The Diving Medical Advisory Committee

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Accelerated Emergency Decompression from Saturation in Commercial Diving Operations

Report of a Workshop held on 13 April 2011 in London, UK

1 Introduction

In all saturation diving situations there is a risk that an unexpected or unpredictable event will threaten the integrity of the saturation system vessel or location. This has led to the development of various means of evacuation of divers under pressure using a bell, transfer under pressure system, hyperbaric lifeboat or hyperbaric rescue vessel (HRV); any of these systems may be referred to as a hyperbaric rescue unit (HRU). In the development of emergency situations there may be the opportunity for emergency decompression of the divers, and in the event that the evacuation system is either unavailable or where its use introduces a very high risk, a rapid decompression may offer the best chance for divers' survival. Similarly, where an HRV has been launched but early retrieval is unavailable, the question of decompression within the HRV arises. These issues represent a real concern for divers and for those responsible for their safety and wellbeing.

Discussion of these issues within the Diving Medical Advisory Committee led to a decision to formulate some guidance concerning emergency decompression procedures.

It was considered appropriate to hold a workshop meeting to establish some consensus on the basis of established procedures, previous experience within the industry and theoretical considerations of the physiological and medical issues involved.

The workshop was held in London on 13 April 2011 and involved a number of diving physicians working within the commercial diving industry, invited experts from diving physiology and related fields, commercial divers and diving supervisors. This workshop included presentations on the development of emergency decompression procedures, factors limiting the rate of decompression, possible new opportunities to enable faster decompression, review of some experimental rapid decompressions, a review of emergency decompression protocols already in existence and review of a number of incidents involving rapid decompression. These presentations were followed by considerable discussion from which the conclusions below emerged.

2 Outcomes

The following incidents were considered

1. North Sea. Rapid surfacing of bell with two divers from 70msw after loss of bell weights (ascent within minutes) led to one immediate death and one survivor with severe permanent injury from DCS.[1]

2. North Sea. Typhoon event. Rapid decompression from saturation at 170ft in 31.5 hours achieved without ill effect.[2]

3. India. Decompression from storage depth of 42msw. Transient descent to 85msw followed by upward excursion to 54msw over 3 hours. Ascent to 34msw over 8 hours, then 2msw per hour to 11msw. Final ascent from 11msw to surface over 25min (total about 23 hours from 85msw but effectively 20 hours from 54msw).[3]

[1] Submex Seminar Report. Underwater Safety in the Offshore Oil Industry. London 16 October 1986
[2] Dr NKI McIver – personal communication
[3] Dr Agit Kulkarni – personal communication

The following trial information was considered:

1. Ascent trials. Divers during routine sat ascent from 200msw, after 30 min on high ppO_2 breathing mixture ascended from 125 to 104msw in 2 minutes – all developed knee pain. Divers at 27msw saturated in heliox given 37min at high ppO_2 1.85ata then ascent to air filled chamber at 9msw followed by 6 hour hold then sat decompression to surface without any signs of decompression illness.[4]

2. Oxygen breathing and pre-breathing trials in swine of decompression from shallow air saturation related to submarine escape.[5] [6]

This historical information was considered relevant:

1. Pol and Wattele.[7] 32.5msw 4hr air exposure twice daily. 30min decompression at 1msw per min = 3% fatal 25% major illness.

Review of 'emergency decompression' tables, e.g. US Navy, Duke Table, Comex decompression procedures demonstrated that although these procedures were faster than decompression schedules in regular commercial use, the timescale for decompression would not have provided a solution for the incidents which have occurred in the past.

Concepts used in development of emergency procedures were commonly based around the assumption that as the speed of decompression was increased the risk of decompression illness would rise from being safe, through an increasing risk of articular pain symptoms, and then more serious symptoms.

It was recognised that other environmental factors such as dehydration, stress, gas contamination and confinement may affect the risks associated with decompression, and that maintenance of hydration was of critical importance.

Decompression modelling suggests that rates of decompression which might result in volumes of gas which are consistent with the absence of symptoms might be as fast as 20msw per hour in those who have not done an excursion within the previous 24 hours. Rates of 10msw per hour will result in fewer bubbles especially from deeper depths. These ascent rates will require a high ppO_2 dependent on the duration of planned decompression.

It was considered that the divers' previous pressure exposure at the time of starting an emergency decompression will have a substantial impact on the outcome of an emergency decompression.

In considering the appropriate partial pressure of oxygen to be used during the decompression, higher levels of exposure than normally used may be appropriate. In the calculation of the UPTD concept[8] [9] the exposure effect relationships at high partial pressure were an extrapolation.

3 Possible Future Opportunities

It was recognised that there is individual variation in susceptibility to DCI and that causes for this are unknown as yet. High physical performance levels achieved as a result of regular physical activity are likely to be protective. Valuable opportunities are available for further investigation (research) to improve our knowledge and enable better advice in this scenario.

Possibilities exist for the use of alternative inert gas mixture breathing mixtures to facilitate excretion of helium.

There were opportunities for investigation of novel methods of protecting divers from the risks of decompression. For example, both exercise and nitroglycerin have been demonstrated to reduce bubble formation during and after decompression.

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4 Peterson, RE and Segadal K (1980). Deep Ex 80: Compression/Decompression Project. NUI rep.no.52/80*

5 Mahon, RT et al. J.Appl.Physiol 2009;10:1152, Short oxygen prebreathe periods reduce or prevent severe decompression sickness in a 70kg swine saturation model

6 Petersen, K et al. Aviat Space Env Med 2010, 81;639. Oxygen breathing accelerates decompression from saturation at 40msw in 70kg swine

7 Pol, B and Wattele, TJJ. Annales d'hygeine publique et de medecine legale (industrielle et sociale) 1854, 1;241-279

8 Bardin, H and Lambertson, CJ. A quantitative method for calculating pulmonary toxicity. Use of the "unit pulmonary toxicity dose". Institute for Environmental Medicine Report 1970. University of Pennsylvania, Philadelphia

9 Lambertson, CJ . Effects of oxygen at high partial pressure. 1965 In Handbook of Physiology. Section 3 Respiration, Vol 1,pp1027-1046. Eds Fenn, WO and Rahn, H. American Physiological Society

4 Outcome of Discussions

Discussions commenced with agreement that accelerated procedures might be applicable where there was a clear requirement to get the divers out as fast as possible and that further discussions should attempt to identify measures which are appropriate to enable that objective.

Consideration was given to whether decompression should be attempted while divers remain in a hyperbaric rescue unit. There was general agreement that various other environmental factors present in an HRU (thermal balance, motion sickness, fluid balance) complicate and increase the risk associated with decompression, and hence decompression should be avoided until the rescue vessel is recovered. A separate issue concerned the potential situation where no method or plan for recovery of a rescue vessel existed in which case the possibility that emergency decompression within the chamber onboard the vessel represents a better option should be considered.

Two alternative profiles for emergency decompression were discussed; the first being a linear decompression, the second an immediate upward excursion followed by continued decompression. The advantage of linear decompression was that it produced the least stimulus to formation of a bubble volume which would be affected by Boyle's Law on further ascent. The advantage of an initial upward excursion was that it brought the divers closer to the surface in the event that some new situation brought forward the time scale for getting the divers out. There was no uniform agreement on the best method but it was accepted that both might have advantages in different circumstances.

It was uniformly agreed that administration of fluids was an important part of any procedure. Fluids could be given by mouth but intravenous fluid administration would be better. Large volumes resulting in high urine outputs were appropriate.

It was uniformly agreed that raising the ppO_2 was reasonable. The ppO_2 selected would be dependent on the time available for the decompression, e.g. up to 2.0ata might be reasonable for a period of 3 hours, up to 1.2 for a period of 6 hours, 1.0 for up to 24 hours. There is also an option to give an increased ppO_2 before commencing decompression (even if this was for 30min or less while the ultimate procedure was selected). It was noted that Comex had used a partial pressure of 800mbar for up to 5 days.

There was no doubt that there had been a number of saturation decompressions completed in times which were much faster than normal procedures and without resulting in symptoms.

It was not possible extrapolate from events or models at one depth to other (deeper) depths.

In the event of requiring a rapid decompression it would be necessary to consider what adverse outcomes would be acceptable, e.g. limb pain might be disregarded, more serious neurological illness leading to long-term disability would need to be considered in balancing the risks against not doing a rapid decompression.

Consideration was given to whether there was a 'safe' surface interval after a rapid decompression assuming that an alternative recompression chamber facility might be available.

Consideration was given to the question of whether there was a safe depth from which divers could be brought rapidly to the surface. It was considered that if a saturation decompression had reached 15msw then bringing the divers to the surface over 30-60 minutes while breathing 100% oxygen on BIBS would be unlikely to carry a high risk of severe adverse effects.

It was agreed that the likelihood of a successful emergency decompression reduces with increasing depth.

5 Consensus Conclusions

HRU issues:

- Decompression in an HRU is not normally considered appropriate unless reducing the depth could prolong the survivability of the environment;
- Lifeboat emergency packs should contain parenteral anti-emetics as cutaneous absorption may be poor;
- It is unlikely that gas switches could be effectively conducted towards the end of a decompression.

Chamber decompression issues:

Where rapid decompression in a chamber facility is considered, a risk evaluation exercise is required to assess the threat to the divers of remaining in the chamber compared to the risks associated with a rapid decompression taking into account the storage depth (see below).

The decompression should be planned to take place at the slowest rate consistent with a safe evaluation of the emergency time scale.

In planning a rapid decompression the selection of either a linear decompression or commencing with an upward excursion (1msw per min) should take into account the divers' recent excursion dive (pressure profile) exposure.

During the decompression a chamber ppO_2 could be raised to 1.0-1.5 ata. Higher ppO_2 mixtures would require administration by BIBS.

Breathing a high ppO_2 gas mixture before starting decompression may be helpful if the opportunity exists without reducing total time available for decompression.

All attempts should be made to obtain assistance from another dive vessel with chamber facilities for the recompression of divers completing decompression at the earliest available opportunity.

Maintaining adequate hydration was considered important. This will require an adequate oral fluid intake. Some advocated the administration of higher volumes of fluid by mouth or by intravenous route if practical. The volumes taken or administered would be dependent on the duration of the decompression but oral intakes as high as 1 litre per hour might be reasonable during a short decompression. For oral hydration, water or oral rehydration mixture should be locked into the chamber shortly before use.

Thermal control of the chamber should be maintained. If environmental control is compromised, this may increase the risk of the procedure.

Where practical, divers should be encouraged to move around but not undertake vigorous exertion during the decompression.

There is no human evidence that any drug would offer benefits but analgesia may be valuable. GTN, anti-inflammatory agents and clopidogrel may all offer some advantage in protection against DCI and are unlikely to increase the risk.

A plan for the management of complications arising during and after the decompression should include access to analgesia and anti-emetics, the availability of continued surface oxygen therapy after completion of decompression and access to recompression elsewhere for treatment of decompression illness.

6 Risk Evaluation Exercise

Evaluation of the risk to divers should cover the following issues:

An emergency accelerated decompression may be considered in any circumstance in which the safety of divers in a decompression chamber system is put at risk as a result of fire or mechanical damage to the vessel or chamber system which may result in loss of the vessel (sinking) or inability to provide continued support to the divers under pressure. Such circumstances have the potential to result in multiple fatalities amongst the divers.

The chances of an emergency situation resulting in fatalities may range from a possibility to an absolute certainty. Both level of risk and the timescale of progression of an emergency situation are difficult to assess but prediction of the outcome is likely to be more accurate as time progresses.

Actions to remove the divers to safety need to be considered at the earliest stage possible.

Two possible actions may be available. These are evacuation using a hyperbaric rescue vessel or emergency decompression. Both carry risks of illness, injury and even a fatal outcome for the divers, dependent on conditions.

For example it has proved possible to evacuate divers using a hyperbaric lifeboat in calm seas when a vessel was at risk and to return the divers to the same vessel when the emergency had been resolved. Conversely, evacuating divers into an HRV in rough sea when there is no facility for recovery within 48hrs is likely to carry a risk of fatality.

Emergency decompression will carry a relatively lower risk when storage depth is shallow, divers have made no recent excursions and when there is a longer time window of opportunity in which to conduct the decompression.

The safest evacuation procedures are likely to be available early in the development of the emergency when the final outcome may be most difficult to predict.

In using an accelerated decompression it will always be safer to reduce the rate of decompression (or stop and recompress) in the event that the emergency resolves then to speed up the rate of decompression if the emergency scenario progresses more rapidly than anticipated.

7 Workshop Participants

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Jean-Pierre Imbert
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Kaare Segadal
Prof Philip James
Prof Mike Tipton
Dr Jan Risberg
Dr Stephen Watt (Chairman DMAC)
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Rob Woodward
Barry Porter
Dr Jurg Wendling
Dr Pasquale Longobardi

Attending as observers

Dr Ravi Ramaswami
Dr Phil Bryson
Dr James Johnson
Dr Stein Modahl
Dr Maarten van Kets