Question: Dr Ray Leach

For Australia, it seems that the pattern is to treat the patient with 100% oxygen as close in time as possible to the accident and then transport him by Hercules to Sydney. But using a large plane like a Hercules does seem somewhat unnecessary. I understand that even commercial aircraft can be pressurised to atmospheric pressure, but at some expense to the airline. Should we not have some sort of simpler aerial ambulance for divers, smaller Jets, which could be pressurised to atmospheric pressure, during which time the diver could receive 100% oxygen during transport, rather than bothering the Air Force for these expensive Hercules?

Dr John Knight

If the diver can afford to charter a Lear Jet he can be flown at ground level. But how many of the divers you know can afford to have his own private jet? That is one of the problems. Another problem is that civilians are only treated at the School of Underwater Medicine because they are emergencies that turn up there.

Because the demand is small outside New South Wales it is very difficult to set up a comprehensive system that will be cost effective. If we are going to have an Australia wide system it is going to have to be Government funded and with present financial attitudes the Commonwealth Government is not going to pay for it.

DYSBARIC OSTEONECROSIS

David Elliott

Dysbaric osteonecrosis, although we are not absolutely certain of its cause, is an association of bone necrosis with exposure to pressure changes. The first cases were reported about 70 years ago. Pain was the problem and they were found on X-ray to have damaged joints.

The British Medical Research Council decided that they would do surveys first on compressed air workers and then on divers. They really got going in the 1950's and 1960's and came up with quite a few useful reports in the Journals. One must appreciate that the radiological classification of bone necrosis scooped in a whole lot of people who were totally asymptomatic. Bone necrosis occurs in two places, in the shaft of a bone and in the juxta-articular region. It is only collapse of the joint surface that will give rise to pain. The shaft lesion is for practical purposes totally benign. The shaft lesions are histologically exactly the same as osteonecrosis due to other aetiologies. It has the same prognosis - a one in approximately 10,000 chance of osteosarcomatous change. Two cases of osteosarcoma occurring in compressed air workers with bone necrosis have been written up.

So far as we are concerned it is a juxta-articular lesion that is important, because it can be a crippling disease. In the 1950s and 1960s there was a ten year survey of divers in the Kiel Canal in North Germany. Of about 40 divers, 7 became totally unable to work.

A group of 79 Japanese divers had about 20% definite lesions, of which about 15 were juxta-articular. John Harrison and myself reviewed Royal Navy divers about the same time. Out of 350 divers we found only 4% with lesions, of which less that 2% were juxta-articular. Ohta and Matsinuka from Japan had 50% of divers with lesions. About 15% or 16% were juxta-articular. There is a significant difference between the British and the Japanese figures. If you look at Ohta's original report, which was in Japanese (I had it translated) you find that the divers aged 18 only had about 2% incidence, the divers in their twenties had a 5%-10% incidence, divers in their thirties about 50% incidence and the divers in their forties had about an 80% incidence of bone necrosis. There were 60 or so divers aged 18 down to 2 divers aged 40. The dive profile for these guys was given. Two divers went down to 120 feet or so for four hours in the morning. Being of peasant stock they knew nothing about decompression tables, so they came up for their lunch and in the afternoon they went down and did the same thing all over again. Which, as was said in the paper, is why the flag of the factory ship was always at half-mast. So there could be some clue there as to the aetiology of bone necrosis.

The shaft lesions are benign and appear to be basically ossified fat. So to the pathology of the juxta-articular lesions. The first change is a creeping substitution. New trabeculae grow over dead trabeculae. The radio-opaque area is a failure of new growth coming into that part. But if you examine the area histologically you would find evidence of new trabeculae replacing trabeculae over as much as two thirds of the head of the humerus. The lesion is very much more widespread than can be seen on X-ray. There is a latent period. It takes three to four months before the first X-ray evidence can be spotted. This makes it very difficult to give a diver the OK at any particular time, if he is going along to a new employer.

What is the possible pathogenesis? As with spinal cord decompression sickness, there are a whole stack of hypotheses and you can take your pick. They are probably all true. There is an embolic hypothesis which suggests that lipid emboli, which are formed from bubble activity, enter the end vessels of the bones. Autochthonous bubbles, bubbles which are generated per se, formed in the bone, may expand and cause occlusion of the blood supply. Then there clever hypotheses like the isobaric counter diffusion of gases inside the bone, gaseous osmosis, change of intermedullary pressure and all those things. What it really means is that we have not got a clue.

After all sorts of clever papers have been written on the pathogenesis of this lesion, what do we actually find? In the original programme that John Harrison and I did the surprising thing was that we got nothing in the hip joints. The hip and shoulder are two juxta-articular regions that are affected. You can get shaft lesions in both upper humerus and upper femur, but they are much more common

in the lower femur. Among other causes of bone necrosis are severe and chronic alcoholism, in which they tend to get a lot of lesions in the femur, both juxta-articular and in the femoral head. Of course some wag said that maybe the cause of the Naval osteonecrosis was alcohol. So, very carefully, we did a controlled survey of an age and rank matched sample in the Navy of over 100 men and found a zero incidence of bone necrosis. This has since been repeated by the US Navy with the same result. So I think that it really is a diving related condition. I am very careful to say that early on because often when I start showing slides of early lesions to orthopaedic surgeons say "Oh, I often see things like that. These things are of no significance".

The Medical Research Council, specifically Dennis Walder, Ian MacCallum and a few others, has established an international classification of this condition.

Our Naval survey showed that dysbaric osteonecrosis is related to age. People under 24 have 0.2%, and remember that this is dealing with both the benign shaft lesions and the juxta-articular lesions, so the figure is a bit misleading. Over the age of 24, the incidence goes up so there is an age association. As to length of experience, there is some relationship, because the older you get the more experience you get. There is a very significant rise in the more experienced divers. They are more likely to have a lesion.

Our Naval survey showed a relationship of bone necrosis to bends. Of those recompressed for decompression sickness, we had 9 out of the total population of 42 with bone necrosis. Whereas in those who had never suffered from decompression sickness we had only 4 cases out of nearly 100 divers. So there seems to be some association with recompression for decompression sickness. There was an association with symptoms of decompression sickness and also an association with experimental diving. So we had a whole lot of things with which there was a statistical association, and all you can say at the end of all that is the more diving you do and the more horrendous the diving, the more likely you are to get bone trouble.

We did get cases of people who dived only on compressed air. The original Kiel Canal work was only on compressed air. You can get it in sports divers, but what we do not know is what those divers have really done with their decompression stops and whether they stayed within the correct Navy tables. We did have one Navy diver who had only done air diving, but again we just have not got the faintest idea what he might or might not have done in his spare time. I do not think you can say that the Navy tables were responsible for that case.

The primary presenting complaint is pain. When the joint spaces are intact the individual is asymptomatic. But when the joint surface is damaged, pain is felt. One diver had a very sudden onset of pain. He was a civilian diver doing a standard dive repairing some lock gates. He put his hand above his head to push up on something and his joint just gave way. So that sharp onset of pain underwater was totally coincidental, he could have done it equally well on the surface. A sudden onset of pain is unusual, but it has happened.

Although the usual latency is about 3 months, it may take up to 5 years to show the lesion. Submarine escape can also cause dysbaric osteonecrosis. In 1931 HMAS POSEIDON, a submarine, sank in about 100 feet of water. Six men escaped from the forward compartment. They all got back to the surface. After twelve years three of them were X-rayed and all three of them had articular lesions. So that demonstrates that one exposure can cause it.

The prognosis is very difficult, on the whole people tend to get worse rather than better. Shaft lesions may regress, but it is unusual. Whether or not one can predict the future of an individual, I think one must assume the worst. If anyone has a juxta-articular lesion you want to get them to give up diving, and give up any work that might stress that particular joint. Perhaps the best treatment is to send them along to an orthopod who can then take the responsibility, for by then it is too late for a diving doctor to do anything for him.

The diagnosis is fairly easy. The only point of the shaft lesion so far as I am concerned is that there is confirming evidence. I have suggested to Denis Walder that he should cut out the knee X-rays, but he likes to see shaft lesions there if there is a doubtful juxta-articular lesion somewhere else, because it helps to support the diagnosis. It is the way in which the X-rays are read that is important. Each set of X-rays is sent to a consultant radiologist, who is experienced in the diagnosis of bone necrosis, and he will classify the lesions, if any, that he sees. The zeros of course can get put on the heap, but the rest will be sent to another consultant of equal experience and are re-read. If there is any difference between them, the films are sent to yet another radiologist, who will try and resolve the difference between the first two. Considering there are eight films per diver, there is quite a lot of hard work establishing the diagnosis at this research level.

Dr Elliott showed slides of typical lesions. For examples please refer to "Dysbarism Related Osteonecrosis" (the proceedings of a symposium held in February 1972) published in 1974 by the US Department of Health, Education and Welfare. Sold by the Superintendent of Documents, US Government Printing Office, Washington DC.

Reading these X-rays is not easy but it has been done in a very scientific manner and therefore may be considered valid.

When it is necessary to do these particular bone X-rays (and anyone who does them should look up the original papers) each X-ray has to be taken in a particular way and external rotation of the shoulder joint is important. Occasionally lesions are only seen on one of the two views.

So here then is the classification as set out in Table 1. The A lesions are the juxta-articular and the B lesions are of the shaft, which of course can occur in the head itself.

TABLE I

CLASSIFICATION OF DYSBARIC OSTEONECROSIS

A LESIONS	JUXTA-ARTICULAR
A1	Dense areas with intact articular cortex.
A2	Spherical segmental opacities
A3	Linear opacities
A4	Structural failures
	a. Translucent subcortical band.
	b. Collapse of cortex
	c. Sequestration of cortex
A5	Secondary degenerative arthritis (osteoarthritis)
B LESIONS	HEAD, NECK AND SHAFT
B1	Dense areas (*not* Bone Islands)
B2	Irregular calcified areas
B3	Translucent areas and cysts
B4	Cortical thickening

Not everything that shows on an X-ray is bone necrosis. A standard cyst of the neck of the femur has been sufficient to stop a diver being employed, which of course is quite unfair. The medico-legal implications of bone necrosis are so great that a lot of diving companies, especially in the USA, are not prepared to take divers on if they have got anything wrong with their bones at all.

What about the distribution? Of over 300 lesions in over 200 men the majority were in the B category. So one can almost dump that lot and forget all about them. Only nine people altogether had structural failure. Those figures come from a survey by the Medical Research Council, which is continuing. The figures which we now have from the Registry were 60 divers with intact juxta-articular lesions and 9 with fractures. An incidence of only 1.4%, because the survey now has over 4,000 divers, a very big collection of X-rays.

The condition is fairly well understood in that we think it is caused by inadequate decompression. We now know enough about it so that we will advise the diver with a shaft-lesion that it does not matter a damn and he can carry on diving. Which is advice that a year or two ago we were not prepared to give. We now advise anybody who has got a juxta-articular lesion that he should give up diving and should see an orthopaedic surgeon.

We have been looking also at other survey techniques. One or two of them are still purely in the research stage, but bone scanning has been really quite interesting. The trouble with bone scanning is that it is too sensitive and if done soon after a dive, you get lesions in a very high proportion of divers, but more than two thirds of them revert back to normal over a year. So scans, which are quite a lot of trouble to do, are not really very helpful. They will merely tell you that if you have got nothing there, the odds are that you are going to get nothing in due course. If you have got a lesion it does not prove anything, but unfortunately about one third of those do go on to produce a radiological lesion sometime later.

DISCUSSION

Dr John Knight

Some of the cases of osteonecrosis that were studied by Ian Unsworth in New South Wales were divers who had a history of trauma from football and suchlike. Their lesions could be detected on X-rays which had been taken for other reasons before their diving.

Dr David Elliott

Fair enough. The official list of the differential diagnosis is given in Table 2. If anyone has got one of those diseases, they should not be diving.

TABLE 2

CAUSES OF OSTEONECROSIS NOT ASSOCIATED WITH DIVING

Steroid Therapy
Excessive Alcohol Consumption
Hepatic Disease
Gout or Hyperuricaemia
Thrombocytopenia
Thrombocythaemia
Hypercholesteraemia
Hyperlipidaemia
Discoid Lupus Erythematosis
Systemic Lupus Erythematosis
Fabry's Disease
Raymaud's Disease
Gaucher's Disease

If you are unfortunate enough to have a juxta-articular lesion, go to your favourite orthopaedic surgeon and have a series of new hips for the rest of your life. Juxta-articular lesions do not necessarily progress from A1 to A5. The trouble is that you do not know which will. Some will remain asymptomatic.

Question:

At what stage do symptoms develop? Do joints have to be involved?

Dr David Elliott

A lot of people with juxta-articular lesions are symptomless. But all people with symptoms have got a juxta-articular lesion with a structural fault of the joint.

Question:

Is there a recommended period of time after a long bone fracture that a person can resume diving?

Dr David Elliott

On the whole people just carry on diving as soon as they are fit to do so. Until we know better, there is no reason to stop them.

Question:

Do you have any evidence that dysbaric osteonecrosis is related more to prolonged exposure under pressure rather than exposure to high pressure?

Dr David Elliott

There are three factors actually: decompression, exposure to high pressure, and the duration of the exposure under pressure. I am on the side of the decompression aspect, which is my particular drum. However the MRC figures tend to show that saturation divers are more prone than bounce divers. I do not know what interpretation to put on that. It is not depth related. But it certainly is duration related for saturation diving. You could say that the saturation diver, so far as bones are concerned, could have a pretty lousy decompression. There is hardly ever a saturation decompression that is bends free. Bends are normal in saturation diving. Limb bends are not regarded as any sort of emergency in commercial diving. It is just part of the daily scene. You know that the pain will go away under recompression. I think that it is probably more related to that, than either the depth or the duration of the saturation.

Question:

I wonder how the companies cope with the problem of the long latent period. If you take a diver from another company and he develops a lesion after twelve months of working for you, who will be responsible?

Dr David Elliott

You are dealing with a complex situation with law suits and juries and all that. Shell only employ contractors. The diving contractor is the person who is responsible. When a diver gets bone necrosis he will sue everybody. That is a bit of good legal strategy. The fact that he had a clean X-ray when he joined the company will usually be judged by a jury as evidence that he was in good nick when he was first employed, and therefore the company is responsible. You will get a lot of people arguing of course, about that sort of point. The latency is well established in the literature. Therefore I believe that a court which has been properly advised by Counsel should not give judgement to one party or the other.

Dr John Knight

In Singapore, where the fishermen divers have much the same sort of incidence as the Japanese, they tend, for reasons of kindness to the patient, to hang the osteo-arthritic hip on the last attack of decompression sickness that gave him pain in the joint, so they can get him some compensation from his current employer. They consider it too difficult to decide who is responsible.

Dr David Elliott

In diving, there are two kinds of insurance, personal liability and personal accident. In the USA divers have had up to $50,000 for a totally benign lesion. But in the UK, there has never yet been a court case about a diver's osteonecrosis. I know of only one case that was settled out of court. It was brought on the accident insurance which was of no great consequence. As it was settled out of court, it does not create a precedent. There are only two big insurance companies in this business. They are saying that they are going to settle out of court until they find a case to act as a precedent. But for that they have to have all the records correct. This is difficult because what happens is that when you go to a diving company to get diver's logs, they can not find them. The diver says "Look here, I got bent, and they did not do the right decompression and it is all their fault". So far the diving company has been unable to disprove that he was bent through negligence. But at the same time it has not been proven either. Once negligence is established in one field, then of course it can be applied all the way through. So it is a complex legal approach, but so far no case has been successful under employer's liability legislation in the UK.

Question:

How often should the screening be?

Dr David Elliott

It is pretty complex. It used to be annual for everybody. But now that it has been recognised that compressed air divers and young divers do not get it so often, that has been changed. I objected to the wording of the new rules and regulations, but my objections were ignored. On the whole the British regulations are quite good. They read as follows:

"X-rays of long bones and joints, in accordance with the recommendations of the MRC decompression sickness panel techniques, should be carried out on all divers at the initial examination, with the exception of divers who indicate that they will not be diving on compressed .natural air to depths greater than 30 metres and whose total exposure to pressure will not exceed four hours in any single occasion. Such examination should then be carried out annually as appropriate considering the diver's experience over the previous three years with the following exceptions. Annual X-rays are not required for divers using only compressed natural air, who have not been exposed to pressure more than the equivalent of 30 metres,

and whose exposure at any one time has not exceeded four hours."

Do you want me to go on? You can get the gist. On the whole it is annual, but for young guys and people who dive at less than 30 metres, and do not stay under for more than four hours, they will be about every three years.

COMMERCIAL HELIUM-OXYGEN DIVING

David Elliott

Diving is a subject in which you are all obviously interested, so having given you some fairly serious papers, I thought that it was time to give you one which is really of interest value only. But, nevertheless, as doctors involved in diving, it is worth your while knowing what is going on in the commercial diving field, if only to appreciate the fact that diving is a very important part of occupational medicine and applied physiology.

Pressure affects every ceil of the body. In fact there is hardly a system that is not affected by pressure. I would remind you that many bio-chemical reactions in the body are not iso-volumetric, which means that they will either be inhibited or accelerated by pressure. This means that literally every cell of the body is affected. There are various rather subtle enzyme changes that can go on in man when he is at very great depth. Pressure is used as a research tool, as an additional variable to basic physiology. There are a number of physiologists who are interested in the effects of pressure, who study various uni-cell preparations and other systems in order to test how pressure affects physiology. I think that it is worthwhile appreciating that there is a lot more to diving applied physiology than the somewhat easy version which we teach in the courses for divers and so forth. I feel very strongly that diving should be part of applied physiology training, because it is a very useful academic subject in the area of altered physiology. I also believe that more occupational medicine should be taught in medical schools. I think as diving doctors and as hospital consultants this is something that you can influence in the future.

Having finished my little sermon, let me now get on to the diving which I am working in myself. Diving is indeed a limiting factor for the future of the offshore gas and oil industry. This talk will not be diving medicine, it will be about practical diving and diving physiology.

The diver is regarded as nothing more than a versatile, effective and relatively cheap underwater tool. If the job could be done by some mechanical device the engineers would prefer it. So far as they are concerned the diver is just a damned nuisance, because he is a biological specimen. Things can go wrong and when they do everything else on the platform can come to a stop. Divers are cheap, and they are versatile, but they are not very popular. But with good diving procedures and well maintained equipment accidents are quite rare. Our problem is that as divers go to deeper and deeper depths, as the world needs oil from deeper water, so the margins of safety for divers associated with the oil industry are getting less and less. Also the cost of supporting a diving system at great depth increases enormously.

This has stimulated a number of developments such as JIM, which is a one-atmosphere suit. I imagine that most people in Australia are familiar with this because it has been used extensively, both in Bass Strait and on the North-west Shelf. The thing about JIM and the other one-atmosphere systems is that the man is totally protected from the high pressure environment. Therefore there are no physiological problems of any significance. The difficulty is that JIM, although pressure rated now to 2,000 feet, is cumbersome. For instance, if he gets his foot caught in something he can not reach down below his knees so another JIM would have to have to be used to rescue him. It is so big that if you design an underwater manifold system for the pipeline you have to design it three to four times as large as you would have to do if you had a diver to do the same job. That costs a lot more money than employing a diver in the first place. Sometimes it is cheaper to employ a diver to do the job because it is so cumbersome. JIM and remote controlled unmanned robots were supposed to virtually replace divers from the off-shore scene. Like most predictions this one was considerably premature. In fact the only place where JIM really works is on the exploration side. Here the drill ship is just testing a well in some remote part of the sea and occasionally may need to send JIM down to do something at the sea bed. For the construction phase of the oil field and later for the life of that oilfield, when there has to be maintenance inspection and occasional repair, there are a lost of tasks for which JIM is quite unsuitable.

Welding underwater is often required. One uses a thing called a pipe alignment frame. The pipe alignment frame links up the bits of an underwater pipeline that have to be joined. The frame is quite a big piece of engineering. The bell will come down and the divers will either get out of the bell and do some sort of job in the water, or they will blow down the little inverted habitat inside the frame and work in a dry environment to weld the two ends of the pipe together.

Divers are essential to the kind of work which the gas industry and the oil industry will need in the future. Therefore the priorities are to try to determine how deep man can go in the open sea to work both effectively and safely, because that is the limit for what we can get back out of the sea in the way of oil and gas. That is my primary job for a particular oil company. Rather surprisingly, there is no other oil company that does this sort of thing. I think they are hoping that we will do it for them. But in the meanwhile we have got a head start on them and are far better able to bid on offshore contracts, because we know as much about commercial diving as any diving concern.

What I would like to do next, is to give you a synoptic history of helium diving. Although I am tempted to go