8 (WR Grace & Co, Chicago, USA) with ethyl violet indicator was used for carbon dioxide (CO₂) removal. This is not the recommended CO₂ absorbent (which is Sofnolime 797) for the *Inspiration* rebreather, and is of a courser mesh. CO₂ absorbent changes were based on time of use or the integrated temperature monitor where fitted. Scrubber durations of up to six hours were reported; however, average change time was approximately 4.5 hours. All the CCRs had integrated timers used to track scrubber use. No scrubber warnings were seen on those units with scrubber monitors. The depth of the used Sodasorb as indicated by the colour change was noted to correspond closely with the scrubber monitor in the Vision electronic package.

POST-DIVE MAINTENANCE

All divers opened their CCRs after each dive to allow any condensation of water onto the O₂ cells to dry. All units were

assembled well before the next dive and a positive-pressure check performed. All divers were observed to perform pre-dive CCR checks and breathe the CCR prior to the dive to activate the CO₂ scrubber. Most CCRs had their loop and counter-lungs washed out in fresh water at the end of each day. Antiseptics were not routinely used.

Results

DIVER HEALTH SURVEY

Daily scores for the Diver Health Status questionnaire are shown in Figure 2. On seven of the potential 48 diver/days (15%), three divers did not dive and a questionnaire was not completed. The maximum DHS recorded during the expedition was five in Diver six. He had a pre-existing musculoskeletal injury in his left arm. On the first day of diving, his arm received pronounced jerking on the shot line during decompression. Self treatment with an anti-inflammatory non-steroidal (naproxen) relieved his pain. Diver four developed right shoulder pain, anatomically related to an old sporting injury, after his fifth dive, giving a score of four for two days. Return to 6 msw breathing 100% O₂ did not relieve this pain. He continued diving and the pain resolved spontaneously. Most other divers had low-level grumbling pains consistent with pre-existing injuries. Three other divers with pre-existing musculoskeletal injuries reported improvement in their condition during the expedition.

DECOMPRESSION INCIDENTS

There were no incidents of divers breaching the decompression ceilings as indicated by their dive computers. Two divers developed symptoms suggestive of marginal DCS (see above). In both cases, the symptoms were clouded by pre-existing musculoskeletal injuries at the anatomical sites and by divers having hung onto the jerking shot line during prolonged decompression. In both cases, the divers continued diving for the remainder of the expedition and their symptoms resolved spontaneously. Divers all flew

Table 2
Equipment events and failures during 74 trimix technical dives

Description	Emergency	Management	Repaired
Hammerhead handset flood	Yes	Ascent using VR3 and secondary handset	No
Diluent LP hose failure	Yes	Ascent (diluent not used on ascent)	Yes
Partial scrubber flood	Yes	Ascent, semi-closed mode; surface supplied O ₂ on deco	No, VR3 interface removed
VR3 electronic interface failure	No	VR3 changed to set-point PPO ₂ mode	Yes, cleaned and dried
Oxygen cell failure	No	Detected on the surface	Replaced
Autoair (combined BC inflator/regulator) damaged	No	Detected on surface	Repaired
Mouthpiece torn	No	None	Replaced
SPG(O ₂) hose failure on surface	No	Removed	No
Primary torch failure	No	Back-up torch used	Yes, but failed again later
Back-up torch failure	No	No, repeated failure	

home approximately 24 hours after the last dive. No divers developed symptoms of DCS associated with or after flying.

OXYGEN TOXICITY

Three divers reported symptoms of chest tightness and a dry cough after the fourth day, consistent with pulmonary O₂ toxicity. One of these divers had an episode of mild haemoptysis and persistent coughing after prolonged O₂ use. Two of the divers using *Vision* units had O₂ toxicity warning alarms during decompression, indicating that they had exceeded the National Oceanic and Atmospheric Administration daily limits. No divers reported symptoms of central nervous system (CNS) O₂ toxicity. No divers exceeded the recommended CNS O₂ limits as calculated by their computers.

Three divers reported a change in visual acuity by the end of the expedition, notably an improvement in near vision and deterioration in distance vision. Unfortunately these changes could not be quantified.

INJURIES

Several divers sustained minor injuries from sea urchin spines or minor stings from hydroids on the wrecks. One diver suffered minor jellyfish stings about the face while on decompression. One diver developed friction ulcers on the feet from his fins, whilst another required antibiotics and drainage of a paronychia. One diver developed an upper respiratory tract infection and did not dive for two days.

EQUIPMENT PROBLEMS

There were 10 equipment failures (Table 2), none resulting in the cancellation of a dive although some dives were subsequently carried out with a reduced level of redundancy. Three incidents, involving two divers, occurred underwater

and resulted in the dive being aborted. Neither diver needed to resort to open-circuit scuba or to violate their decompression obligations.

The VR3 O₂ cell interface unit caused one CCR to partially flood as a result of a displaced O-ring. This then caused a CO₂ breakthrough and failure of the scrubber monitor. The diver involved converted to a 'semi-closed' mode, where gas is vented from the loop after every fifth breath, while ascending to the decompression station where he then utilised open-circuit O₂. The VR3 interface was not subsequently used with this unit. In a second unit, corrosion of the electrical connection between the VR3 and the O₂ cell caused intermittent problems for several dives but this was resolved by the end of the expedition.

On another unit, the handset of the Hammerhead unit flooded resulting in a loss of the primary PPO₂ display, decompression data and automatic O₂ solenoid control. However, this unit had a secondary handset that provides redundant PPO₂ monitoring hence allowing manual O₂ addition. Further back-up PPO₂ monitoring and decompression data were provided by the integrated VR3. The owner of this unit elected to continue to dive the CCR manually on subsequent dives controlling his unit via the remaining handset and VR3.

One diver reported a headache associated with a very high workload at depth. His scrubber had two hours' use prior to this event.

Discussion

The ready availability of decompression software and the ease of obtaining helium have resulted in a rapid growth in technical diving. In conjunction with this boom has been the introduction in the late 1990s into the recreational arena of closed-circuit, mixed-gas rebreathers of which several models, including the APD *Inspiration*, are now available.

The reluctance of manufacturers to disclose their sales numbers makes accurate estimations of total rebreather numbers difficult. However, these units are widely used in the Northern Hemisphere and increasingly in Australasia.

Unlike open-circuit scuba, gas consumption of a CCR is essentially independent of depth. Gas is recirculated through the 'loop' via one-way valves past a 'scrubber' to remove CO₂. Oxygen levels are sensed via several oxygen cells, and O₂ is added either via a computer-controlled solenoid or via manual injection from the user, depending on the model, to maintain a constant PPO₂ in the breathing loop. Diluent gas is added to the loop to maintain loop volume as the diver descends. Gas consumption is, therefore, dependent only on the diver's O₂ consumption, with a small volume of diluent used to bring the loop to ambient pressure. Typical gas consumption during this expedition, with total dive times of approximately 100 minutes, was about 150 litres of diluent and 150 litres of O₂ per dive compared with some 6,500 litres of gas that would be expected to be consumed for a similar dive on open-circuit scuba. This represents a saving on gas costs from approximately AU\$150 per day per open-circuit diver to AU\$25 per day per CCR diver for gas and CO₂ absorbent.

While open-circuit dive planning is limited by the gas supply that can be carried and/or staged and the decompression needs of the dive, CCR planning is limited largely by the scrubber duration (in the case of the *Inspiration* about 4–6 hours, dependent on depth, water temperature, grade of soda lime used, etc.) and O₂ supply. This allows CCR divers large margins with regards to dive duration and contingency planning over open-circuit divers at the expense of the substantially increased complexity of the scuba system. In both cases, hypothermia may be an important factor.

Potential complications of rebreathers include hyperoxia, hypoxia, hypercarbia and 'caustic cocktail' (the last of these if water should enter the scrubber and allow alkaline soda lime to enter the breathing loop). The increased complexity both in operation and care has also come at a human cost, with a relatively high mortality rate amongst CCR divers, mostly ascribed to user error. During this expedition, there were relatively few incidents or problems with the rebreathers per se and these were largely confined to the oldest and most modified CCR in the group. The divers, being very experienced, managed these incidents without requiring external help and without the need to resort to their open-circuit bailout option. In a less experienced group of divers outcomes may have been less favourable.

The lack of formal dive planning and the high level of solo diving are both of concern. In an internet survey of *Inspiration* users in 2002, Hawkins found that 42% dived solo and almost 20% chose to carry no open-circuit bailout.¹⁰ These behaviours appeared to correspond to divers who subsequently showed a high mortality. The lack of detailed planning was facilitated particularly by the availability

of continuous decompression solutions produced by decompression computers. However, given the substantial amount of accrued decompression on each dive, the reliance on this technology alone without a written back-up plan would seem somewhat cavalier.

The type and depth of diving during this expedition was fairly typical of that being practised by recreational technical divers. Most of the dives would have been placed in the 'extreme exposure' category in the DCIEM decompression tables, with an expected DCS rate of approximately 4%.¹¹ In practice, no DCS was observed on this expedition or in a cave-diving group also using the Buhlmann ZHL-16 algorithm.³ However, the numbers of dives were relatively small. Both 'forward' and 'reverse' profile dives were performed. No divers used the popular 'bubble' models, VPM or RGBM, which introduce a series of deep decompression stops and, often, reduced shallow decompression times.^{12,13}

The low observed rate of DCS might be ascribed to several factors. Ideal temperature conditions were present with divers cool on the bottom and decompressing in 30 °C water, enhancing blood flow and gas elimination. This was somewhat offset by the difficulties produced by the currents experienced during decompression. The diver lift minimised the need for divers to strain getting back onto the boat. Also, CCRs maintain a constant PPO₂, keeping the 'oxygen window' optimised during decompression.^{14,15} Finally the use of near 100% O₂ at the 6 msw stop would optimise the inert gas gradients and help minimise any bubbles that had formed.

No problems were encountered during the expedition in the divers who switched diluents to accelerate decompression, a practice that is controversial as it appears to be associated with a high incidence of inner ear decompression sickness (IEDCS).^{16,17} Some technical diving agencies now limit the changes in inert gas concentrations during decompression. For CCR divers, as the PPO₂ is kept constant, the partial pressure of inert gases falls proportionally as the diver ascends. Switching diluent offers only a small additional reduction in decompression obligation for most dives and it would appear difficult to justify the risks of developing IEDCS for this small gain. A recent animal study has suggested that the gas kinetics of nitrogen and helium are not, in fact, as different as predicted by most decompression models.¹⁸ If correct, this would mean that the predicted acceleration in decompression by switching gases may not occur.

Pre-existing musculoskeletal injuries in this group provided some difficulty in making a diagnosis of marginal DCS. Typically divers tend to rationalise marginal symptoms as being due to other causes and will self treat where possible. The author was not asked to formally deliberate on the exact nature of these symptoms despite his background as a diving physician being well known to the divers.

DHS scores have been correlated to decompression stress in occupational and technical diving groups, with scores of six or greater being associated with the development of clinical DCS requiring treatment.^{2,4,19} No divers reached a score of six during this expedition, and none developed overt DCS. DHS has also been correlated to diving depth. Doolette found an increase of one DHS unit per 13 msw increase in depth.³ For this expedition, scores of one to two would, therefore, have been expected and were indeed seen for most divers on most days. The lack of DCS symptoms despite the divers being in what would generally be considered relatively high-risk categories (overweight, middle-aged, relatively unfit, alcohol intake the night before diving, etc.) would imply that the decompression algorithm used and the decompression practices engaged in produced satisfactory decompression solutions within the depth/time profiles conducted. No symptoms of DCS post flying were observed despite deep, repetitive mixed-gas dives and a relatively short interval between the last dive and flying home.

The incidence of pulmonary oxygen toxicity symptoms (three divers) and of minor visual changes (three divers) is indicative of the high oxygen exposure associated with repetitive deep CCR diving. Both have been reported previously by technical divers in the popular literature. In all cases these symptoms were reported to have resolved post expedition. In two cases, divers reduced their number of dives (after the 69 msw dives) to reduce the oxygen exposure.

Conclusions

The use of CCRs for 74 man dives in the 50 to 70 msw depth range by six experienced technical divers, total time underwater of 100.4 hours, was associated with few technical problems. Diver health survey scores were five or less and no clinical cases of DCS were observed.

Acknowledgements

Thanks to the divers who participated and the captain and crew of the *MV Empress* for their help and cooperation.

References

- 1 Edmonds C, Lowry C, Pennefather J, Walker R. *Diving and subaquatic medicine*. 4th ed. London: Arnold; 2002.
- 2 Doolette DJ, Gorman DF. Evaluation of decompression safety in an occupational diving group using self reported diving exposure and health status. *Occup Environ Med*. 2003; 60: 418-22.
- 3 Doolette D. Decompression practice and health outcome during a technical diving project. *SPUMS J*. 2004; 34: 189-95.
- 4 Doolette DJ. Health outcome following multi-day occupational air diving. *Undersea Hyperb Med*. 2003; 30: 127-34.
- 5 Bozanic JE. *Mastering rebreathers*. Flagstaff: Best Publication Co; 2002.
- 6 Buhlmann AA. *Decompression-Decompression sickness*. English ed. Berlin: Springer-Verlag; 1984.
- 7 Pyle RL. Insights on deep bounce dive safety from the technical diving community. In: Line YC, editor. *Proceedings of the United States-Japan Cooperative Programs on Natural Resources (UJNR)*; 2001 1-3 Nov 2001; East West Centre Honolulu, Hawaii; 2001. p. 47-53.
- 8 Baker EC. Understanding M-values. Available from <<http://www.gap-software.com/staticfiles/UnderstandingMvalues.pdf>>.
- 9 Hamilton RW, Kenyon DJ, Peterson RE, Butler GJ, Beers DM. REPEX: Development of repetitive excursions, surfacing techniques, and oxygen procedures for habitat diving: *NURP Technical Report 88-1A*. 1988.
- 10 Hawkins S. Diver Mole Inspiration survey. Internet survey of Inspiration users. Voluntary participation. Available from <<http://www.btinternet.com/~madmole/divemole.htm>>.
- 11 DCIEM diving tables. In: *DCIEM Diving Manual*. Canada DoND, editor. Richmond, BC: Universal Dive Techtronics, Inc. (UDT); 1992.
- 12 Yount DE, Hoffman DC. On the use of a bubble formation model to calculate diving tables. *Aviat Space Environ Med*. 1986; 57: 149-56.
- 13 Wienke BR. Reduced gradient bubble model. *Int J Biomed Comput*. 1990; 26: 237-56.
- 14 Behnke AR. The isobaric (oxygen window) principle of decompression. In: *Trans. Third Annual Conference of Marine Technol*. Washington: Marine Technology Society; 1967. p. 213-28.
- 15 Hills B. *Decompression sickness volume 1, the biophysical basis of prevention and treatment*. New York: John Wiley & Sons; 1977.
- 16 Bennett PB, Vann RD, Roby J, Youngblood D. Theory and development of subsaturation decompression procedures for depths in excess of 400 feet. In: Shilling CW, Beckett MW, editors. *Underwater physiology*. Bethesda, Maryland: FASEB; 1978. p. 367-82.
- 17 Doolette DJ, Mitchell SJ. Biophysical basis for inner ear decompression sickness. *J Appl Physiol*. 2003; 94: 2145-50.
- 18 Doolette DJ, Upton RN, Grant C. Perfusion-diffusion compartmental models describe cerebral helium kinetics at high and low cerebral blood flows in sheep. *J Physiol*. 2005; 563(Pt 2): 529-39.
- 19 Doolette D. Psychometric testing of a health survey for field reporting of decompression outcome. *Undersea Hyperb Med*. 2000; 27: 137-42.

Andrew Fock, MBBS, FANZCA, is a senior specialist for the Hyperbaric Services, The Alfred Hospital, Melbourne, Commercial Road, Prahran, Victoria 3181, Australia
Phone: +61-(0)3-9276-2269
Fax: +61-(0)3-9276-3052
E-mail: <a.fock@alfred.org.au>