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ON-SITE RECOMPRESSION TREATMENT IS ACCEPTABLE FOR DCI

Alf Brubakk

Key Words

Accidents, decompression illness, treatment.

Introduction

"I think it has been clearly established, that treatment in a recompression chamber by people who are trained and competent probably constitutes the best scenario. On the other hand, if that treatment can't be carried out for six or seven hours because of the location of the dive or for any other reasons mentioned today, then transport may not be the best decision for that diver." Overlock 1999.[1]

There is general agreement that treatment of DCI using the USN 6 with oxygen at 18 m is the standard treatment.[2] However, in most parts of the world, the diver is far away from any proper treatment facility for DCI. Pressure chambers are only available on site in commercial operations in parts of the industrial world. Furthermore, many of these chambers are operated by individuals with only limited experience and certainly little medical know-how. Thus, proper treatment and diagnosis is only available to divers after lengthy and often difficult transport. Due to the fact that it is accepted that the time to treatment is important, transport is often performed under dangerous conditions. All the above would indicate that it is well worth exploring if there are other possibilities.

For many years there was a discussion about the advisability of training the average citizen in cardio-pulmonary resuscitation (CPR). The discussion was mostly centred around the problems and the risks to the patient, ignoring the fact that there were few alternative to prevent death of the patient. It is recognised today that even if the treatment performed by a layman is not optimal, it can be of benefit to the patient. This analogy is not perfect in so far as we are in many cases not dealing with a life threatening condition, but still one which may lead to serious morbidity.

Why on-site recompression treatment?

It is accepted that pressure and oxygen are the main ingredients of DCI treatment. Oxygen at the surface is now widely used as a primary treatment for DCI symptoms and data indicate that the use of oxygen will reduce symptoms before definite treatment can be instituted.[3] However, for definite treatment, pressure is also needed, in particular in severe cases. The main point about on-site recompression is to reduce the time between injury and treatment.

What is the result of traditional treatment ?

In a report from the treatment chamber in Barcelona, the majority of the patients arrived after 1-6 hours, but many with a considerable longer delay.[4] Most of the diving was done within one hour's flight of the chamber and many sites were much closer. Even so, the usual time to treatment was quite long. Their results showed that about 30% had mild sequelae and 4-5% had serious sequelae or handicap after the treatment. The results are similar to those seen in many centres, approximately 70% of those who get treated after a 6 hour delay get better or are healed.[5,6] The results can be seen in Figure 1.

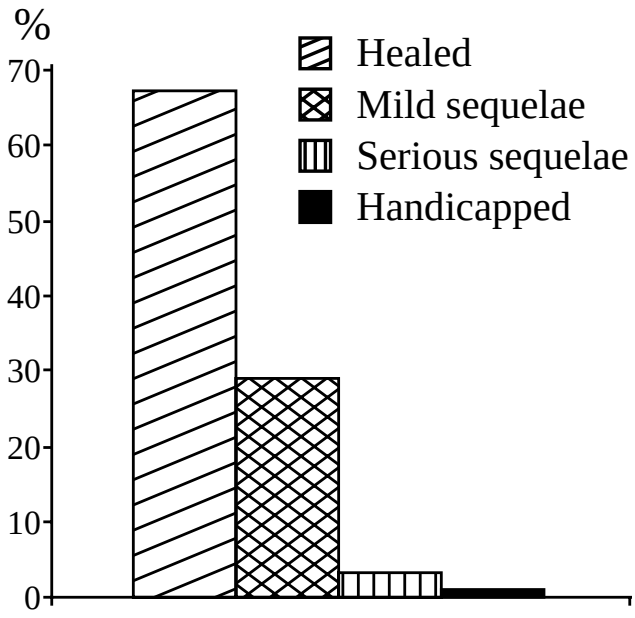

Figure 1. The outcome of treatment in a major treatment centre (Barcelona).[4]

In another study, from Hawaii, the delay to treatment was considerably longer.[7] Here over half the patients had a delay of 12 hours or more before they got to treatment. Regrettably their data are not presented in the same way as that from Barcelona, but rather as improvement in symptoms. Their results show that about 21% of the patients with AGE and 30-35% of the patients with spinal and cerebral DCS had only slight improvement by the treatment. There are always problems with comparing results from different centres, but the results seem to indicate that time may matter, in the sense that a significant number of patients had sequela after finishing treatments.

The conclusion of the study by Desola et al. was that time to treatment is not important, they could not find any correlation with time and the end result.[4] The same conclusions could be drawn from a study by Ross et al. in Aberdeen.[8] In their study of 269 cases of DCI, the median time to treatment was 5.5 hours and 14% had significant sequelae after treatment.

One explanation for these findings could be that after a rather short time period, probably in the order of 30–60 minutes (see later), time is not any longer of major importance for the final outcome, but rather, as Ross et al. point out, the severity of the symptoms.

It is interesting to note that in a much older study, looking at the treatment results after using USN air treatment tables (1A and 2A), the failure rates were 21% and 19% respectively.[9] This eventually led to the abandonment of the air treatment tables.

Why can we expect on-site treatment to give better results ?

This is based on the following hypothesis. Initially, I believe that the mechanical effects of the bubbles are the main problem. Following decompression, there is a time delay before bubbles start to grow, this delay is shorter the more severe the decompression insult. From air dives this delay is typically 20–40 minutes. If recompression is started at this point, then the bubbles will be reduced in size and removed. If however the bubbles are allowed to stay on, the early mechanical effects of the bubbles are no longer reversible, and the secondary effects of the bubbles is now what has to be treated. These could be ischaemia due to vascular obstruction or secondary inflammatory effects set off by the bubble surface or the injury. Once the secondary effects have really started with all their inflammatory processes, then apparently that is still treatable, but the effectiveness of treatment is less, so that the time to further treatment is not particularly critical. Based on this scenario of the pathophysiology of this disease, the time to treatment is the most important factor in determining the outcome of the decompression accident.

There are some clinical experiences to support this scenario. Surface decompression using oxygen is a standard method used in commercial diving all over the world. Using this method, divers are rapidly decompressed and then recompressed within 5 minutes in a deck chamber, usually to 220 kPa (2.2 bar). Studies have shown that this procedure has no higher incidence of DCI than other procedures,[10] while studies both in man[11] and in animals[12] have shown that accepted decompression procedures produce a significant amount of bubbles in the surface period before recompression

During the development of new decompression schedules for the Navies around the world, it is customary to test the procedures in human dives, some of which produce serious decompression sickness. These trials are designed so that the individuals with symptoms are treated immediately and it is the belief of the testing agencies, as expressed in their application for approval to ethics committees, that immediate treatment does not leave any sequelae.

There are also some clinical decompression studies that would seem to support rapid treatment. Ball found that delay in treatment did not influence outcome in mild cases of DCI, but that delays over one hour in the severe cases did.[13] Lam and Yao found. in tunnel workers. that delay increased the depth of relief.[14]

Does rapid recompression give better results?

In animals we performed a study where we recompressed animals to 200 kPa (2 bar) breathing air following a dive to 500 kPa (5 bar) for 40 minutes, decompressing at 200 kPa (2 bar)/minute.[15] The animals were recompressed at the time of maximum bubble formation, 20-40 minutes after surfacing. The animals were kept at pressure until all gas had disappeared then 30 minutes more, after which they were rapidly decompressed to the surface. The animals were observed for a week and then sacrificed. Only one out of seven animals developed symptoms of decompression sickness, at autopsy this animal had a small infarct in the spinal cord, no pathology was detected in the central nervous system, the lungs nor in the endothelium of the pulmonary artery in any of the other animals. The pressure exposure which these animals were given produces a large amount of gas, which in many cases was lethal. We were also very impressed with the effectiveness of treatment in these animals, some of the animals were dying with no respiration and hardly any heart activity at the time of recompression; they immediately improved at pressure and their experience had no long term effect.

This study is supported by the results from in-water recompressions where probably the recompression is in most cases rapidly performed. In a study from Hawaii, 525 divers

were treated, the result of the treatments can be seen in Figure 2.[16] All treatments in this study were performed on air, the difference to the traditional treatment shown in Figure 1 is apparent. A later prospective study on 86 cases, where 94% of the cases were treated on air only, showed a similar trend, but here only 58% were termed asymptomatic after treatment.[17] It must however be pointed out that this last study is severely biased, as nearly all of these cases are divers who sought additional treatment. This may reflect a change in attitude in the diving population, but it is reasonable to assume that a large proportion of those who did not have any symptoms after treatment returned to work.

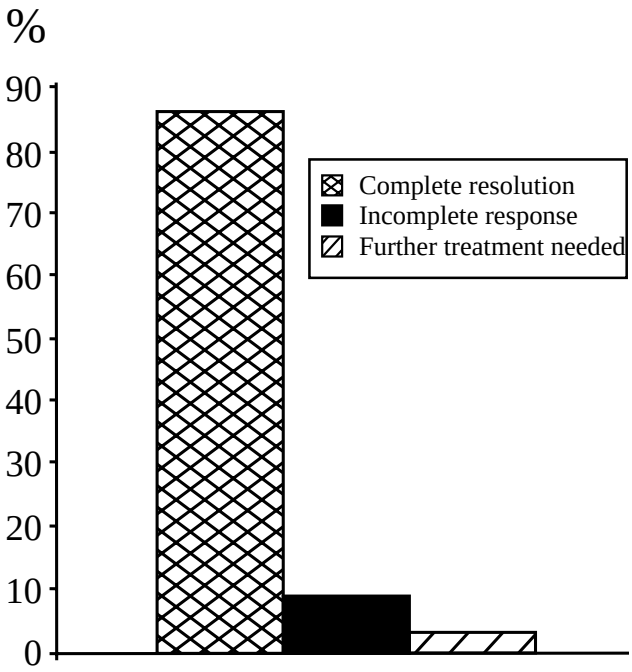

Figure 2. The outcome of in-water treatment.[16]

In the Australian experience, oxygen has mostly been used at 9 metres. According to the report by Edmonds,[18] about 500 cases of DCI was treated with underwater oxygen, only one individual required Medevac and further treatment.

In the Australian oxygen procedures only 9 m treatment depth is used. That this may be adequate for immediate treatment is supported by the study of Koteng et al. who compared the time to disappearance of gas bubbles from the pulmonary artery following recompression on various procedures to 200, 280 and 400 kPa breathing either air, oxygen or a nitrogen or helium/oxygen mix.[19] This can be seen in Figure 3. The addition of pressure increased the time to disappearance significantly, as compared to the use of oxygen on the surface, but there was no difference between the different treatment regimes. A subsequent study showed that the addition of pressure probably did not increase the elimination time for inert gas, this time is only dependent upon the composition of the breathing gas.[20]

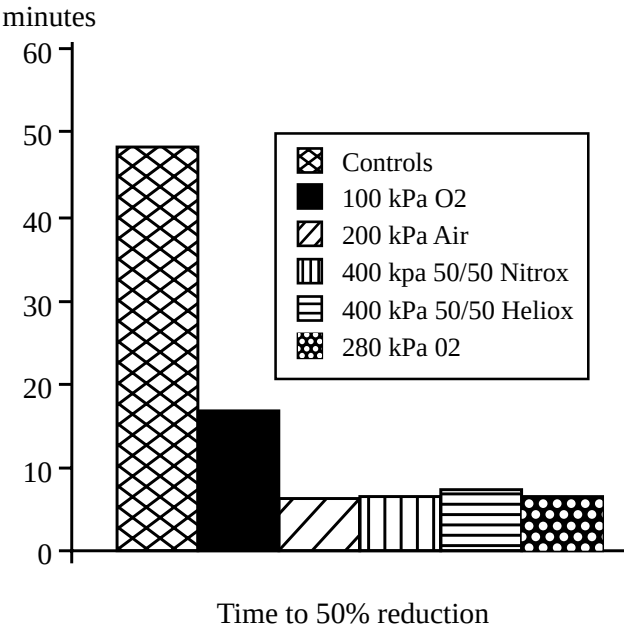

Figure 3. Time from recompression to elimination of 50% of the gas bubbles from the pulmonary artery.[19]

All the above indicate that rapid recompression treatment can by effective, at least as a first-aid measure, and it is reasonable to assume that this procedure can be performed safely and effectively.

On-site treatment options.

Oxygen at the surface has now been recommended for years as a useful first aid for diving accidents. As mentioned above, the data from DAN Europe show that oxygen is effective in relieving symptoms.[3] However, a recent study from DAN USA show that of 179 divers who received oxygen before recompression, 71% experienced complete relief after recompression compared to 64% of the 250 divers who received no oxygen before recompression treatment. This would indicate that the effect of oxygen as first aid on the final outcome was less than could be hoped.[21] It would support the idea that on-site treatment should include pressure.

In planning to use on site treatment, two things are important. First, what kind of equipment are available? Second, what is the danger of performing a treatment, for the patient, the treaters and all those involved.

In-water recompression

Medical experts have had a long, and very heated, debate about whether this treatment modality is acceptable or not. It is important to remember that this is medical first-aid, with the aim of saving the patient's life or reducing his or her risk for permanent damage. As was pointed out above,

all published accounts of this treatment modality indicates that this is a very efficient treatment. Both in the recreational and technical diving community there is a large group of people who simply do it and they do not make much fuss about it. In many cases, I suspect that the treatments are not even reported. That is particularly the case for the so-called technical divers who have the expertise and equipment for performing this procedure. Perhaps that is one of the reasons why the incidence of decompression problems in this community is so low, in spite of some of the extreme diving that is done.

It is now recommended that all in-water recompression is performed on oxygen. The main difference between the Hawaiian and the Australian procedure, is that the former uses a deep spike to depth of relief plus 30 feet (9 m), down to a maximum of 165 feet (50 m).[22] This recommendation is probably based on clinical experience, but has little experimental support, most treatment centres now use a maximum pressure of 280 kPa (2.8 bar corresponding to a depth of 60 feet) for all treatments.[2]

The treatment procedure which was advocated in Australia is at 9 m, usually with a surface supply of oxygen, using a full face mask. One needs a tender, an underwater attendant, a method to control depth, and the Australian Underwater Oxygen table.[23] For mild symptoms 30 minutes at 9 m, then a gradual reduction in pressure of 1 m every 12 minutes (or 1 foot every 4 minutes), if improvement has occurred. If there has been no improvement the patient stays at 9 m for a further 30 minutes before starting the ascent. The total treatment time for mild symptoms is 2 hours 6 minutes to 2 hours 36 minutes in more severe cases. Divers with severe symptoms spend an extra 30 minutes at 9 m and surface at the same rate as those with mild symptoms. Ideally, if the treatment is performed from the shore, one can have the patient moving slowly up the sloping bottom. The reality is probably in many cases not like that. It may be in open water, hanging on a line. It cannot be very easy to follow this table accurately unless one uses 1 m stages.

One potentially serious problem in using oxygen, as described above, is oxygen convulsions. A dive on oxygen to any toxic pressure involves a risk which is difficult to assess. Donald concluded that there is a risk for convulsions from oxygen toxicity in water deeper than 7.5 m (25 ft), that is an oxygen tension of 170 kPa (1.7 bar),[24] or less than that of the treatment tables 190 kPa (1.9 bar). Donald showed that sensitivity to oxygen toxicity of the individual varies considerably over time and that it varies quite a bit between individuals. An individual who has been treated on oxygen on one occasion with no problems, can easily get convulsions with a second treatment. In spite of this, this may be more a potential problem than a real one, as there has to my knowledge been no published reports of such an incident. Due to the seriousness of this complication no in-water recompression should be attempted without the tender being trained in how to handle this problem as it is described in the USN diving manual.[25]

In-water oxygen is not a treatment that should be lightly considered, but it is clearly an alternative, and seems to be very efficient as a first treatment, in many cases even as a definite treatment. One needs, however, to consider whether one has the equipment to and the proper training to do the job.

An important question is of course, will the results justify the risks? The risks are numerous, including convulsions; cold, even in warm water, because the person is sitting motionless in the water for several hours; also dangerous animals have to be considered.

Because of this, I believe one needs a training program if this treatment is going to be used more extensively. One needs personnel who are trained; the patient needs a face mask with oxygen compatibility; there must be some way of keeping absolute depth control. There must be thermal protection. One must have procedures and training to handle convulsions, not an easy matter. Both equipment and training programs are needed for in-water recompression to be a serious alternative.

Single person emergency chambers

An alternative is to use one man chambers. Up till now the alternatives have been rather big and also quite expensive. With the introduction of new materials it should be possible to develop a much simpler, lighter and cheaper type chamber that can be part of any diving operation. Such a chamber, if generally available, would be an alternative to in-water recompression. Figure 4 (page 165) shows one such chamber, which fits into a tube about the size of a golf bag, that was demonstrated at the 1999 Annual Scientfic Meeting. The bag is unrolled, the air supply is plugged in and the patient enters feet first. When all is ready the bag is folded over at the end and a U tube is slid over the folded end to seal it. As can be seen there is an oxygen mask for the patient.

Treatment on land has several advantages. The patient is not in the water, which means that the risk of oxygen convulsions is much lower and the consequences, should it happen much less severe. In Donald's studies it took, approximately, between 2.5 and 5 times longer to get convulsions in the dry than in the water.[26]

In such a chamber, air may be used as a treatment gas if the initial treatment is performed quickly as is described above. Figure 5 shows the result from one of the experimental animals from our study.[15] The amount of bubbles after the initial dive was at the level comparable to Grade 4 + on the Doppler scale, a very severe gas load, that

Figure 4. Portable chamber demonstrated at SPUMS 1999 ASM

in the majority of cases is lethal in pigs. Note that the bubbles disappear quite quickly upon compression, but some bubbles return when the animal is decompressed to the surface, this indicates that the pressure exposure probably was too short.

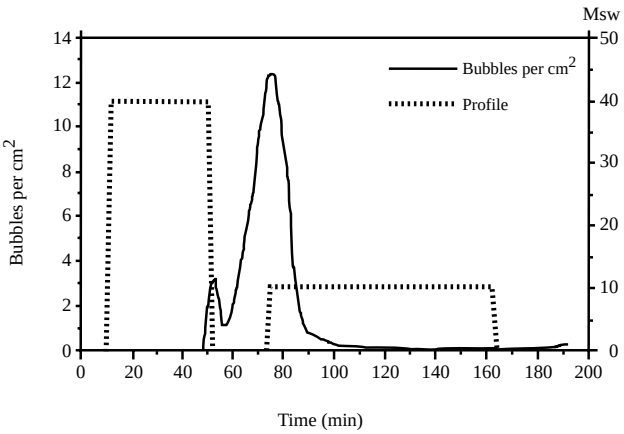

Figure 5. Effect of recompression to 200 kPa (2 bar) on pulmonary artery bubbles.[15]

What are the advantages and disadvantages of on site treatment?

In my opinion, one of the major advantages is that there seems to be better results from immediate treatment. We can avoid immediate transport and can postpone that transport until it is safer or more economical to do so. We have a fully controlled situation, because if we have the capability to treat initially. It is also possible that the on-site treatment, at least in some cases, could be definitive treatment. If the patient is free of all symptoms and signs after the initial treatment, transport by air over long distances is probably not even advisable.

One major advantage of initiating on-site treatment would be that the threshold for reporting symptoms and signs would be lower. The fact that divers often will deny symptoms is well known. We did a survey of Norwegian divers and found that 20% of the sports divers and 60% of the experienced professional divers had had clinical symptoms of decompression sickness without reporting it.[27] If on-site treatment gets recognised as a useful primary treatment, then it is possible that more divers will report problems.

There are also clear disadvantages to introducing such procedures. The most serious one is perhaps that the a significant number of divers will not receive adequate treatment or that it will be postponed. Another is that if the divers know there is a treatment possibility close by, then they may perhaps take more risks. In addition there are of course problems related to the procedures itself, in-water treatment has already been mentioned.

A possible procedure for treatment of DCI in remote areas

On-site recompression is only an option in remote areas. If, however, one defines a remote area as one that is more than six hours away from a proper treatment facility, then most areas in the world would qualify. In 1998, only 20% of the divers in the DAN study were recompressed within six hours.[28]

Oxygen on the surface (if available) is already accepted as a useful first-aid measure, Furthermore, oral fluids are also recommended. Intravenous fluids and drugs may by considered but will obviously require more skill and equipment than we can expect the average dive team to carry.

It is the argument of this paper that pressure should also be considered as an additional treatment option, either using air or oxygen. In order to introduce this possibility there obviously has to be improved training and the introduction of adequate equipment. In particular, we have to train our divers much better in recognising the signs and symptoms of DCI. The on-site option will, in my opinion, be much less effective and useful if many hours have passed since symptoms were detected.

I think, however, that the most important point is to get the medical and diving community to accept that the majority of the diving is done at locations where optimal treatment facilities are not available. Thus, we must be willing to accept solutions that could benefit the patient, solutions that may not be totally adequate from a medical

point of view, but that would improve the end results. Such an acceptance would encourage the production of suitable equipment and the necessary research into the many problems that still exist in this area. I think there is sufficient data to show that on-site treatment is worth further investigation.

A final thought is that there is a lot of commercial diving going on in the Third World that is totally unregulated and where the incidence of DCI is extremely high. These individuals usually have no access to proper treatment facilities and simpler methods of treatment may benefit them considerably.

AUDIENCE PARTICIPATION

John Knight

You asked if any one here had any experience with in-water oxygen treatment. I have not had any experience, but I have carried out, at the SPUMS meeting in 1977, a demonstration of it. We had a victim who was wearing a wetsuit, we had a line, which she sat in, to the diver, and that line was marked in metres. We had a stand by diver on the surface, and we had an attendant diver with her. We put her down, and then we brought her up at 1 m every 12 minutes, a 12 minute pull is very difficult, but a 1 m lift every 12 minutes is easy, which is what we did. We used nine 1 m stages each of 12 minutes. This is a very much slower ascent than any other treatment table (108 minutes for 9 m). In imperial units, one comes up a foot every 4 minutes, which means that the steps are less steep, which may, or may not, be better for avoiding bubbles reforming. Our volunteer complained that her bottom felt that it had been cut in half while sitting in the bight of the rope. If one is going to do in-water recompression one must give the patient a seat to sit on. They need extra weights on their legs, because we found the legs floated up. There have to be at least 2 attendants, a rope tender and an oxygen tender, who can be the supervisor. He has to make sure the oxygen does not run out. The patient can be assessed any time by sending the stand-by diver down, and the attendant comes to the surface and reports the patient's condition.

It was a most useful exercise for SPUMS, using the full face mask, oxygen, etc because we were at Truk Lagoon. The hospital there had a one person chamber, but there was a problem with the gas supplies. The only compressed oxygen normally on the island was what they used for the anaesthetics for women who could not deliver and had to have a Caesarean section. We were so far away from Guam, the nearest USN chamber, that we thought we really should take everything necessary with us, so we really could treat anybody who was unfortunate enough to get decompression illness.

Robyn Walker

Talking about in-water oxygen, we must remember that technical divers are using oxygen at 9 m to decrease their risk of DCI. These guys are out there using oxygen now. There was a technical diving conference in Sydney last weekend, where there was a debate on in-water decompression. Despite having listened to it, I do not believe any consensus came out of that. However, I am told that on the Web site, it was already saying that the consensus of that meeting was that in-water recompression is the way to go. Perhaps we will see more people using it.

Alf Brubakk

Technical divers use in-water oxygen regularly. They use surface oxygen for treatment of symptoms. I am convinced that one of the reasons they report so few symptoms is that they do that. They have the equipment and experience to do it. Whether we like it or not, in-water recompression is here. The question is whether we can do it better, or are there alternatives? But the technical diver is a special breed.

Mike Bennett

Amongst the things that you said, the thing that I did not hear was how I am going to improve the situation around our area. The problem is not transport time. When we look at our figures and delays to treatment, we cannot see a trend where the outcome is worse the longer the wait. That is because we have so few people with very short times to treatment. They are not late because of some problem with distance. They are late is because they diagnose themselves late. Typically, people coming by air ambulance transport, where flight times are an hour to an hour and a half, actually get to the unit 24 to 48 hours after their injury. That is where the problem lies. We are not going to get a chance to treat them on site.

Alf Brubakk

There are several studies which show that there is a long time to reporting. My argument for seriously discussing the possibilities of increasing on site treatment is that I believe it is easier to report symptoms if you know you can be treated on site and not have to have the long transport. I remember some years back, when I talked to someone in the airline industry, where they had a lot of problems with people not reporting errors. The way they solved this was by introducing non-punitive reporting. The reporting has no consequences for the reporter. This means that even if you do something very stupid, everybody just notes that it happened and you and others can learn from it.

In diving it is something very similar. People feel that the rigmarole of treatment and follow up that they start when they report symptoms interferes too much with their lives. I believe that many symptoms would get reported more quickly if they knew they could get treatment and that was the end of it.

I agree that late reporting is a serious problem. Even people who are very experienced, when they start getting

symptoms, they deny them. The best example of denial that I know of was when I was a medical student. We had an excellent Professor of Surgery. For one lecture, he came with a couple of x-rays and gave us a talk on how an x-ray of ulcer could be mistaken for cancer. It was quite obvious, even to a student, that it probably was cancer. They were his own x-rays. He simply denied what was reasonably clear. That was, for me, a clear indication that we have very powerful forces of imagination when things are happening that we do not want to happen.

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PANEL DISCUSSION ON THE TREATMENT OF DECOMPRESSION ILLNESS

Moderator Dr Chris Acott

Panellists
Drs Michael Bennett, Alf Brubakk, Richard Moon and Robyn Walker.
(with audience participation)

Key Words
Decompression illness, treatment.

Moderator (Chris Acott)
What symptoms would the panel treat?

Alf Brubakk

With minor symptoms which do not progress, I do not think there has been anybody who has shown that not treating with recompression leads to serious damage. As we have shown ourselves, non-treatment does, however, lead to mild CNS symptoms. I think there is a considerable under-reporting, minor symptoms are in many cases not treated today. However, if someone has neurological symptoms, these should be treated. I believe that if we insist that everybody should be treated with the standard procedure, a large number of patients will not come forward. I admit that this is perhaps a dangerous statement.

Richard Moon

I think that anyone with symptoms that could be attributable to decompression illness should receive recompression treatment. That would include classical, well defined instances of pain not attributable to other causes, and neurological symptoms. Occasionally it may be worthwhile to treat someone complaining of extreme fatigue.

Mike Bennett

I am pretty much in agreement with Richard Moon there. As many people in this audience are aware, and as we have heard several times over the past few days, the experience of what exactly is decompression illness and who presents can be vastly different in different settings. In most of our recreational diving settings, the patients are, in the vast majority, not extremely seriously bent, in a sense of having dramatic symptoms and signs. Most of them have some subtle signs, but mainly they are complaining of fairly non-specific symptomatology. When we see such people who have not been treated, and we often, perhaps a dozen times a year, see people several weeks after their last dive who have been feeling this way for that time, their lifestyle is seriously affected. They are not happy people. The question of whether, after several weeks, it is worth recompressing them, is not really my point. Actually most of the time we end up recompressing them as an act of desperation as much as anything else. But those people who have apparently fairly trivial signs in our opinion need to be compressed, otherwise they end up with ongoing minor illness, which actually takes up most of their attention, and they do not work well. They continually ring us up to complain about their performance at work and so on. While some sort of one atmosphere oxygen immediately after the dive might have been adequate treatment for their symptoms, we seldom see that situation. When people get to a facility with a recompression chamber and complain that they have had symptoms since diving, then I think they should all be taken seriously.

Robyn Walker

I agree with the others.

Richard Moon

I would like to comment on what Mike Bennett just said. It has been said that only a small proportion of patients who have been treated for decompression illness have long term sequelae, and that most of these are minor. In my experience, the anxiety that is induced by even minor symptoms is extremely important. Divers with ambiguous or minor symptoms may not need to be treated, and if they are treated, the degree of improvement after recompression may be similarly ambiguous. But the fact of their having received the ultimate in treatment, such as a Table 6, means that the patient can be reassured that the bubbles that may have been causing their symptoms, have now gone. This goes a long way toward relieving anxiety.

Chris Acott

It has always appeared slightly illogical to me that we have the same treatment table for a disease which presents in so many different ways, but also from so many different gas loads and diving profiles. However I think Table 6 has been the only table with any data to support using it.