are micro-emboli of gas bubbles in capillary networks in the spinal cord and subsequent oedema and ischaemia of the spinal cord. Some people would clearly argue that this should be treated quite aggressively and vigorously with early recompression. Should decompression be used diagnostically in this regard? That is another possibility, another question to raise.

Another big factor that comes up is the cost benefit of recompression when one considers the enormous increase in the amount of sports diving that is being done and the big demand that a recompression treatment makes, particularly on human resources, not to mention the cost in dollars. In North Queensland where the human resource commodity is spread so thinly it is quite a demand. I think these cases, particularly the latter case, raises that important point.

These two cases of decompression sickness, one with obvious demonstrable neurological lesion where the US Navy, less conservative, tables were not exceeded but where the guy had obviously thrashed himself around that weekend and really overdone things, the second have a very marginal case where the diagnosis was in doubt and the treatment was not effective in that it did not improve her, ie. suspected bends only, where the US tables were obviously very well exceeded, leave us with the dilemma that we have always been in. Just what value are decompression tables in helping us decide when to treat someone and just how should we be interpreting them?

DECOMPRESSION SICKNESS AN OVERVIEW

Bart McKenzie

I have to try to compress decompression sickness into 25 minutes, which is going to be no mean feat.

To start with there are a few basic physical principles. The first one is the concept of pressure. There is about 100 km of atmosphere above us and that exerts a certain amount of pressure which is called one atmosphere pressure. Ten metres of sea water exerts the same pressure as one atmosphere. So at 10 metres there are two atmospheres of pressure acting on the diver. At 20 metres there will be a pressure of three atmospheres, and so on. A diver does not have to go very deep before there is a considerable pressure acting on him or her.

Now to mention a few gas laws. The first one is Boyle's Law which states that volume varies inversely with pressure. If one takes an inverted open jar and pushes it down under the water, as the water pressure increases the volume will decrease. This has a lot of importance in the treatment of various things in diving medicine. If a diver has gas bubbles in his tissues and one applies increased ambient pressure to the diver then the bubbles will decrease in size. This may eliminate his symptoms. If the diver goes up in an aeroplane while he had bubbles in his tissues, the bubbles get larger. This has relevance to the transportation of divers. If he was breathing from compressed gas equipment and took a breath at some depth and came to the surface holding his breath, then that would spoil his whole day. The next concept is Henry's Law. When gas is in contact with a liquid some of the gas will dissolve in the liquid. Double the partial pressure of the gas over the liquid then twice as much gas will be dissolved in the liquid at equilibration. So when a diver is breathing compressed air under water nitrogen is taken up by his tissues and that has certain consequences which I will go into later. An important concept is diffusion. If someone was to pass flatus on one side of the room then it would not be long before people on the other side of the room were looking accusingly at each other. That is the process of diffusion. You can use diffusion and diffusion gradients in the treatment of decompression sickness by modifying gas partial pressures. Another important law in diving is Murphy's Law which states that if something can go wrong it will go wrong, usually at the most inconvenient time.

I would like to stress that diving is great fun. However, like all things that are great fun it has some drawbacks. One of the big drawbacks of diving is decompression sickness. A sports diver breathing under water has a demand valve which delivers gas to him at a pressure which is roughly equivalent to the ambient water pressure. So the deeper he goes the higher partial pressure of nitrogen he is breathing. This nitrogen is taken up. It equilibrates instantly in his alveoli and then it is delivered by the blood to the various tissues. Tissue uptake of nitrogen is dependant on several factors, the main one being the blood flow of the tissues. So tissues that have a high blood flow take up nitrogen quickly and equilibrate quickly. While tissues that have a low blood flow do not equilibrate so quickly. When a diver comes back to the surface he has an excess of nitrogen dissolved in his tissues. If the partial pressure of nitrogen exceeds a certain critical limit the nitrogen will come out of solution and form bubbles. This is analogous to the situation of carbonated beverages. If one looks at a bottle of champagne before taking the cork out there are no bubbles in it. There is carbon dioxide in the bottle but it is dissolved under pressure and the cork holds the pressure in. When the cork is taken out the pressure is released, the bubbles come out of solution quickly and everybody has a good time. But divers with bubbles do not have a good time.

When diving with compressed air equipment started about 150 years ago the divers found that if they spent a long time under water, especially at great depth, they would develop the symptoms of decompression sickness. They also figured out by trial and error that if they came up in stages, rather than coming straight up, that could minimise the symptoms and sometimes stop them from getting decompression sickness altogether. So there were various ad hoc decompression routines built up over the years. However early in this century Haldane worked out some decent decompression tables which would allow divers to dive to practically any depth that they wanted to, at that time, and come back using decompression stops and not get decompression sickness. He based his tables on two basic hypotheses. The first was that the gas uptake by a tissue, or gas uptake by the body occurs in an exponential fashion and also that gas elimination occurs in an exponential fashion. He also dreamed up some hypothetical tissues in the body and worked out his tables on the basis that there were probably half a dozen tissues in the body which took up nitrogen at different rates. Using exponential equations he could work out at any given time, for any given depth, what the partial pressure of nitrogen in these tissues would be. His second hypothesis was that divers could withstand a two to one difference in pressure between the pressure of nitrogen in the tissues and the ambient pressure without developing decompression sickness. The reason he came to this conclusion was that he observed that divers could spend almost an unlimited amount of time at depths less than 10 metres and come straight to the surface and they did not seem to get decompression sickness. The pressure at 10 metres is two atmospheres and the pressure at the surface is one atmosphere, so he concluded that divers could go from two atmospheres to one atmosphere and not get bent. He then extended that to suggest that maybe they could go from six to three or from four to two and so on. He worked out his tables on that basis.

During a dive the tension of nitrogen in the tissues gradually increases. In the fast tissue it increases quickly and in the slow tissue it increases slowly. When the diver starts to come up nitrogen starts to be eliminated from the tissues. But the diver will get to a stage where the ambient pressure is half the pressure of nitrogen in the tissue that contains the most nitrogen, which is the fast tissue. According to Haldane's hypothesis, if he is not to get decompression sickness, he has got to stop there. He spends a bit of time at that depth and waits for the partial pressure of nitrogen in the tissues to drop, so that he can come up a bit more and a bit more. So he comes up in stages waiting for the partial pressure of nitrogen in the tissues to drop so that it can be eliminated rather than forming bubbles. The critical tissue depends on time. Initially it is the five minute tissue. But further into the decompression routine, it becomes the ten minute tissue and if he stays long enough it might even become the seventy-five minute tissue. When he stops at the first stop, although the fast tissues are eliminating nitrogen, slow tissues such as the seventy-five minute tissue, are actually taking up nitrogen. Even when the diver is doing his decompression stops, some of his tissues are actually taking nitrogen up, not eliminating it. When they tried the Haldane tables out in practice they worked reasonably well, but they were not totally effective. The US Navy got hold of them and modified them a bit. In fact the US Navy tables that most divers use these days are based on the Haldane tables with some modifications that were made, basically by trial and error, by the US Navy.

The unfortunate thing about Haldane's tables is that both Haldane's hypotheses were totally invalid. It is quite amazing that the tables work at all. The first hypothesis that the uptake and elimination is exponential is invalid because we now know that when a diver comes back to the surface, if one puts an ultrasonic bubble detector on the diver's legs or on his chest, it will detect bubbles during routine dives, especially deep dives, even when the diver does not get decompression sickness. There is bubble formation in the tissues, but they do not get symptoms. So his hypothesis that the elimination of nitrogen from the tissues was exponential was quite invalid because as soon as you get bubbles in the tissues, that completely disrupts the dynamics of nitrogen elimination. The second one was this 2:1 ratio hypothesis. We now know that if divers spend long enough at 10 metres and then come to the surface they will get decompression sickness. There have been lots of cases described now of divers who have saturated at 10 metres and come to the surface and got bent. So the tissues cannot even stand a 2:1 reduction in pressure without producing decompression sickness. Although the tables work to some extent and stop people getting symptoms of decompression sickness they do no stop bubble formation in the tissues.

Various workers over the years have recognized that Haldane's concepts were fallacious and have tried to improve on them. They worked on various other theories for decompression and worked out tables. Oddly enough these other tables were not much more effective than the modified Haldane tables. The important thing that I want to stress after all this is that ALL THE TABLES ARE UNRELIABLE. It does not matter which tables one uses, the Royal Navy tables, the US Navy tables, or any other tables for that matter, they are not completely reliable. Divers find this idea heretical. They seem to have blind faith in these tables. They think that if they follow the tables they will be OK, and usually they will. We certainly urge them to follow the tables, but you cannot bet your life on them. Divers sometimes quote US Navy figures. The US Navy claim a less than one per cent failure with their tables which is pretty good. But if one looks at the kind of diving that US Navy divers are doing, one finds that they never push their tables to the limit. Most of the diving in fact is just odd jobs around ships. They clean the propellors on ships and they dive down to the bottom of harbours and pick up things that have been dropped off the ship. They tend not to do a lot of deep diving, they do very little repetitive diving, and they employ fudge factors. When they start to get to the fixed points of the tables, they start fudging. They add a little bit to the depth just to be on the safe side. And they also add a little bit to the time. Part of the reason for adding a bit to the time, I think, is the fact that they get paid a bonus for the time that they spend in the water. But it works both ways, it is a good arrangement, by putting the diver on to a longer decompression schedule it makes the tables safer and they get a bit more money.

Sports divers if they are sensible, should employ fudge factors too. They should not trust the tables. They should add a little bit onto their depth, a little bit onto their time and decompress accordingly. That is a good practice. But a lot of sports divers do not. A lot of them want to spend as much time in the water as they can and get the most out of their weekend. So they tend to dive deep. They tend to push the tables. They do not employ fudge factors. They use depth gauges to measure their depth. Incidentally how many sports divers calibrate their depth gauges? When they buy one off the counter, do they calibrate it then? If they have had it for a year or two do they ever check the calibration on their depth gauges? It is a real enlightenment to take a sample of divers' depth gauges and calibrate them. They can vary quite enormously. When sports divers are using inaccurate depth gauges they are pushing the tables to the limit. They do not know accurately how deep they have been, even if they watch their gauges. So one cannot extrapolate the US Navy safety figures to sports diving.

There are other predisposing factors to decompression sickness apart from being a sports diver, which is a strong predisposing factor. They are things like age, older people tend to get decompression sickness more than younger people. Diving in cold water tends to be a predisposing factor. If the divers work hard during the dive, that tends to increase nitrogen uptake. Divers who are overweight, although it is good insulation, it is not good for preventing decompression sickness. Females have about a threefold increase in decompression sickness, compared with males. There are other predisposing factors. Diving at altitude, if one uses the ordinary tables in a mountain lake decompression sickness is much more likely. There have to be some modifications to the tables with altitude. Bounce diving or rapid changes in depth during the dive are predisposing factors. Flying after diving, especially after decompression dives is likely to cause decompression sickness. If one flies high enough in high performance aircraft one can get decompression sickness, simply from the reduction of pressure with altitude. The same thing can happen in altitude chambers.

One of the important concepts in the pathophysiology decompression sickness is the concept of gas nucleii. It appears that there are little bubble nuclei throughout our tissues. These are microscopic pockets of gas that are found in little hydrophobic niches in the tissues. With nitrogen coming into the tissues because the diver is breathing compressed gas, the extra nitrogen will diffuse into these gas nuclei and make them bigger. If they get big enough surface tension effects will cause a little bubble to enucleate from that and go off into the blood or into the tissues. One can observe these gas nuclei if you have a look at a glass of beer. You will notice that the bubbles do not come out in a haphazard fashion, they come out as streams of bubbles from little points on the glass. These are bubble nuclei, gas nuclei, and they exist in the tissues. Another important pathophysiological point is that once a bubble forms in the tissues it then acts as a foreign body and it brings into play the coagulation mechanisms. Platelets adhere to it and fibrin deposition occurs. Which can mean that even if the bubble is eliminated by recompression there is still all the gubbins that was around the bubble which can occlude blood vessels and cause space occupying lesions.

The symptoms of decompression sickness usually come on early. Fifty per cent of the symptoms will occur within the first hour and by 6 hours 90 per cent of them will have occurred. The earlier they occur the more serious the decompression sickness is likely to be. In the sort of divers that the people in the audience are likely to see, the most common symptom will be skeletal pain, the next most common will be cerebral symptoms and spinal symptoms as well. The pain is usually in the region of the joints, generally the shoulder joints. There are other joints which often produce symptoms. Often the symptoms occur in the adjacent joints, for instance the right shoulder and the right elbow, or the right elbow and the right wrist. The pain is of an aching quality and it gets worse with time and it hurts to move the joint. Especially after deeper dives, the divers are likely to present with neurological symptoms. The most common one is symptoms suggesting a bubble in the cerebral region and they can get just about any constellation of symptoms. Very commonly they get a headache, but they can get sensory disturbances over varying parts of the body or they can get motor disturbances. Sometimes they can get cerebellar symptoms with ataxia. They will often get spinal symptoms with paraplegia. In sports divers you will never see vestibular symptoms due to decompression sickness. This is something that is confined, as far as I know, to helium divers. So if you have got a diver with vestibular symptoms watch out, you may be missing something else, like barotrauma to the ears for instance.

Slow tissues tend to produce skeletal type bends. If a diver does shallow dives he tends to get slow tissue skeletal bends and if a diver does deep dives, deeper than about 80 feet or so, he is likely to get fast tissue bends which are neurological symptoms. If he does a short deep dive he will probably only get neurological symptoms. If he does a long deep dive he will get neurological and skeletal symptoms because he will put nitrogen into both his slow and his fast tissues. If he only does a shallow dive he is unlikely to get cerebral symptoms. One is unlikely to get cerebral symptoms from a 60 foot dive. The exception to this is the spinal cord, you seem to get spinal cord symptoms from just about any kind of dive. So I guess the spinal cord is probably a slow tissue, even though it is nerve tissue. One can work out the treatment of decompression sickness from first principles. Putting the diver in a recompression chamber and increasing the ambient pressure will make the bubbles smaller and that, hopefully, will relieve his symptoms. The sooner it is done the better because this avoids the secondary effects of coagulation, etc. The advantages of recompression, are to make the bubbles smaller and to increase the surface area to volume ratio which aids diffusion into and out of the bubble. High partial pressures of oxygen help increase the gradient encouraging nitrogen to leave the body.

I have run out of time. I would like to emphasise two points. The first is that in order to make a diagnosis of decompression sickness you first have to know that the patient has been diving, otherwise you can miss the diagnosis. The second point is that you can always get advice from the Navy. They have someone on call 24 hours a day, 7 days a week. If you have any diagnostic problems or if you want someone treated the Navy can organise that with the co-operation of the Airforce. The telephone contact number in working hours, Monday to Friday 0800-1600, is (02) 960 0333. Out of working hours it is (02) 960 0321.

SPUMS ANNUAL SCIENTIFIC MEETING 1985

This will be held on Bandos Island in the Maldives from Thursday 18 April to Wednesday 24 April 1985. Dr Carl Edmonds has accepted an invitation to be a guest speaker.

Further details on page 40.