Summary

The management of risk is the central process in most human occupations. The established techniques in this context are directly applicable to diving.

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TREATMENT OF DECOMPRESSION ILLNESS FOLLOWING MIXED GAS RECREATIONAL DIVES

David Elliott

Key Words
Decompression illness, hyperbaric oxygen, mixed gas, recreational, treatment.

Introduction

In 1995 the Undersea and Hyperbaric Medical Society held a two-day workshop jointly with the Aerospace Medical Association on the “Treatment of Decompression Illness”. Three weeks after the 1996 Annual Meeting of SPUMS, there will be a two-day conference in Marseilles on “Decompression accidents among amateur scuba divers” organised by the European Committee for Hyperbaric Medicine and later in 1996 there will be a further workshop on “Decompression illness in recreational diving” at the International Joint Meeting on Hyperbaric and Underwater Medicine in Milan. From so many meetings in so short a space of time and on such a relatively rare condition, there can be only one conclusion. There is no consensus.

Yet the obstacles to consensus are slowly being cleared away. There is recognition of the need to use agreed descriptive nomenclature, to collect detailed case histories (not anecdotes) from different treatment centres for analysis and, wherever feasible, to conduct trials of therapy on a scientific basis. In the meanwhile, we are forced to rely upon personal observations and experience, based on case histories. These are traditional tools in medicine which are still useful and, at the very least, can lead to the development of new hypotheses.

In the continuous search for some unifying solution, reports are presented in which treatments are compared with other treatments when, from the diverse nature and time scales of the original decompressions, one should not expect such cases to have evolved comparable pathology. The pattern of illness appears to vary with the nature of the preceding pressure exposure. For example, there are the gross differences in clinical presentation and time-course between the “bends” (old terminology) of aviators, tunnel workers and divers. Within diving itself there are differences, not surprisingly, in the presentations of decompression illness between oxy-helium saturation, oxy-helium excursions, and surface-orientated diving. Similarly, within the broad range of compressed air recreational diving there seem to be clinical differences, for instance, between those who stick to the no-stop protocols of 2 tanks-a-day for 6 days of sub-tropical resort diving and those who dive on deep wrecks in cold waters. To take this example further one could run into trouble with confounding individual variables such as acclimatisation, complement levels and hangovers that might or might not be associated with some types of diving and/or decompression illness. So there is reason to suggest that the presentation, nature and severity of decompression illness arising from advanced recreational diving might not be the same as that arising from other types of recreational diving.

Also consider how the clinical features of any decompression illness change during the first few hours after onset. Bubbling is a dynamic condition as are the sequelae. The underlying pathological status when the initial manifestations first arise is quite different from that in the same individual some 12 hours later. Most algorithms for recompression fail to acknowledge this time factor. The “Time From Surfacing to Onset” and the “Time From Onset to Recompression” are part of the management assessment and these factors should feature in the decision-trees.

Diagnosis

It is not sufficiently acknowledged that an accurate pathological diagnosis is often impossible. Also the bubble has, so to speak, much to do before its host will be diagnosed. The bubble must cause sufficient symptoms so that the diver recognises that he or she has a problem. The threshold for reporting this to somebody else is likely to vary from the hardened professional, who has been through it all before, to the anxious novice who, as Carl Edmonds suggested,[1] may report anything if he feeling less than 110%. This reporting of subjective symptoms then needs to be interpreted by a third party, a diver or a doctor who may, or who may not, take appropriate action. Of course, *we* all know that *any* manifestation arising after a dive must be managed as a potential case of acute decompression illness, but there are many who do not. This sequence of decisions will affect diagnosis, management and outcome and so, in turn, they will influence any subsequent statistical analysis.

Management

In this discussion of the management of “tekkie bends”, it seems wise to avoid considering symptoms that may be denied or subconsciously suppressed but, instead, consider a peripheral motor deficit of early onset that is more objective. The underlying pathology may be air embolism from pulmonary barotrauma, it may be decompression sickness from dissolved gas or it may be a combination of both but, for management at a remote location, does that matter? The essential issue is one of practical management, and not one of pathogenesis.

Diving first aid

Oxygen by tight-fitting mask leads the conventional list of actions to be taken without delay. A transient Trendelenberg, while the oxygen is being readied, does no harm and, in quite a few cases, may be associated with a rapid recovery. But that might have happened anyway and, if so, beware the “lucid interval”, because the condition may return.

Immediate management

At this point one the actions that can be taken are very dependent on local circumstances and what has been done at the planning stage of the dive trip. Are team individuals each well trained for such an emergency? How good are the communications? Does the boat have a radio? Where to seek help? What equipment is available? In the case of a neurological deficit, treatment is needed urgently and much depends on what local support exists, if any. Possibly nothing.

Those who have participated in experimental diving in the navy or commercial diving in the North Sea, have always dived in the immediate vicinity of a chamber. This is kept at readiness for any decompression illness. *Recompress first and diagnose later* is the rule and, under these circumstances, an immediate recompression usually leads to immediate and complete relief. This experience has led to the concept of a “magic window”, a period of up to some 60 minutes from the rapid onset of symptoms during which pressure seems able to reverse the pathological process completely. Sometimes this will not work because there may be just too many bubbles but in every case as time passes there is a potential deterioration of symptoms and an increasing difficulty of achieving full relief. Thus a treatment centre and its supporting emergency services could set targets, worthy of audit, for the time from reporting symptoms to recompression.

In the absence of a chamber on site, one has a different problem. One must consider either evacuation or in-water compression.

Evacuation

Picking up a diving casualty from a boat by helicopter for transfer to a hyperbaric centre relatively nearby is quite common in some parts of the USA and UK. This complies with the principle of urgency of treatment, but is not a standard to be expected at very many diving locations.

Evacuation to a more remote recompression chamber can take time to organise and, while waiting, catheterisation if needed, an intravenous drip and other therapeutic procedures can be started, as are well described elsewhere. With a simple semi-closed oxygen rebreathing circuit the useful life of a relatively small supply of oxygen can be extended to last for the whole period of evacuation. Several commercial versions are available and seem to provide an effective interim treatment until recompression becomes available.

Numerous reports suggest that less than 5 hours retrieval to hospital is considered rapid in some parts of the world and that, for some treatment centres, a 12 to 24 hour delay is fairly usual. Given remote geographical and other difficult logistical factors, achievement of such standards may be considered good for that area, but one should not forget that an earlier recompression might have led to better treatment results.

Recompression on site

Given the effectiveness of immediate recompression and the almost insurmountable problems from the delay associated with so many evacuations, the costs and benefits of on-site recompression for recreational diving, and “tekkie diving” in particular, deserve some reconsideration.

The choice falls between in-water recompression and having a chamber on site. The current possibilities for in-water recompression were reviewed by Pyle and Youngblood[2] but there has been no clinical trial on the relative effectiveness of the Hawaiian, US Navy or Australian in-water recompression procedures. For a number of reasons I would be reluctant to recommend the deep Hawaiian spike as a general procedure, so this leaves the two 9 m (30 ft) treatments on oxygen as practical options, the principle difference being that the US Navy version is twice as long as the Australian. Of these, the use of underwater oxygen, pioneered by the RAN,[1] appears to have been the most widely used. Success of in-water oxygen has spread by word of mouth but hard data is not available.[3] In contrast, in-water recompression using only compressed air is generally thought to have worsened more cases than it has cured.

A standard procedure for in-water oxygen recompression has been described[4] but 9 m (1.9 bar PO_2) seems to be rather shallow to be effective, so why does it work? If its effectiveness is true, one answer may be the relative immediacy of recompression in contrast to a delay potentially of many hours in evacuating to a distant chamber for an 2.8 bar recompression.

The use of a transportable one-man chamber for the evacuation of decompression casualties has been remarkably successful[5] but this too has its limitations, particularly the delay which occurs when the transportable chamber needs first to be taken to the casualty.[6]

For the provision of a prompt 18 m recompression on site there is now a more recent solution: a light-weight chamber which packs into a small volume and which can be kept close to the dive site, ready for use. This may be in a dive shop, on board a live-aboard or at any remote dive location. It can be taken there by the dive team themselves. When in use, the same chamber can be used also for airborne evacuation, at sea-level or raised pressure, and it has a small enough diameter that it can taken into most hyperbaric chambers so that a patient could be transferred while still at raised pressure. I also understand that the cost equates to that of one closed-circuit rebreather, so it would be worth considering by any isolated diving expedition. Of course, there is likely to be no doctor present when recompression is needed but this circumstance is true also for the working diver whenever he or she needs recompression. Each diving location should have one or two appropriately trained diver medics and a radio with which to call up a treatment centre for advice if needed. Not very sophisticated, but better than paraplegia.

Recompression at a treatment centre

The algorithms followed by different treatment centres are very varied. Much of the apparent difference in protocol and procedure between different centres may a consequence of their local circumstances, such as the availability of trained staff (e.g. a Grand Cayman modification of USN Table 6 enabling easier switching of attendants). Another factor is the local style of diving e.g. the deep dives of Hawaii which is associated with their use of a 66 m (220 ft) “deep spike” at the beginning of a modified USN Table 6A. Diving accidents arising in areas of French influence are likely to be treated on the GERS 30 m tables generated by the French Navy or their derivatives such as “Comex 30” which is also used regularly in commercial diving in the UK. Cases arising in many other locations worldwide will be treated by USN Table 6, extended if necessary, and possibly followed by 5 days or so of daily shallow HBO treatments for residual manifestations. Many such courses of repetitive HBO treatments are a result of geographic distances and associated delay over which a treatment centre has little or no control. In contrast, in chambers for the treatment of naval and offshore commercial divers recompression can be provided within *minutes* of onset and the divers expect to make a rapid 100% recovery on the first recompression. Indeed, any persistent residua would mean unfitness to resume diving.

Depth of dive

The majority of recreational treatment centres use the 18 m recompression algorithms, predominantly for cases arising from diving to less than 40 m and often after more than 6 hours delay from onset. Are the same procedures appropriate for decompression illness arising from shallow nitrox diving, from extreme air diving or from surface-orientated deep mixed gas diving? My answers are speculative but one must begin somewhere.

Nitrox cases can be regarded as suitable for the conventional algorithms designed for air decompression illness. Any pulmonary oxygen problems can be dealt with if and when they arise.

After deep dives on any breathing gas, if there has been a delay of some 6 or more hours from onset before recompression, one is in the salvage business and the odds are that the 18 m treatment will be a suitable approach. Given a chamber available within, say, some 3 hours then some debate is appropriate. If the condition of a deep diver is life-threatening then my personal experience would be to take a deep diver deeper than 18 m. Given a “blow-up” and a chamber immediately available on site I have taken several deeper than 50 m but the number of successful cases is probably insufficient to convince others.

Given a chamber on site that is capable of 18 m there is some evidence that this will be effective for the relatively rapid treatment of decompression illness arising from 270 feet (80 m) surface-orientated mixed gas dives. In 1966, thirteen cases of decompression illness arose from a naval series of oxy-helium dives with 20 minute bottom times, and symptoms arising within 3 hours were treated on site with the then experimental version of the Goodman and Workman 60 feet (18 m) oxygen tables. Of 8 cases so treated, all made a full and rapid recovery. After around 3 hours after each experimental dive the divers transferred to another location where the chamber staff were not authorised to use this shallow treatment and, of the 5 cases in whom the onset of symptoms was delayed more than 3 hours, all made a full recovery on a deeper air table. This is no more than an encouraging tale since it tells us nothing about deeper or longer dives or about the use of possibly more extreme decompression profiles.

Conclusion

The treatment of decompression illness arising after any type of diving is urgent. After only a few hours the medical emphasis is on neural salvage but, if recompression can be made almost immediately available at the diving site, the chances of a full recovery are likely to be maximised. This is probably true after any depth or breathing mix. The relative costs and benefits of having a small 18 m chamber on site need to be assessed before diving more than one to three hours away from a conventional hyperbaric treatment centre.

Audience participation

Unidentified speaker

Should one aim for complete resolution of all DCI symptoms and signs at the first treatment? Or should one accept some residual symptoms at the end of the first treatment and then give repeat treatments with hyperbaric oxygen?

David Elliott

I do not handle cases with a long delay before treatment so I go for complete resolution. The professional diver, if he has any residua, will lose his livelihood and therefore one wants to get, if one possibly can, a 100% recovery, even of numbness and tingling in the fingertips, before he comes out of his first recompression. Of five cases that have now settled in the courts, there were two relevant features. One was that all were suing because they were unfit to dive as a result of an incomplete initial treatment and because the subsequent hyperbaric oxygens did not cure them. The other interesting thing, all five also had a PFO (patent foramen ovale). When one looked through the records each had very unusual presentations that were not recognised by the diving superintendent. Hopefully education is now putting that right. So with anything after any dive, treat immediately.

John Knight

This is a request from a technical diver. One of his friends had two buoyancy compensator blow ups on a very deep dive in Sydney harbour. The dive boat skipper put the diver, who had missed a lot of decompression, back into the water on a hose with oxygen at 6 m (1.6 bar) for 30 minutes, then took her out and they set off straight for the hospital. She had developed a few symptoms by the time she got to the hospital and she was cured with her first treatment. Her diving buddies were sure that she would have developed symptoms much earlier if they had not put her in the water. My informant wanted to ask SPUMS, and this seems the best place to ask, whether they did the right thing or not. Can David Elliott and Bill Hamilton to give their opinions on what one should do with somebody who has missed decompression. Would it be reasonable to put them back in the water for oxygen decompression?

David Elliott

In the old days the British Sub-Aqua Club (BS-AC) used to put divers with omitted decompression back in the water to do a few prescribed stops and bring them out. It was based on naval experience and was a good routine. The current BS-AC manual says that one should keep them on deck and observe them for the onset of decompression sickness. There is current litigation by two divers who then were observed to develop decompression sickness. Their lawyer has agreed that this hazard is so serious that I am allowed to talk about it before it comes to court. I have been on to the BS-AC and hopefully they will produce a better omitted decompression routine. [*Editorial note. In fact surface oxygen is now (May 1997) recommended with no further diving for 24 hours provided the diver remains symptom free*.]

Omitted decompression is quite different from treatment. If there are no symptoms and the person has a blow up, it is a standard practice in commercial diving, and in the Navy, to get them back in the water to do the stops that they should have done and preferably a little bit extra. If one can do that within five to seven minutes missed decompression is not a problem. I think what these individuals did in Sydney is basically correct. There were no symptoms, therefore this was omitted decompression, therefore they gave the individual who had had the blow up some omitted decompression stops. I think they did the right thing. They had oxygen, they might have planned to do oxygen stops in the water which I regard as reasonably safe. I am not frightened of oxygen in the water if the person is at rest. It is when they are swimming hard that it is a problem.

Bill Hamilton

I agree entirely. I tell the people that if divers miss decompression, they should go back in the water and do it. It has to be done very quickly. I recommend using oxygen in the water if it is available. Donald showed that the 25 foot (7.5 m or 1.75 bar) oxygen fits were all in working divers. In resting divers, there were no fits or convulsions and just some minor symptoms. Even so, I do not advise using oxygen at nine metres if it can be avoided.

Chris Acott did not mention what I call the Catch 22 of in water recompression. If one has the capacity to evacuate one is going to a lot of trouble and a lot of risk to treat a sore knee. On the other hand if somebody really needs treatment because of a bad neurological hit, does one want to put that person back in the water?

Chris Acott

If the diver is paralysed one knows that Goodman and Workman showed that all those they treated at 33 feet (10 m or 2 bar) had to be treated again. At the Diver Emergency Service in Australia we get a lot of calls about people in remote locations outside Australia. Some of them are on normobaric oxygen. Sometimes their clinical condition has improved quite dramatically by the time we talk to the local doctors. Then it is often difficult to convince the patient to accept a medical evacuation because they are feeling so much better. We know that they will probably relapse as soon as the oxygen comes off but they do not believe us. So we lose twelve hours getting the plane up to them.

Des Gorman

In-water oxygen decompression is the single most commonly practiced form of decompression for virtually any form of diving below 50 m. It has significant advantages. There are discernible disadvantages.

The major disadvantage of in-water oxygen decompression is oxygen toxicity. I think a stage is inadequate for oxygen decompression deeper than 6 m. I do not believe there is any correct answer to the response to a fit in the water unless one has an open or a closed bell. Then the answer is to control the airway, go to a lower oxygen fraction and when the fits stop, resume oxygen and continue the decompression. In an open bell I can hook someone up. I can take their hat off. I can maintain their airway. The Royal New Zealand Navy practices exactly that when they use open bells. A closed bell is the complete answer. It enables one to do a transfer under pressure, the diver can have an oxygen fit in the comfort of a dry recompression chamber and anyway the chances of a fit are significantly lower once out of the water.

On a stage or with a free swimming diver my answer is simply to get the diver out of the water. But I believe that any action taken then should be the least obnoxious option and depends on the equipment being used and the risk of drowning.

Bill Hamilton

We have a room full of anaesthesiologists. Is the glottis going to be closed or not on a person who is having a convulsion and during what phase of the tonic/clonic seizure?

M Davis (Chairman)

As an anaesthetist I might answer that. I would suspect that during the tonic phase the glottis is almost certainly closed and in spasm along with all the rest of the musculature. But soon after that it is going to open again. However it is not only the glottis that determines the patency of the airway. In fact it is usually the position of the tongue, the jaw and the epiglottis.

Bill Hamilton

What are the contra-indications to trying to get the person to the surface? I am not talking about someone in a bell, or with a full face mask, but about someone who has spat out the mouth piece. My personal feeling is that one should avoid drowning them. Someone said earlier that when choosing between embolism and drowning, take drowning as one can treat that. I would say take the embolism because it probably will not happen and try to avoid having to treat the drowning.

David Elliott

I have no disagreement with what Des has said. When the odds are that the mouthpiece is going to be out, I think the PADI recommendation, of bringing them up, is correct. If the diver is actively fitting, *and has the mouthpiece in*, then postpone going to the surface until the fit is over.

Bill Hamilton

An AGA full face mask costs about 800 or 1,000 dollars. It is not cheap. But there are full face masks for a couple of hundred. It is claimed that wearing a full face mask results in about a 20-25% increase in gas use. With microphones used for communication divers use even more gas. It is increase in gas consumption which puts divers off buying full face masks. I do not understand why the diver uses more gas when using a full face mask. It should not be any different from any other demand valve. Even if it is true I think a full face mask is worth using when at risk of oxygen toxicity. I certainly would want one.

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A COMPLETE SUBMARINE ESCAPE AND RESCUE ORGANISATION

Robyn Walker

Abstract

A complete submarine escape and rescue organisation should allow the survivors of a submarine accident to exit the submarine, be rescued and be provided with appropriate medical treatment for resultant injuries. Survivors may leave the submarine in two ways. The first involves an “escape” where the survivors leave the submarine through an escape hatch and make a buoyant ascent to the surface. This is limited to a depth of 180 m. Alternatively the survivors can be “rescued” by a rescue vehicle and be transported back to the surface where subsequent decompression can be undertaken. Rescue is required to cover the depths from 180 m down to the crush depth of the submarine.

Predicted medical conditions in submarine accident survivors include decompression illness, gas toxicities, near drowning, traumatic injury, thermal stress, sea sickness and psychological trauma.

The Royal Australian Navy (RAN) has a commitment to provide a full submarine escape and rescue organisation for the benefit of the submarine arm. This paper discusses the development, and trial, of a medical contingency plan to treat 55 survivors of a submarine accident. The integration of a full rescue capability into this plan will be presented.

Key Words

Accident, bell diving, decompression illness, emergency ascent, hyperbaric facilities, surface decompression, transport, treatment.

Introduction

If a submarine becomes disabled and sinks how the crew gets back to the surface is dependent on a number of factors. These include the internal pressure of the submarine, the internal atmosphere of the submarine, the weather conditions and the state of readiness of the rescue forces.

There are two methods of leaving a disabled submarine, escape and rescue. Escape is where the survivors leave the submarine through an escape hatch and make a buoyant ascent to the surface. Escape may be using the single escape tower (SET) hooded free ascent method or by rush, or compartment, escape. SET escape, which reduces the time each individual is under increased